



INTRODUCTION TO

OLI Studio

V10

think simulation

getting the
chemistry right

Introduction to OLI Studio

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Version: OLI Studio V10

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- OLI Systems Support Email: oli.support@olisystems.com
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Disclaimer

This manual was produced using the OLI Studio / OLI Analyzer 10.1 build 1 (10.1.1). As time progresses, new data and refinements to existing data sets can result in values that you obtain being slightly different than what is presented in this manual. This is a natural progress and cannot be avoided. When large systematic changes to the software occur, this manual will be updated.

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About This Manual

This manual will provide an introductory guide for new OLI Studio Software users. The OLI Studio is a software suite containing several modules including, Stream Analyzer, ScaleChem and Corrosion Analyzer. A client's license determines which modules are enabled within the OLI Studio Software.

This introductory manual consists of one chapter showcasing the OLI Studio User Interface, and three main chapters showcasing the three main modules of OLI Studio: Stream Analyzer, ScaleChem and Corrosion Analyzer.

If you have not yet installed the software, please install it following the instructions given in Installation and Security page in our Wikipage at: http://wiki.olisystems.com/wiki/Installation_and_security.

OLI Studio Components



Stream Analyzer

Stream Analyzer is standalone software, and it is the main interface of the OLI Studio. Stream Analyzer is a comprehensive thermodynamic tool that calculates speciation, phase equilibria, enthalpies, heat capacities and densities in mixed-solvent, multicomponent systems. Capabilities and features of Stream Analyzer are:

- Three different thermodynamic frameworks:
 - Aqueous (AQ) model
 - Mixed Solvent Electrolyte (MSE) model
 - Mixed Solvent Electrolyte and Soave-Redlich-Kwong (MSE-SRK) model
- Thermophysical properties: Stream Analyzer has thermophysical models to predict surface tension, interfacial tension, viscosity, electrical conductivity, thermal conductivity, diffusivity, and osmotic pressure.
- Molecular and ionic inflows: Stream Analyzer accepts molecular inflows, typical of a process stream, and ion inflows, typical of a sample water analysis.

ScaleChem



ScaleChem is a simulation software tool that predicts scaling problems during oil and gas production. ScaleChem simulates fluid production from the reservoir to the sales point, and computes the phase mass balance, scale tendencies, and scale mass of production fluid at each location in the production line. Capabilities and features of ScaleChem are:

- Brine, gas and oil analysis
- Scaling scenarios
- Compatibility testing of brines using the stream mixing function
- Phase equilibrium calculation used to perform four-phase reservoir saturation, from which as whole fluid reservoir composition is determined
- Contour plots to study produced brine properties across a broad temperature and pressure range

Corrosion Analyzer

Corrosion Analyzer is a module within the OLI Studio. A separate license enables this module. Corrosion Analyzer is first-principles corrosion prediction tool. It is used to predict the corrosion rates of general corrosion, propensity of alloys to undergo localized corrosion, depletion profiles of heat-treated alloys, and thermodynamic stability of metals and alloys. It enables users to address the causes of aqueous corrosion by identifying its mechanistic reasons. As a result, users take informed action on how to mitigate or eliminate this risk.

Corrosion Analyzer calculates corrosion by quantifying the bulk chemistry, transport phenomena, and surface reactions through a thermophysical and electrochemical module.

- The thermophysical module calculates the aqueous solution speciation and obtains concentrations, activities and transport properties of the reacting species.
- The electrochemical module simulates partial oxidation and reduction process on the metal surface.

The tool reproduces the active-to-passive transition and the effects of solution species on passivity.

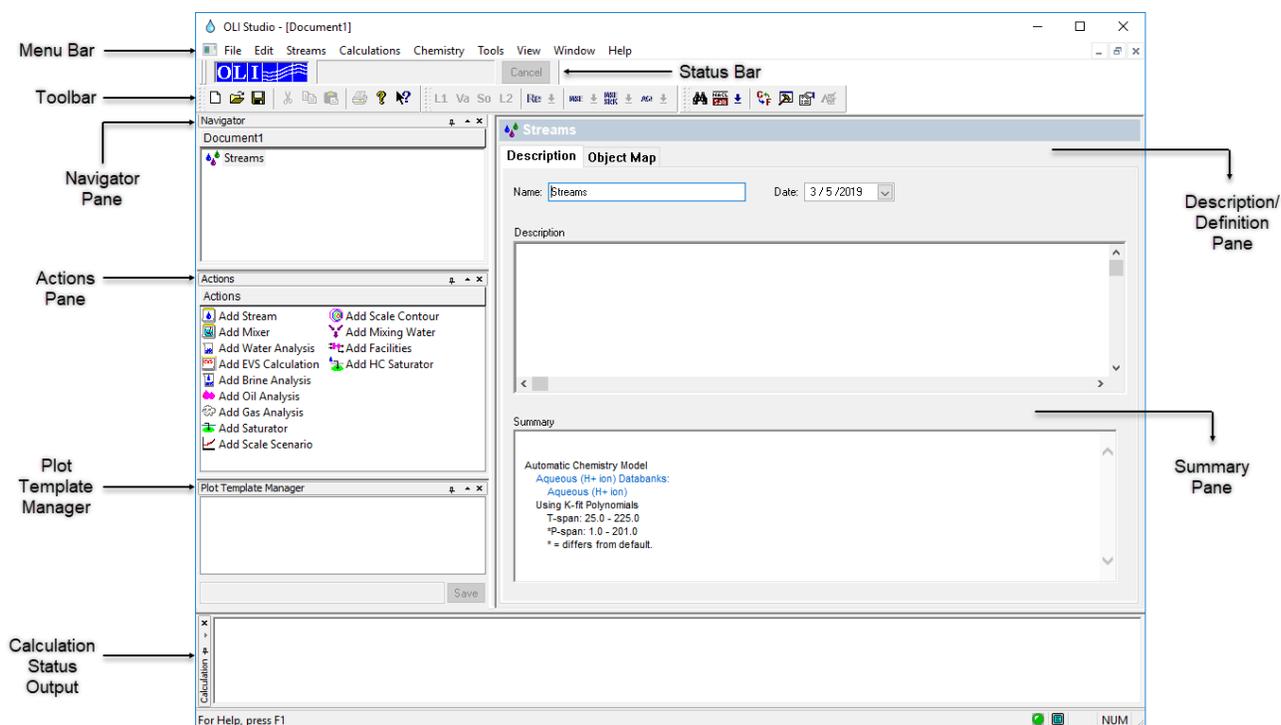
Effects of temperatures, pressure, pH, concentration, and velocity on corrosion are also included. Capabilities and features of Corrosion Analyzer are:

- Generation of Pourbaix (E vs pH) diagrams
- Calculation of general corrosion rates
- Localized corrosion susceptibility
- Heat treatment effect
- Generation of polarization curves plots

Chapter I – The OLI Studio Software User Interface

General View of the User Interface

In the OLI Studio Software, the OLI Studio Desktop User Interface provides the environment to create, analyze and interpret the results of your application chemistry. In this manual, an overview of the different windows and tools that you will be using within the software, as well as how to navigate the OLI Studio User Interface, will be provided here.



The screenshot shown above is what you will see when you first start OLI Studio. You can customize the desktop to your own needs. The windows can be resized, moved, docked and detached.

Menu Bar

The Menu Bar gives access to the following options: File, Edit, Streams, Calculations, Chemistry, Tools, View, Window and Help.

File: Gives access to functionality such as New, Open, Close, and Save a file

Edit: Cut, Copy, Paste, Delete and Clear calculation results

Stream: The Streams menu contains actions that can also be performed using the Actions Pane

Calculations: The calculation menu contains all the calculations found in the Actions Pane

Chemistry: Advanced changes to the chemistry can be made here.

Tools: Gives access to tools such as component search, names manager, units manager and other customizations.

View: Gives the option to customize the view of the interface.

Window: Allows to arrange the different OLI Studio documents in the window.

Help: Here you can have access to the Technical Support or any content that you may need related to OLI Software.

Tool Bar

The Tool Bar gives quick access to different functions and sits below the Menu Bar. Tools within this bar can be added, removed or repositioned. When a tool is selected (or turned ON) it is highlighted in light blue. When deselected (or turned OFF) comes back to gray.



They are laid out in the following order:

Quick access to **File:**



Quick access to **Edit:**



Quick access to **Help:**



Quick access to **Chemistry:**



Quick access to **Tools:**



Icons in the Chemistry section

In the quick access to **Chemistry** you find: Phases, Redox and Databanks.

Phases: Turns ON/OFF specific phases. Four different phases are available:

L1: Liquid 1 or water-rich phase

Va: Vapor phase

So: Solid phase

L2: Usually organic rich phase, also referred to as Liquid 2 phase.

Redox: Denoted as **Re**. Turns ON/OFF Reduction/Oxidation (REDOX) reactions.

Databanks: Turn ON/OFF a specific thermodynamic databank. There are three thermodynamic databanks available:

AQ: Aqueous databank

MSE: Mixed Solvent Electrolyte databank

MSE-SRK: Mixed Solvent Electrolyte and Soave-Redlich-Kwong databank

Icons in the Tools section

A description of each icon in the Tools section is given below:

Component search:



This tool helps you to look for a component using Formula, CAS number, or via using the periodic table.

Names manager:



This tool shows you the name of components in different styles in tables and reports. The style options are: Display name, Formula or OLI Name.

Units manager:



This tool allows you to select or change to preferred units for all calculations.

Customize toolbars:



This tool allows you to remove or add preferred tools to the Tool Bar. For example, you can add or remove Chemistry from the Tool Bar.

General options:



This tool allows you to adjust or change default software settings.

Calculation options:



This tool allows you to include or exclude different types of properties into the calculations.

Navigator Pane

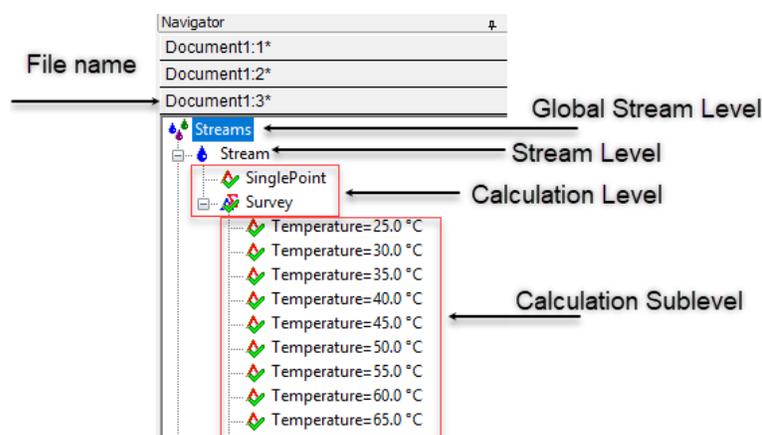
The Navigator Pane (or tree level) contains the list of streams and calculations that are active within a file. This view contains the icons and names of each action in a hierarchical tree. The Description/Definition pane changes depending on the level that is highlighted. A plus sign next to an object in the stream level indicates that that stream or object has sub-streams or branches. There are four levels: Global Stream Level, Stream Level, Calculation Level, and Calculation Sublevel.

Global Stream Level: Provides the broadest view of the navigator objects. At this level the user can define default units, default components name, and general preferred calculation options.

Stream Level: Chemistry options such as phase selection, REDOX reactions, and the thermodynamic databanks can be selected as this level.

Calculation Level: Calculation types such as Single point calculations, Survey calculations, etc., are subordinate to streams, and appear in this level. A more detailed explanation of calculation types can be found in [Chapter II](#) of this manual.

Calculation Sublevel: Some calculations, such as Survey calculations, have their own calculation sublevels. They can be expanded or maximized using the small icon ( or ) next to the calculation type.

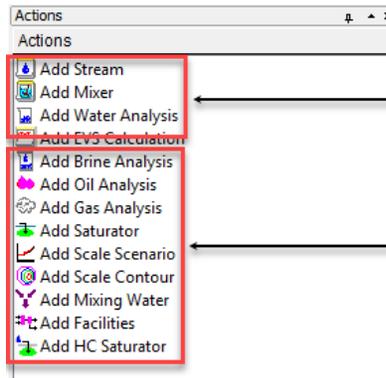


Note: A star (*) next to the file name indicates that the file has not been saved.

Actions Pane

This view contains selectable action icons. Each icon represents either a new stream input or new calculation. Additional actions will appear depending on what kind of stream we are working with. You can change the view of the actions pane by right clicking in the white area. You can show the icons as a List, Small Icons or Large Icons. In this case the List option was selected.

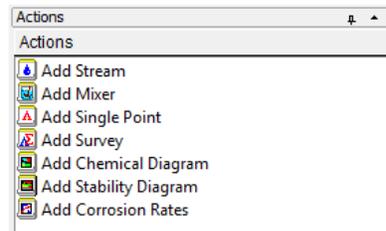
When located at the **Global Stream Level** the following action icons appear on the Actions Pane.



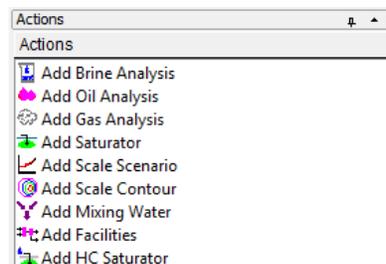
These actions come with Stream and Corrosion Analyzers

These actions come with ScaleChem

If you select an action item that belongs to Stream Analyzer, this action item will be located at the **Stream Level**, and only the following action icons appear on the Actions Pane.

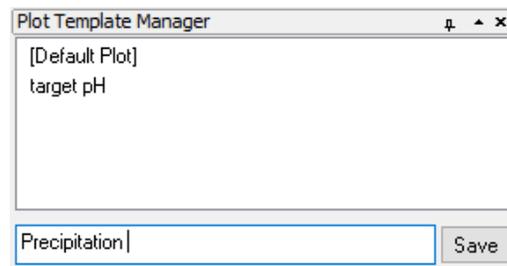


If you select an action item that belongs to ScaleChem, this action item will be located at the **Stream Level**, and only the following action icons appear on the Actions pane.



Plot Template Manager

The default location for the Plot Template Manager is in the lower left-hand corner of the main window. The Plot Template Manager is a tool that allows the user to create, save and use plot templates. This tool allows a fast plotting and analysis of the users results.



Description / Definition Pane

Users work most of the time on the Description / Definition area, which changes depending on which action object is being used.

The screenshot displays the OLI Studio interface with the 'Streams' pane open. The 'Description' tab is selected, showing a table of stream parameters and inflows. The 'Definition' tab is also visible, showing a table of variables and values. The 'Report' tab is also present. The 'Summary' pane on the right provides additional details about the stream, including the unit set and the automatic chemistry model used.

Variable	Value
Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
NaCl	1.00000

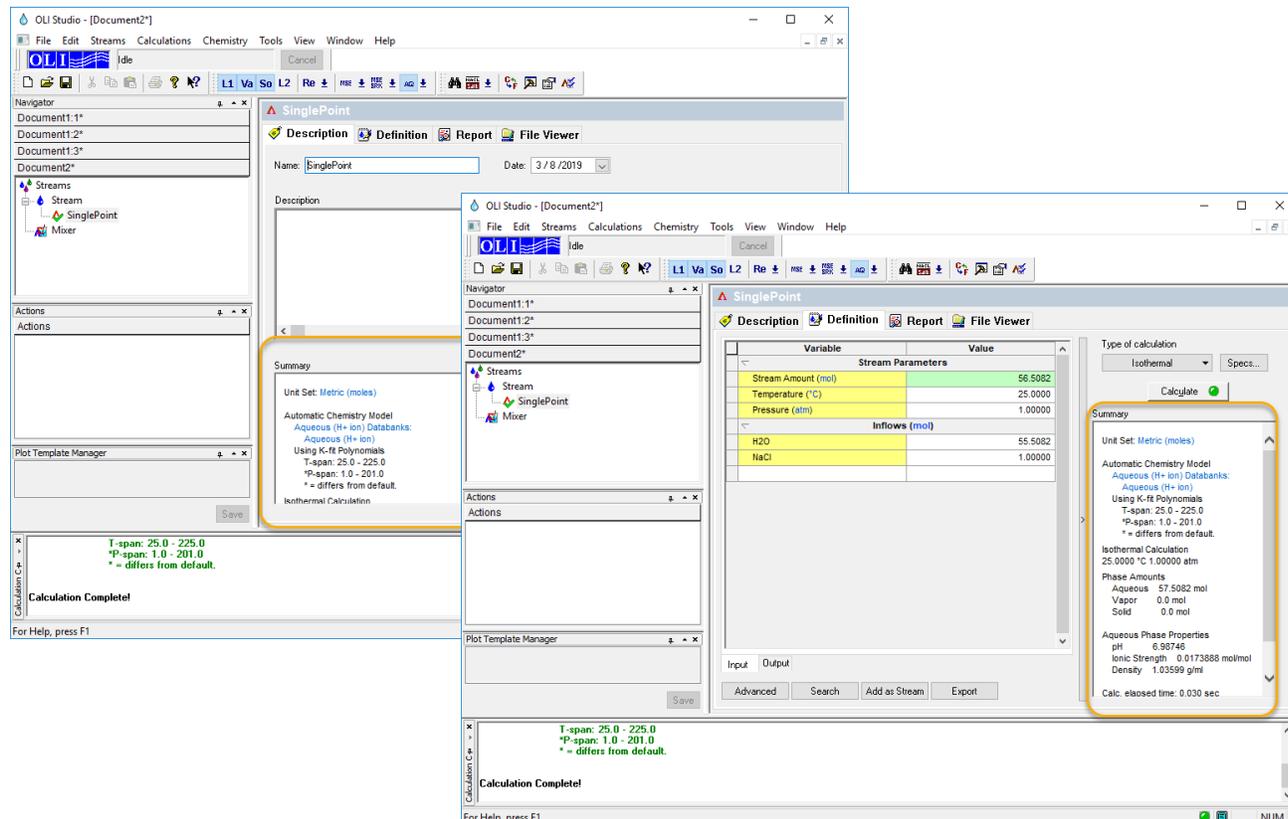
Summary

Unit Set: Metric (moles)

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

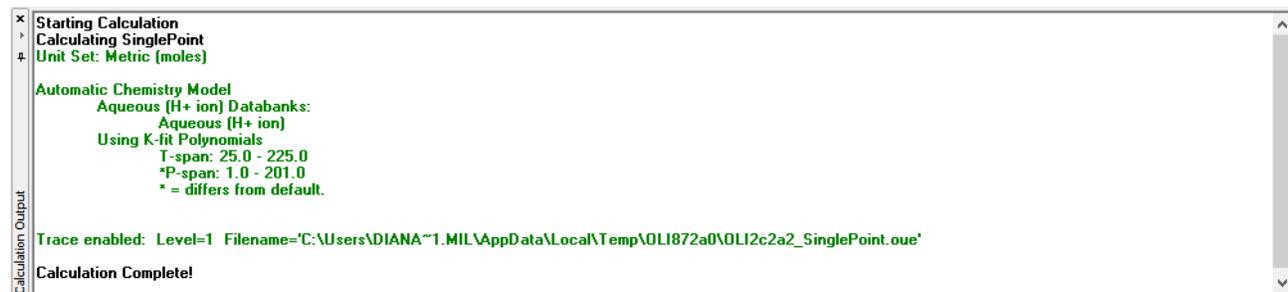
Summary Pane

The Summary Pane can be viewed in both the Description and Definition Tabs. The Summary Pane shows inputs, calculation outputs, warnings, and has hyperlinks to the Units and Databank Managers. This window varies with object.



Calculation Status Output

The Calculation Status Output window shows progress, errors, warnings, temporary file locations, and other data.



Thermodynamic Frameworks and their Databases

You can access the databanks from the Menu Bar: **Chemistry > Model Options...** or via the quick access from the Tool Bar.

There are three main thermodynamic frameworks in OLI Studio. The user can pick the thermodynamic framework that is more suitable for their chemistry. These are the **AQ** (Aqueous), the **MSE** (Mixed Solvent Electrolyte), and the **MSE-SRK** (Mixed Solvent Electrolyte – Soave Redlich-Kwong) Thermodynamic Frameworks. A more detail description of each framework is given below:

Aqueous (AQ) Thermodynamic Framework

The OLI Aqueous (AQ) thermodynamic framework, is a mature electrolyte activity coefficient model that predicts the properties of solutions up to 30 molal ionic strength. Its accompanying database contains 6,000 species for 80+ elements (metals and non-metals) across multiple oxidation states.

This AQ framework is suitable for application involving electrolytes, gases and hydrocarbons dissolved in water.

The AQ framework utilizes the Bromley-Zemaitis activity model:

$$\log \gamma_{\pm} = -\frac{A|Z_+Z_-|\sqrt{I}}{1 + \sqrt{I}} + \frac{(0.06 + 0.6B)|Z_+Z_-|\sqrt{I}}{\left(1 + \frac{1.5}{|Z_+Z_-|}I\right)^2} + BI + CI^2 + DI^3$$

The model is capable of producing valid results in the following ranges:

Temperature	-50°C to 300°C
Pressure	0 – 1500 bar
Ionic Strength	0 – 30 molal

The AQ-framework selects the PUBLIC¹ database by default. Frequently there is more to the chemistry than what is covered in the PUBLIC database. The following is a partial list of additional databases available in the AQ framework:

1. Aqueous (H⁺ ion) – Public Database and selected by default
2. Geochemical (AQ)
3. Ceramics (AQ)
4. Corrosion (AQ)
5. Low Temperature (AQ)
6. Alloys (AQ)
7. Ion Exchange (AQ)
8. Surface Complexation Double Layer Model (AQ)

¹ The PUBLIC database is the main OLI database, containing nearly 70 percent of the thermodynamic data available from OLI and 100 percent of the supporting information.

Mixed Solvent Electrolyte (MSE) Thermodynamic Framework

A system's thermodynamic properties are calculated from two sources; the first is from the Temperature and Pressure dependent standard-state Gibbs energies (i.e., $\overline{G}_i^0(T, P)$) of each species present. The second is from the temperature, pressure and composition dependent excess Gibbs energy (i.e., $\gamma_i(m, T)$) for each species present. In the combined relationship, the partial molal Gibbs energy of the i^{th} species is, $\overline{G}_i = \overline{G}_i^0 + RT \ln m_i \gamma_i$, where \overline{G}_i^0 is the standard-state partial Gibbs energy and γ_i is the activity coefficient. This activity coefficient γ_i , is computed using the MSE theory. A comprehensive explanation of the MSE theory is given in Wang et al. [7].

The MSE framework utilizes the MSE activity model which contains the extended Debye-Huckel term, that accounts for **long-range** interactions, an UNIQUAC term that accounts for **short-range** interactions, and a **middle-range** that includes the ionic interactions:

$$\log \gamma_i = \log \gamma_i^{SR} + \log \gamma_i^{MR} + \log \gamma_i^{LR}$$

The model is capable of producing results for the following ranges:

Temperature	-50°C – to 90% T _{crit}
Pressure	0 – 1500 bar
Ionic Strength	no limit

The MSE framework contains the following databanks:

1. MSE (H₃O⁺ ion) – Selected by default
2. Corrosion (MSE)
3. Geochemical (MSE)
4. Urea (MSE)
5. Surface Complexation Double Layer Model (MSE)

Mixed Solvent Electrolyte with Soave-Redlich-Kwong Equation of State (MSE-SRK) Thermodynamic Framework

The MSE-SRK model is based on the Mixed-Solvent Electrolyte (MSE) framework, which provides a very accurate representation of electrolyte systems in both aqueous and mixed-solvent (e.g., glycol-containing) environments. The MSE-SRK framework combines an equation of state for standard-state properties of individual species, an excess Gibbs energy model to account for solution non-ideality in the aqueous electrolyte phase, and the Soave-Redlich-Kwong equation of state (SRK EOS) to calculate the properties of the gas phase. The MSE-SRK framework, however, provides a different treatment of the non-electrolyte-rich second liquid phase for liquid-liquid equilibria. MSE-SRK assumes the second (usually organic-rich) liquid phase to be non-ionic, and reproduces its properties using the SRK EOS. This allows the MSE-SRK framework to more easily reproduce the critical behavior of nonelectrolyte systems.

In the MSE-SRK model, the electrolyte-containing (usually aqueous) liquid phase is represented by a combination of the Helgeson-Kirkham-Flowers (HKF) equation of state for standard-state properties and the MSE activity coefficient model for solution nonideality. Accordingly, the chemical potential of a species i in a liquid (electrolyte) phase is calculated as:

$$\mu_i^L = \mu_i^{L,0,x}(T, P) + RT \ln x_i \gamma_i^{x,*}(T, P, x) \quad (1)$$

where $\mu_i^{L,0,x}(T, P)$ is the standard-state chemical potential from the HKF theory [9], [10], x_i is the mole fraction, and $x_i\gamma_i^{x,*}(T, P, x)$ is the activity coefficient from the MSE theory of Wang et al. [7], which accounts for long-range electrostatic, specific ionic, and short-range intermolecular interactions.

The second liquid phase is assumed to be non-ionic and is modeled using the Soave-Redlich-Kwong equation of state (SRK-EOS) [11]. The chemical potential in the non-ionic liquid phase is then calculated as:

$$\mu_i^G = \mu_i^{G,0}(T) + RT \ln \frac{Py_i\varphi_i(T,P,y)}{P^0} \quad (2)$$

where $\mu_i^{G,0}(T)$ is the chemical potential of pure component i in the ideal gas state, y_i is the mole fraction, $\varphi_i(T, P, y)$ is the fugacity coefficient from the SRK-EOS, P is the total pressure, and $P^0 = 1 \text{ atm}$.

The properties of the gas phase are also obtained from the SRK equation according to Equation (2).

The MSE-SRK framework contains the following databanks:

1. MSE (H₃O⁺ ion) – Selected by default
2. MSE-SRK (H₃O⁺ ion) – Selected by default
3. Corrosion (MSE)
4. Geochemical (MSE)
5. Urea (MSE)
6. Surface Complexation Double Layer Model (MSE)

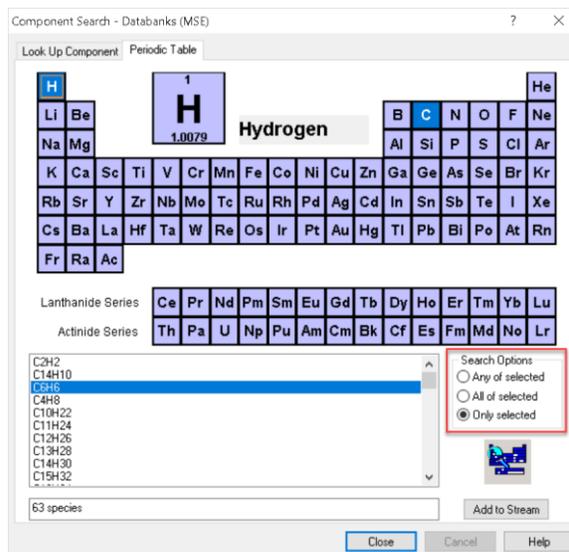
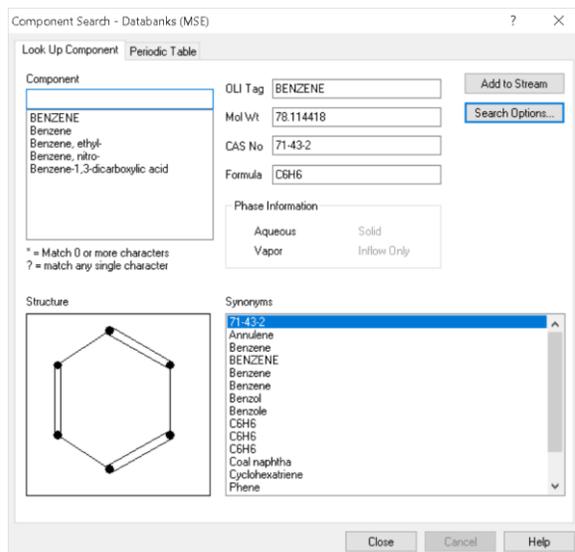
Component Search

You can access the **Component Search** from the Menu Bar: **Tools > Component Search...** or via the quick access from the Tool Bar .

Note: When using the **Component Search** tool will only show components in the database that you have selected.

The **Component Search** option opens new window where you can search for the component of interest by typing the component name or look up components using the Periodic Table option. In the periodic table option, you have 3 search options:

- Any of selected: Will show elements that you have
- All of selected:
- Only selected:



In any of the two options for component search, you can click on the **Add to Stream** button to add the component in your chemistry.

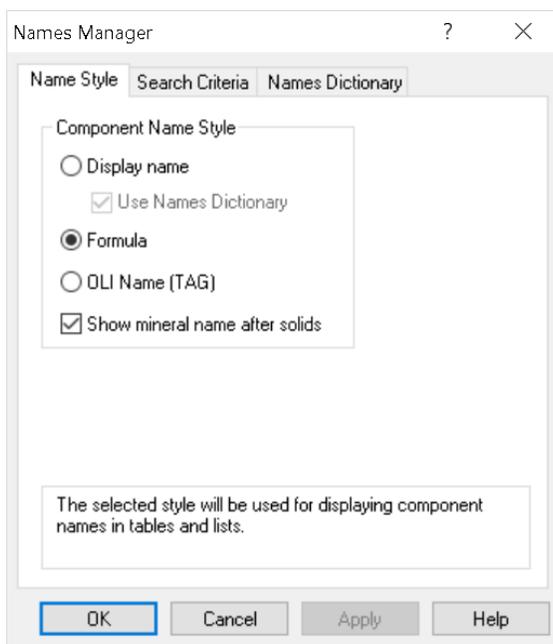
Names Manager

You can access the **Names Manager** from the Menu Bar: **Tools > Names Manager...** or via the quick access from the Tool Bar .

The **Names Manager** option opens new window where you can select the component name style. There are three different styles:

- **Display name:** This is the name that is commonly displayed when a species is entered. This is the default display. For example, Benzene, Cyclohexane, Sodium Chloride
- **Formula:** This is the chemical formula name. For example, C₆H₆, C₆H₁₂, NaCl
- **OLI Name (TAG):** This is the traditional name for the species stored internally in the OLI software. For example: BENZENE, CYCLOHEXAN, NaCl (Note: These names are usually for OLI internal use).

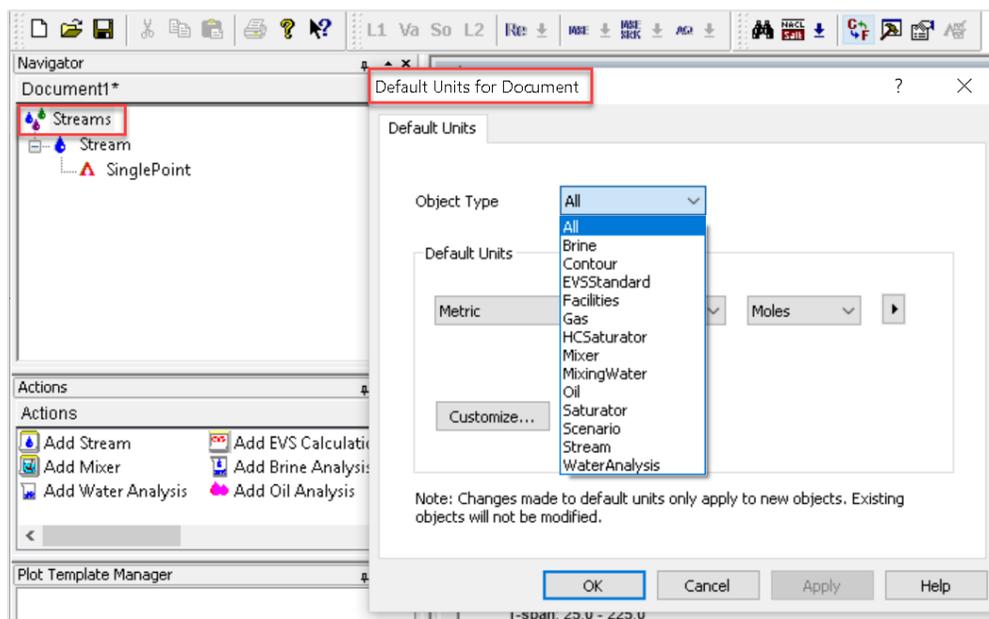
Additionally, you can select if you prefer the mineral name to appear after the solids. For example, NaCl (halite), KCl (sylvite), etc.



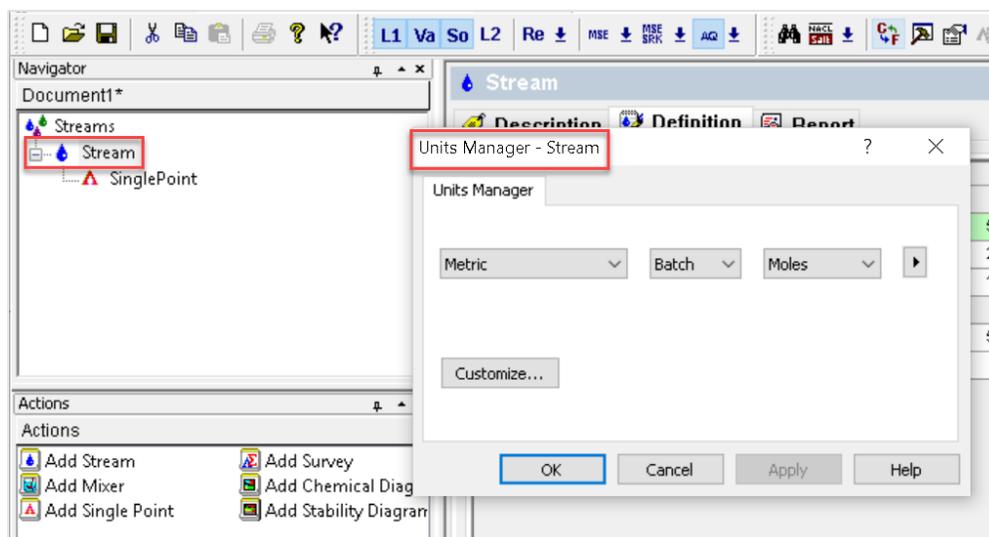
Units Manager

You can access the **Units Manager** from the Menu Bar: **Tools > Units Manager...** or via the quick access from the Tool Bar .

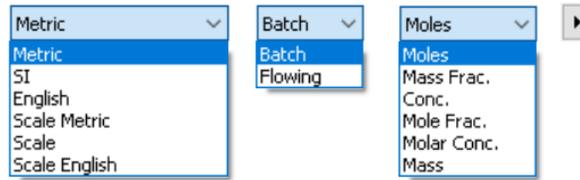
If you are changing units at the Global Stream Level, the **Units Manager** tool will open a new window where you can change the default units for the whole document. You can also select the default units of the different calculation objects.



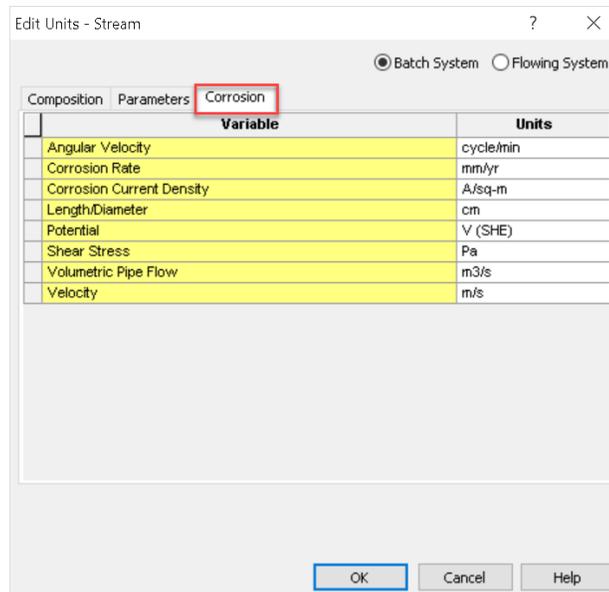
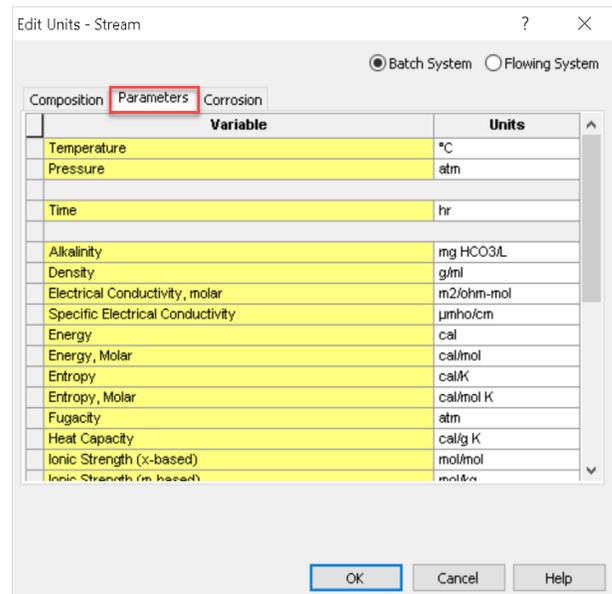
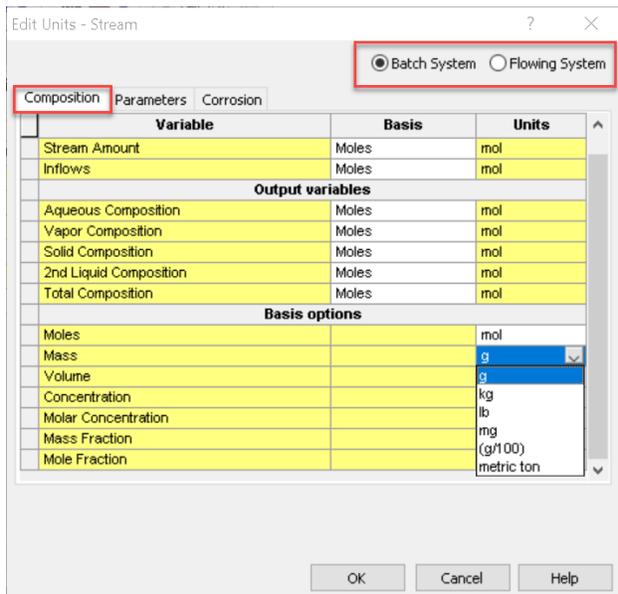
At the Stream Level, the Units Manager tool will open a slightly different window and will change the units only at the Stream Level and Calculation Level.



The default units are Metric, Batch and Moles, but you can change to any of the following default options:



You can customize specific units, by clicking on the **Customize...** button. This will open a new window where you can customize composition units, parameters units, and corrosion units. You can also select units for a Batch system or a flowing system.



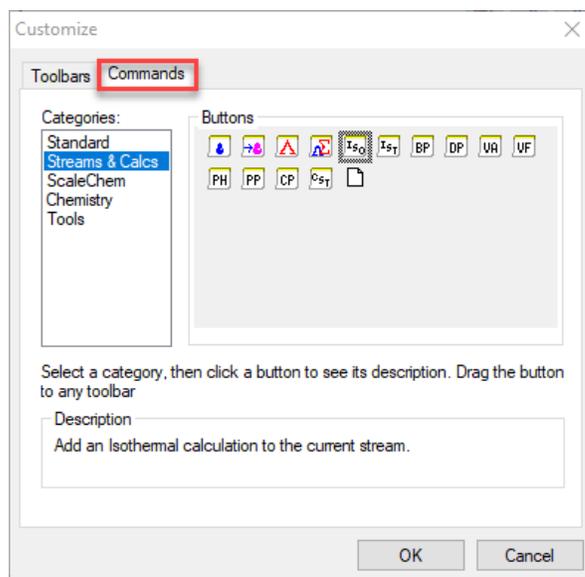
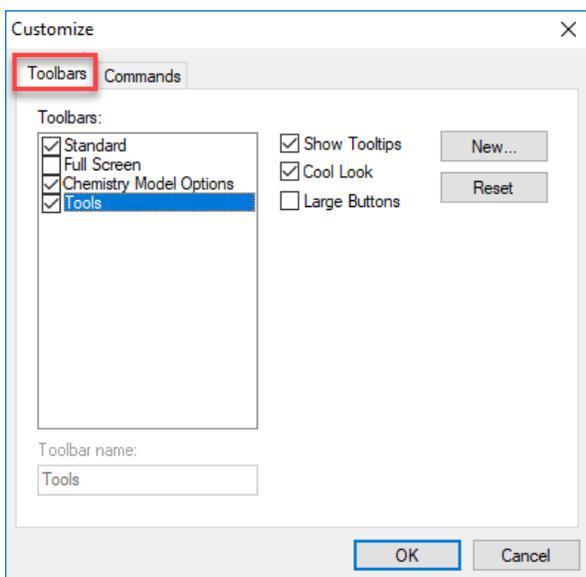
Another option to access the **Units Manager tool** is by clicking on the units highlighted in **blue**. This is a hyperlink to the Units Manager tool, and there you can make changes to the units.

Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
FeCl3	1.00000

Customize Toolbars

You can access the **Customize Toolbars** from the Menu Bar: **Tools > Customize...** or via the quick access from the Tool Bar . This will open a new window where you can disable or enable toolbars under **Toolbars** tab.

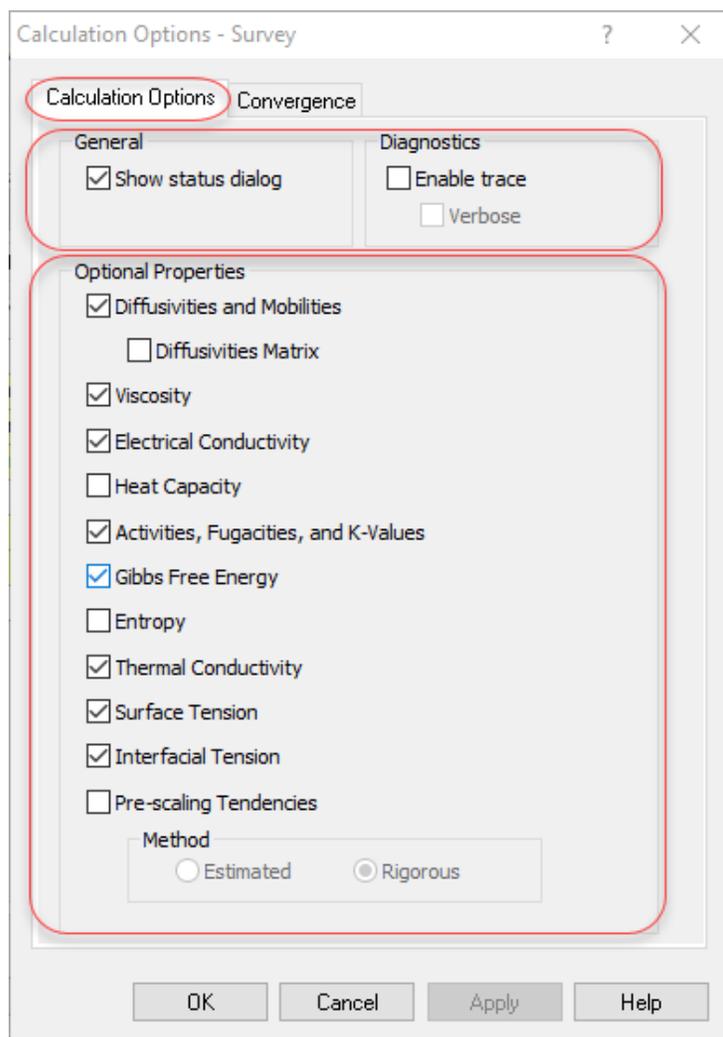
Under the **Commands** tab, you can also add your preferred buttons in the tool bar. If you click on any of them, it will give you a description of the actions the selected button will perform.



Calculation Options

You can access the **Calculation Options** from the Menu Bar: **Tools > Options...** or via the quick access from the Tool Bar . This will open a new window. Under the **Calculation Options** tab you can enable or disable the following options:

1. General
 - a. Allows you to disable or enable
2. Diagnostics
 - a. Enable trace
3. Optional Properties
 - a. Diffusivities, electrical conductivity, heat capacity, activities, fugacities, and K-values, Gibbs free energy, entropy, thermal conductivity, surface tension, interfacial tension, and pre-scaling tendencies.

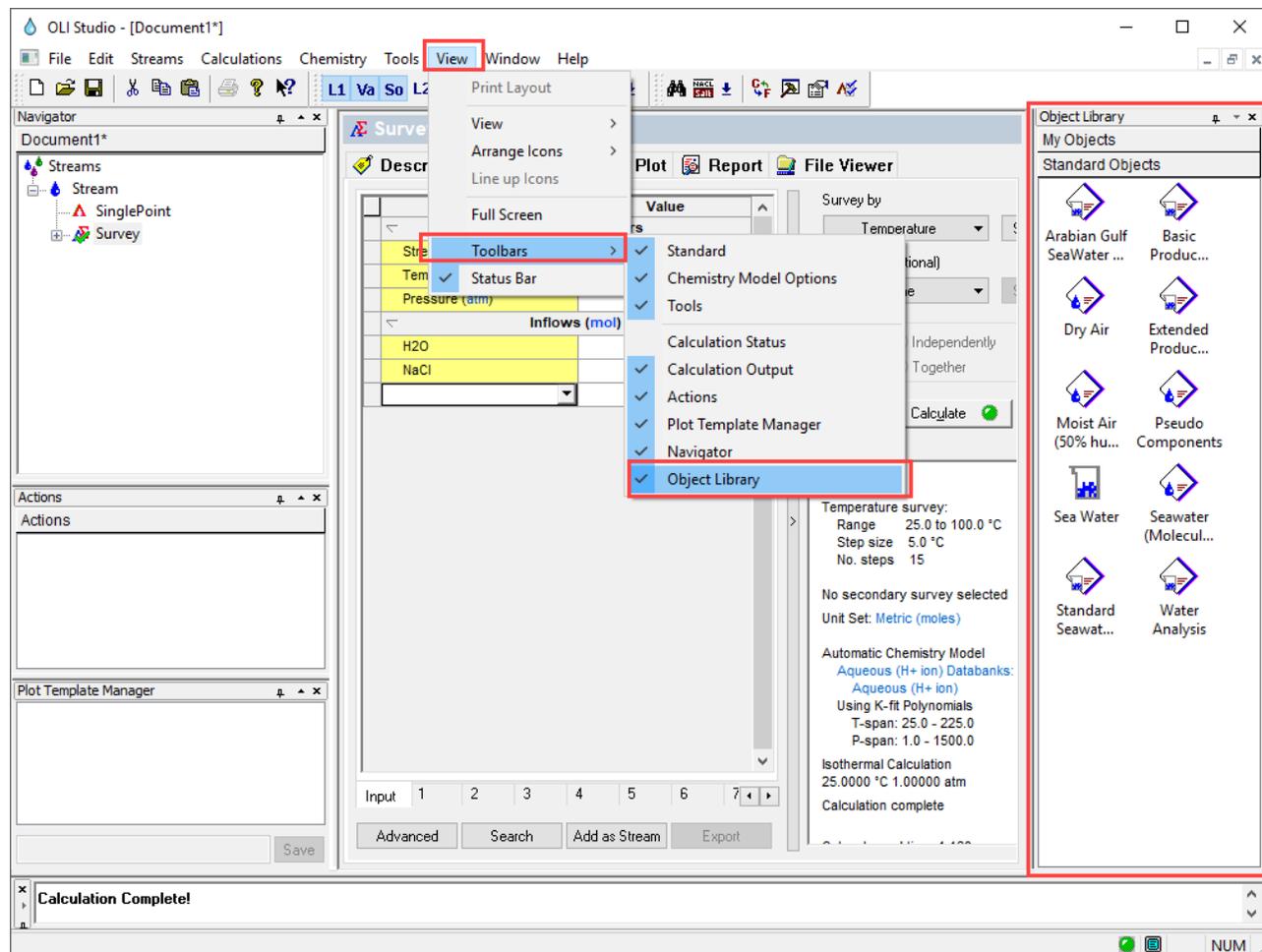


Object Library

You can access the **Object Library** from the Menu Bar: **View > Toolbars > Object Library**.

This option will create a new window (to the right). You can find commonly used objects like standard sea water, dry air, etc.

My Objects – save your own objects, such as a commonly used stream. You can drag an object and save it here for your future use.



Tip: If by accident we lose a tool bar, we can go to **View > Toolbars >...** and select the toolbar that is missing.

Chapter II – OLI Studio: Stream Analyzer

For all calculations we will create one or more objects, referred to as a **Streams**, which are used to define a particular chemistry, temperature and pressure.

There are five different types of calculations that can be carried out in OLI Studio: Stream Analyzer: Single point, Survey (multiple point), Water Analysis, Mixer, and Chemical Diagram calculations. A brief definition of each type of calculation is given below.



Add Stream

Add Stream is used to add a **New Stream** as a molecular input and define a specific chemistry.



Add Single Point

Single Point Calculations are used to find information (pH, volume, speciation, etc.) at one specific equilibrium state.



Add Survey

Survey Calculations are useful for plotting changes in stream parameters against temperature, pressure, or composition.



Add Water Analysis

Water Analysis allows you to enter ionic inflows. i.e. allows you to enter anions and cations.



Add Mixer

Mixer Calculations are useful for mixing different streams. You will familiarize yourselves with its four different mixing options, Single Point Mix, Multiplier, Ratio, and Volume.



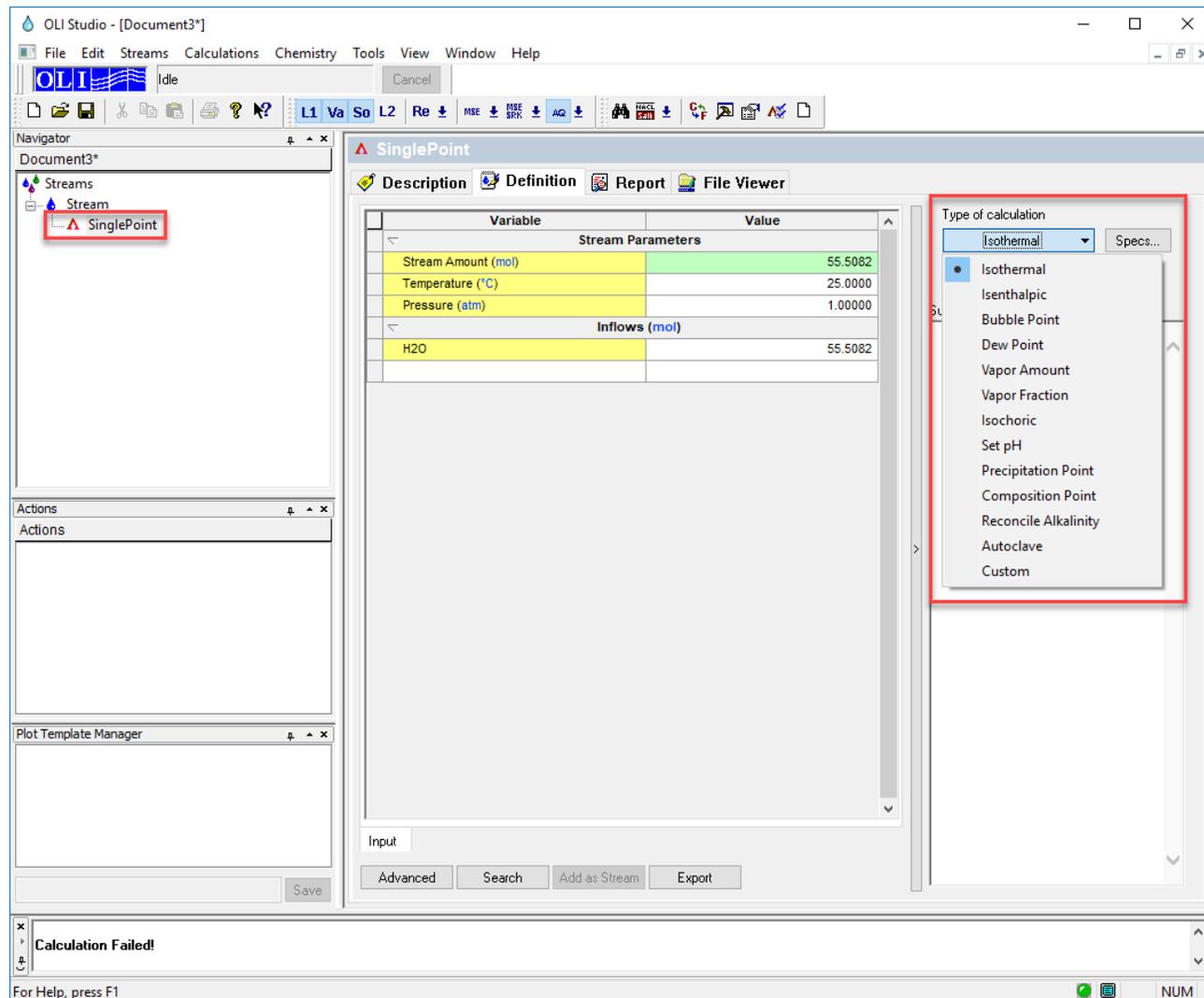
Add Chemical Diagram

Chemical Diagram Calculations allows you to create a stability map for species based on concentration and other parameters such as pH. A contour map is created showing the user where some solids are stable and where others are not.

In these chapter several examples will be provided to cover all of these calculation types.

Section 1. Single Point Calculations

Single point calculations are the simplest set of calculation in the software. There are 13 different single-point calculation types, and a brief explanation of each single point calculation is provided below.



Isothermal

The software computes solution properties based on a known composition, at a constant temperature and pressure.

Isenthalpic

A constant heat loss/gain is applied to the calculation and a temperature or pressure can be adjusted to meet this new heat content.

Bubble Point

The temperature or pressure is adjusted to reach a condition where a small amount of vapor begins to appear.

Dew Point	The temperature or pressure is adjusted to reach a condition where a small amount of aqueous liquid appears.
Vapor Amount	The temperature or pressure is adjusted to produce a (user) specified amount of vapor.
Vapor Fraction	The temperature or pressure is adjusted to produce a (user) specified amount of vapor as a fraction of the total quantity.
Isochoric	The temperature or pressure is adjusted to produce the (user) specified total volume.
Set pH	The software adjusts the flowrate of a species to calculate the (user) specified pH of the aqueous solution.
Precipitation Point	The software adjusts the flowrate of a species until a small amount of solid precipitates.
Composition Point	The composition point calculation is used to fix a species value. The software adjusts the flowrate of a species until it reaches the (user) specified/fixed species value.
Reconcile Alkalinity	The software reconciliates the alkalinity of a solution by adjusting a titrant, by default the software uses CO ₂ .
Autoclave	It is an isochoric (constant volume) calculation in which mass, pressure and temperature are allowed to vary. This simulates a closed pressure vessel. ²
Custom	With the calculations stated so far, variables are predefined. For instance, we must select either temperature or pressure as a variable in the dew point calculation. With the Custom single point calculation, we can select from a wider variety of variables.

In this section, we will learn how to set up each one of these single point calculations, and will also introduce how to use custom units, the names manager, modify the report, and other useful tips to get the most out of your simulation results.

² You may have to enable this calculation from Tools | Options | Enable Features Under Development

1.1. Isothermal

The default and most basic single point calculation is the **Isothermal calculation**. The software computes solution properties based on a known composition, pressure and temperature.

Example 1: Speciation and its importance for pH calculations

After completing this example, you will learn how to set up an **Isothermal calculation** and will also get a better understanding of the importance of full speciation on the calculation of pH. Let's calculate the pH of a 1 m FeCl₃ solutions at 25 °C and 1 atm.

Starting the Simulation

To start the software, double-click the **OLI Studio** icon on the desktop, which will take you to the OLI Studio interface where you can start creating your calculations.



1. Let's create a new stream. Click on the **Add Stream** located in the **Action Pane**. When a stream is created only H₂O is present in the grid. Its cell is yellow because it cannot be removed, it is a permanent inflow.
2. For this example, we are going to use the **AQ-Databank** (The default databank)
3. Type **FeCl₃** in the white cell below H₂O inflows grid, and press **<Tab>** or **<Enter>**
4. Enter the value **1.0 mol** in the next cell.

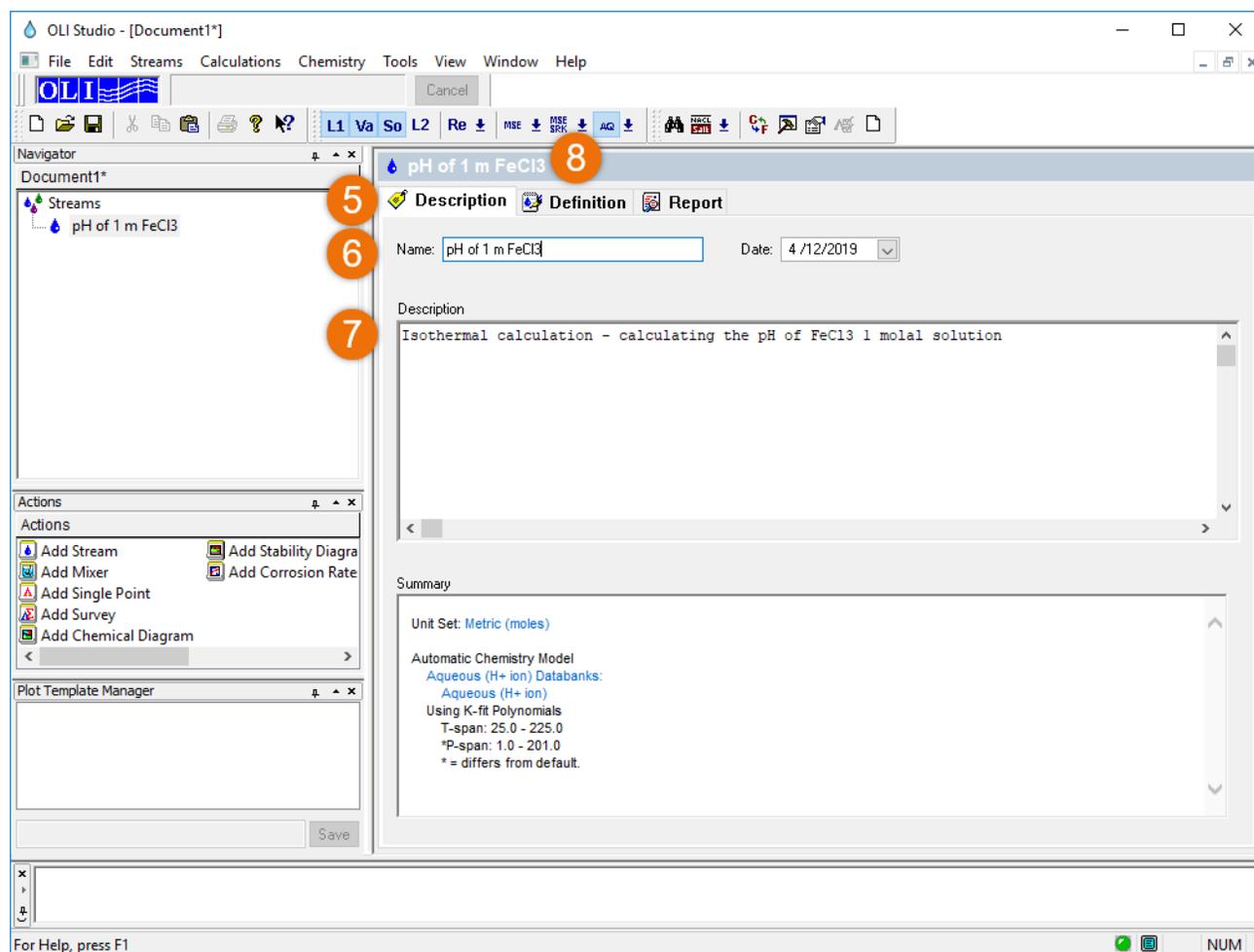
The screenshot shows the OLI Studio interface with the 'Stream' definition window open. The 'Inflows (mol)' table is highlighted with red boxes and numbers 1 through 4. The 'Add Stream' button in the Actions pane is also highlighted with a red box and number 1.

Variable	Value
Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H ₂ O	55.5082
FeCl ₃	1.00000

Note: By default, the software populates the stream parameters table with 25°C, 1 atm, and 55.5082 moles of water. This amount of water is 1 kg of water. All of OLI's internal aqueous concentrations are based on the molal concentration scale. You will see this value frequently throughout this manual. This effectively makes any component concentration a molal concentration.

Also, notice that the stream amount will be automatically calculated from the sum of the component inflows. To indicate that the summation has occurred, the grid will highlight the stream amount cell in green.

5. Click the **Description** tab to change the name of the Stream. You can also change the name using the **<F2>** key or by **right-mouse click** on the object and selecting rename.
6. **Change** the generic name **Stream** to **pH of 1 m FeCl₃**
7. **Add** the following **Description:** *Isothermal calculation - calculating the pH of FeCl₃ 1 molal solution*
8. Go back to the **Definition** Tab



Now, we are ready to perform a calculation

9. Go to the **Add Calculation** button

10. Select **Single Point**

Note: By default, the software selects the **Isothermal** type of calculation

The screenshot shows the OLI Studio software interface for a calculation titled "pH of 1 m FeCl3". The main window displays a table of variables and values, and a dropdown menu for adding calculations.

Variable	Value
Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
FeCl3	1.00000

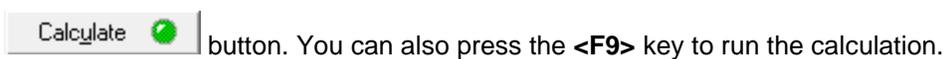
The "Add Calculation" dropdown menu is open, showing the following options:

- Add Calculation
- Single Point
- Survey
- Chemical Diagram
- Stability Diagram
- Corrosion Rates

The "Single Point" option is highlighted. The software also displays a summary of the Automatic Chemistry Model settings:

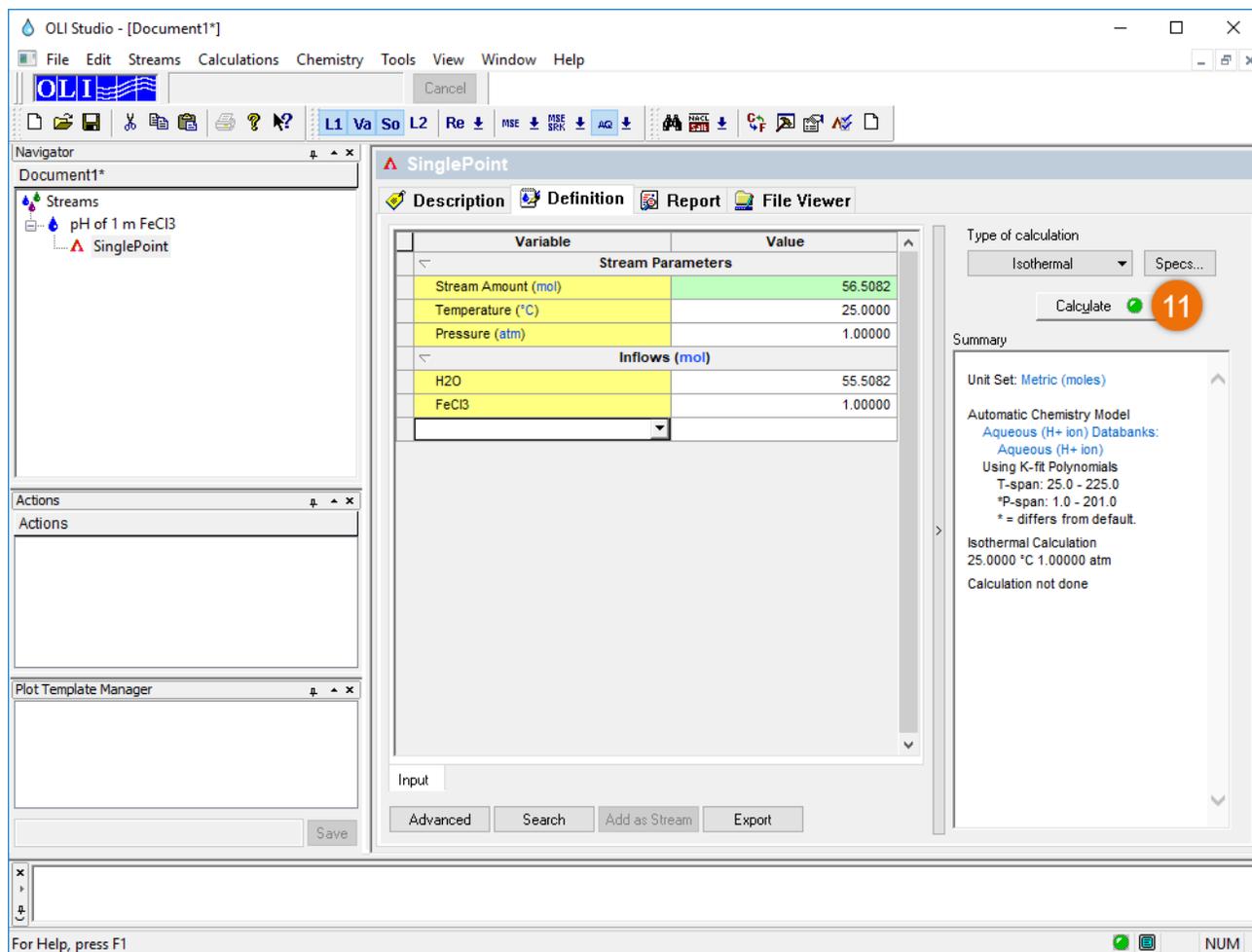
Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

11. All the required variables have been entered, and the **Calculate** button has turned green. Click on the



Note: The calculation button has three colors depending upon the specifications:

- Red** – Insufficient specifications for a calculation
- Yellow** – Incomplete specifications but calculation can continue
- Green** – Completed specifications, the calculation is ready



The screenshot shows the OLI Studio software interface. The main window is titled 'SinglePoint' and contains a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
FeCl3	1.00000

The 'Calculate' button is green and has a red '11' badge. The summary panel on the right shows the following information:

Type of calculation: Isothermal
Calculate button: Calculate (green) 11
Summary:
Unit Set: Metric (moles)
Automatic Chemistry Model:
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.
Isothermal Calculation
25.0000 °C 1.00000 atm
Calculation not done

12. Please **save** the file (**File >Save as...**) and type an appropriate name, for example *Single Point Calculations*.

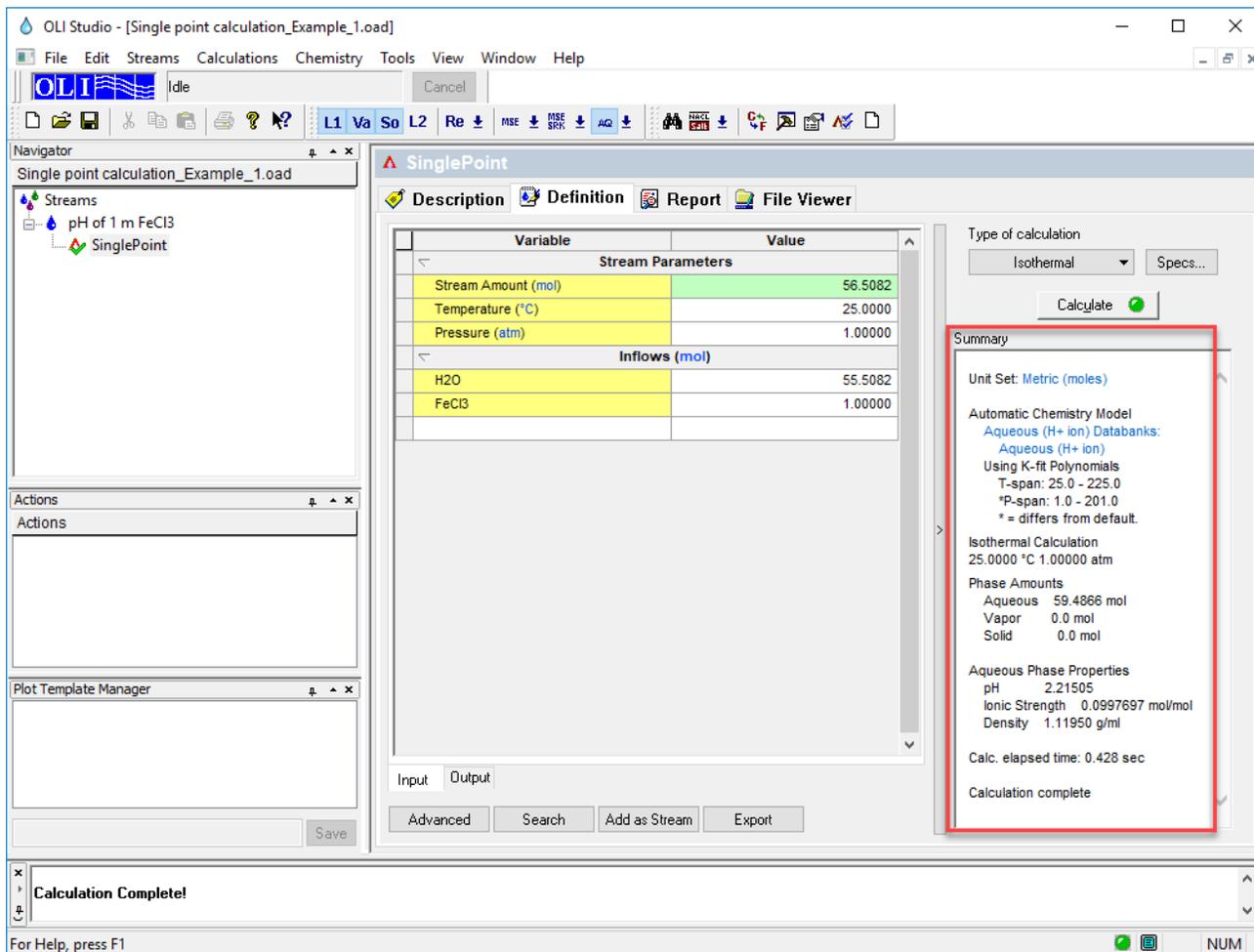
The screenshot shows the OLI Studio interface. The 'File' menu is open, and 'Save As...' is highlighted. The main window displays the 'pH of 1 m FeCl3' calculation. The 'Description' tab is active, showing a table of variables and values.

Variable	Value
Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
FeCl3	1.00000

Additional details from the interface:

- Unit Set: Metric (moles)
- Automatic Chemistry Model: Aqueous (H+ ion) Databanks: Aqueous (H+ ion)
- Using K-fit Polynomials
- T-span: 25.0 - 225.0
- *P-span: 1.0 - 201.0
- * = differs from default.

When the “**Calculation is complete**” a check mark appears on the calculation object . Now, let’s analyze the results of the simulation.



The screenshot shows the OLI Studio interface with the 'SinglePoint' calculation object selected. The 'Summary' box on the right contains the following information:

Unit Set: Metric (moles)

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 Using K-fit Polynomials
 T-span: 25.0 - 225.0
 *P-span: 1.0 - 201.0
 * = differs from default.

Isothermal Calculation
 25.0000 °C 1.00000 atm

Phase Amounts
 Aqueous 59.4866 mol
 Vapor 0.0 mol
 Solid 0.0 mol

Aqueous Phase Properties
 pH 2.21505
 Ionic Strength 0.0997697 mol/mol
 Density 1.11950 g/ml

Calc. elapsed time: 0.428 sec
 Calculation complete

The status bar at the bottom of the window displays "Calculation Complete!" and "For Help, press F1".

Analyzing the Results

The summary box displays a partial set of results including pH, density, and volume, as well as the total calculation time.

The **pH** is calculated to be approximately **2.2**

Let's analyze the simulation results in more detail

13. Click on the **Report** Tab

14. **Scroll down** and find **Species Output (True Species)**. You will find a list of the all the different species present in the aqueous phase.

OLI Studio - [Single point calculation_Example_1.oad]

File Edit Streams Calculations Chemistry Tools View Window Help

SinglePoint

Jump to: Species Output (True Species)

Species Output (True Species)

Row Filter Applied: Only Non Zero Values
column Filter Applied: Only Non Zero Values

	Total mol	Aqueous mol
H2O	55.503	55.503
Cl-1	2.97833	2.97833
Fe+3	0.983345	0.983345
FeCl2+1	9.83218e-3	9.83218e-3
H+1	5.2894e-3	5.2894e-3
FeOH+2	5.27572e-3	5.27572e-3
FeCl+2	1.30791e-3	1.30791e-3
FeCl3 (Molysite)	2.25081e-4	2.25081e-4
FeCl4-1	6.4732e-6	6.4732e-6
Fe(OH)2+1	6.35892e-6	6.35892e-6
Fe2(OH)2+4	4.78545e-7	4.78545e-7
HCl	2.63792e-9	2.63792e-9
Fe(OH)3 (Bernalite)	2.07037e-9	2.07037e-9
OH-1	9.05652e-13	9.05652e-13
Fe(OH)4-1	1.11803e-16	1.11803e-16
Total (by phase)	59.4866	59.4866

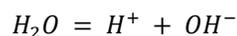
Calculation Complete!

For Help, press F1

Why is the **pH** so low?

The aqueous iron species complexes the hydroxide ions. The water dissociation shifts in the direction to replenish the hydroxide ions³.

This equilibrium is always present:



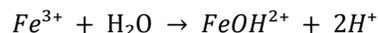
³ Le Châtelier's principle. P.W. Atkins. Physical Chemistry. W.H. Freeman and Company, San Francisco (1982) p 269.

Speciation Reactions

First iron (III) chloride dissociates:



Then the Fe^{3+} interacts with water; hydrolysis reaction:



Then another water molecule enters into the reaction:



These last two reactions take up the OH^- from solution, and release H^+ into the solution

More speciation reactions occur, but the reactions above were shown as an illustration. The following is a list of all the species that are formed in the aqueous phase:

Fe^{+3}	$FeCl_2^{+1}$	$Fe(OH)_3^0$	H_2O^0
$FeCl^{+2}$	$Fe(OH)_2^{+1}$	OH^{-1}	HCl^0
$FeOH^{+2}$	H^{+1}	$FeCl_4^{-1}$	$Fe_2(OH)_2^{+4}$
Cl^{-1}	$FeCl_3^0$	$Fe(OH)_4^{-1}$	

pH Calculation

The pH is calculated using the following formula:

$$pH = -\log(m_{H^+}\gamma_{H^+})$$

For the pH calculation the molality and the activity coefficient of the H^+ species is needed. To reveal the activity coefficients calculated by software follow the steps below.

15. Click on the **Customize** Button
16. Select **Species Activity Coefficients**
17. Click **OK**

The screenshot shows the OLI Studio interface. The 'Report Contents' dialog box is open, with 'Species Activity Coefficients' selected in the 'Report Contents' list. The 'SinglePoint' report window is also open, displaying the 'Species Output (True Species)' table. A 'Customize' button is highlighted in the report window, and an 'OK' button is highlighted in the 'Report Contents' dialog box.

Species Output (True Species)

Row Filter Applied: Only Non Zero Values
Column Filter Applied: Only Non Zero Values

	Total	Aqueous
	mol	mol
H2O	55.503	55.503
Cl-1	2.97833	2.97833
Fe+3	0.983345	0.983345
FeCl2+1	9.83218e-3	9.83218e-3
H+1	5.2894e-3	5.2894e-3
FeOH+2	5.27572e-3	5.27572e-3
FeCl+2	1.30791e-3	1.30791e-3
FeCl3 (Molysite)	2.25081e-4	2.25081e-4
FeCl4-1	6.4732e-6	6.4732e-6
Fe(OH)2+1	6.35892e-6	6.35892e-6
Fe2(OH)2+4	4.78545e-7	4.78545e-7
HCl	2.63792e-9	2.63792e-9
Fe(OH)3 (Bernalite)	2.07037e-9	2.07037e-9
OH-1	9.05652e-13	9.05652e-13
Fe(OH)4-1	1.11803e-16	1.11803e-16
Total (by phase)	59.4866	59.4866

18. Go to the **Report** and **scroll down** or use the **Jump to** option and select **Species Activities/Fugacity Coefficients**.

OLI Studio - [Single point calculation_Example_1.oad]

File Edit Streams Calculations Chemistry Tools View Window Help

Navigator: Single point calculation_Example_1.oad

Streams: pH of 1 m FeCl3, SinglePoint

SinglePoint Report

Jump to: Species Activity/Fugacity Coefficient: (selected)

Species Activity/Fugacity Coefficients

Species	γ		Fugacity Coefficients
	x-based	m-based	
Cl-1	0.62871	0.58607	
FeCl3 - Aq	2.56304	2.3914	
Fe2(OH)2+4	4.86608e-3	4.54021e-3	
FeCl2+1	0.458943	0.428209	
FeCl4-1	1.87391	1.74842	
FeCl+2	0.269701	0.25164	
Fe+3	1.4323e-3	1.33639e-3	
Fe(OH)2+1	0.701115	0.654164	
Fe(OH)3 - Aq	2.56304	2.3914	
Fe(OH)4-1	1.87391	1.74842	
FeOH+2	0.269701	0.25164	
H2O	1.01807	0.949897	
HCl - Aq	2.56304	2.3914	
H+1	1.2348	1.15211	
OH-1	1.87255	1.74715	

Calculation Complete!

For Help, press F1

Thus, the pH is:

$$pH = -\log(m_{H^+}\gamma_{H^+})$$

$$pH = -\log[(5.28940 \times 10^{-3})(1.15211)]$$

$$pH = -\log[6.094 \times 10^{-3}]$$

$$pH = 2.2151$$

It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. We save this example initially as *Single Point Calculations*.

Example 2: Calculating the pH of an acetic acid solution

In this example, we will explore an isothermal calculation and how to set up the right units before you start your calculation. Let's calculate the pH of a 10 wt% acetic acid solution. The temperature and pressure will be 75°C and 1 atm, respectively.

Starting the Simulation

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Isothermal – acetic acid*
3. Select the AQ thermodynamic Framework (selected by default)
4. **Click** on the **Units Manager** Icon, and the Units Manger window opens

The screenshot shows the OLI Studio interface with the following components:

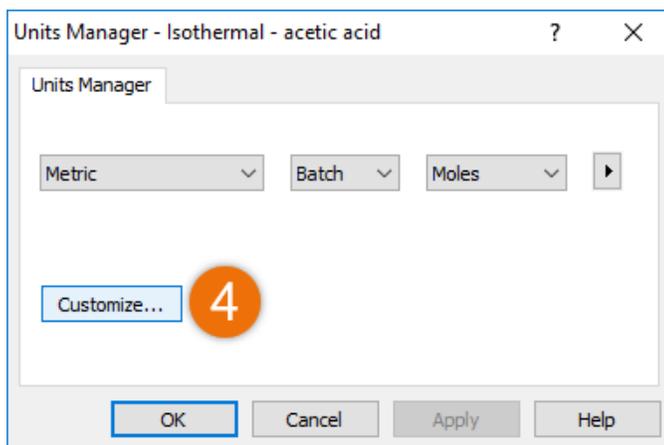
- Actions Panel (1):** The 'Add Stream' button is highlighted with a red box and a circled '1'.
- Navigator (2):** The stream 'Isothermal - acetic acid' is highlighted with a blue box and a circled '2'.
- Toolbar (3):** The 'AQ' (Aqueous) framework icon is highlighted with a red box and a circled '3'.
- Toolbar (4):** The 'Units Manager' icon is highlighted with a red box and a circled '4'.
- Main Window:** Displays the 'Isothermal - acetic acid' stream details. The 'Description' tab is active, showing a table of variables and values.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082

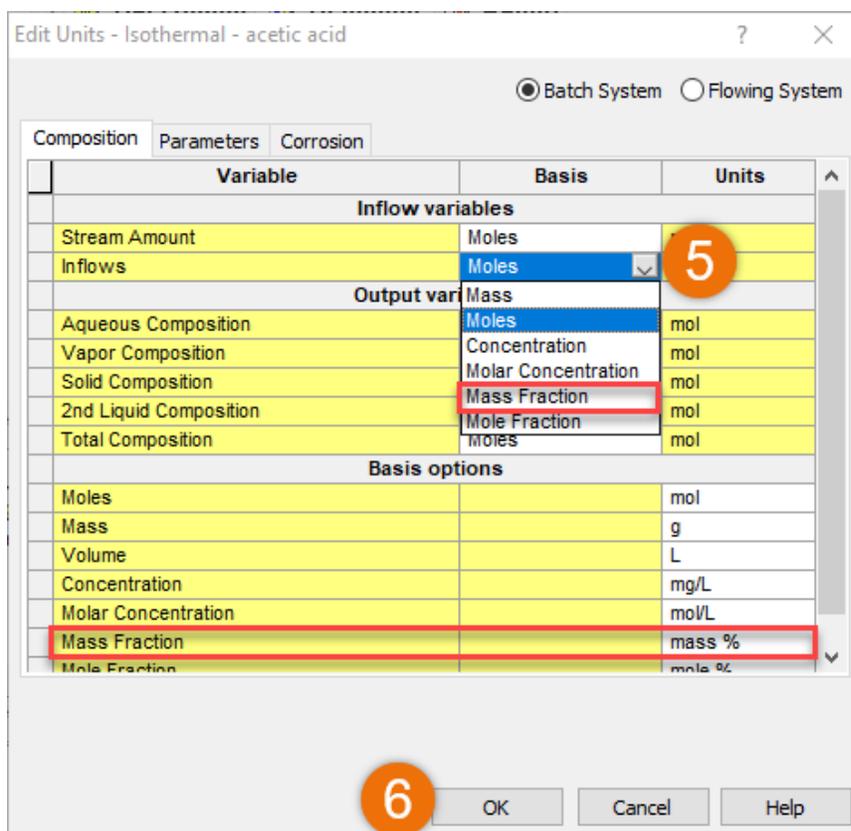
Summary:

- Unit Set: Metric (moles)
- Automatic Chemistry Model
- Aqueous (H+ ion) Databanks:
- Aqueous (H+ ion)
- Using K-fit Polynomials
- T-span: 25.0 - 225.0
- *P-span: 1.0 - 201.0
- * = differs from default.

- Click on the **Customize** Button



- Let's change only the **Inflows** units. Click on the white box, **select** the drop-down arrow next to the unit, and **select Mass Fraction**. **Click OK**, to exit the Units Manager and go back to the **Definition** tab.



Note: The default unit is **mass%**, however you can change it to other to ppm (mass) or g/g.

Mass Fraction	mass %
Mole Fraction	g/g
	mass %
	ppm (mass)

We are now ready to enter the information to set up the single point calculation.

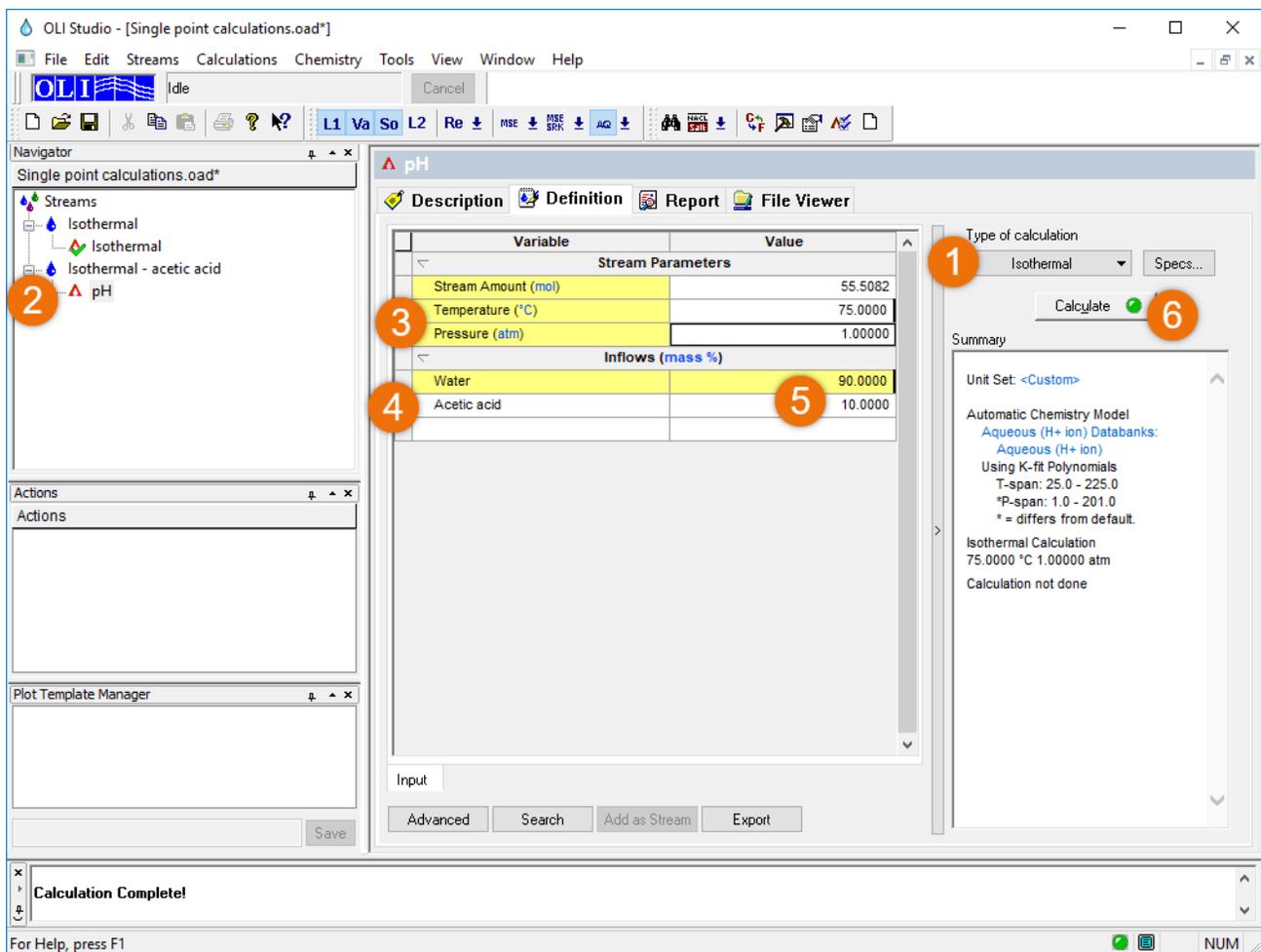
1. Go to the **Add Calculation** button and select **Single Point**. Select the default calculation type – **Isothermal**
2. **Change** the name to **pH** using the **<F2>** key or by **right-mouse click** on the object and selecting **rename**
3. **Change** the temperature to **75°C** and pressure to **1 atm**
4. Type **Acetic Acid** in the white cell below H₂O inflows grid, and press **<Tab>** or **<Enter>**

Note: If the name *Acetic Acid* changed to the formula type i.e. *CH₃COOH*, or the OLI TAG name, i.e. *ACETACID*, you can change the name style to *Display Name* by clicking on the **Names Manager** icon 

5. **Enter** the value 10 mass% in the next cell.

Note: When using mass-fraction units, it is assumed that the amount of water will be the difference of the components entered. In this case, the value field is highlighted in yellow to inform you that the value will be determined from the values of the other components.

6. Click on the **Calculate** button



The screenshot shows the OLI Studio interface for a single point calculation. The main window displays a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	75.0000
Pressure (atm)	1.00000
Inflows (mass %)	
Water	90.0000
Acetic acid	10.0000

The Summary panel on the right shows the following information:

Unit Set: <Custom>

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

Isothermal Calculation
75.0000 °C 1.00000 atm
Calculation not done

Analyzing the Results

After the calculation is complete, another way of analyzing the results is using the **Output** mini-tab.

1. Click on the **Output** mini-tab
2. Right-click on the gray area and select **Sections**
3. Select **Additional Stream Parameters**

The screenshot displays the OLI Studio interface. The main window shows a 'pH' calculation with a 'Description' tab selected. The 'Output' mini-tab is active at the bottom. A right-click context menu is open over the gray area of the 'Description' tab, with 'Sections' selected. The 'Sections' menu is further expanded, showing 'Additional Stream Parameters' highlighted. Three red circles with numbers 1, 2, and 3 indicate the steps: 1 points to the 'Output' mini-tab, 2 points to the 'Sections' option in the context menu, and 3 points to the 'Additional Stream Parameters' option in the expanded menu. The background shows the 'Variable' and 'Inflows (mass %)' tables, and a 'Calculation Complete!' message at the bottom.

Variable	
Stream Parameters	
<input type="checkbox"/>	Stream Amount (mol)
<input type="checkbox"/>	Moles (True) - Aqueous (mol)
	Temperature (°C)
	Pressure (atm)
Inflows (mass %)	
	Water
	Acetic acid

Inflows (mass %)	
	Water
	Acetic acid

The Sections section offer more results such as Thermodynamic Properties, Scaling Tendencies, Equilibrium constants (K-values), etc., that you can further explore.

So, the calculated pH of this acetic acid solution is approximately 2.3.

The screenshot displays a software interface with a table of variables and a summary panel. The table is divided into sections: Stream Parameters, Inflows (mass %), and Additional Stream Parameters. The 'Additional Stream Parameters' section is highlighted with a red box. The summary panel on the right shows the calculated results, with the 'Aqueous Phase Properties' section also highlighted with a red box.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Moles (True) - Aqueous (mol)	55.5133
Temperature (°C)	75.0000
Pressure (atm)	1.00000
Inflows (mass %)	
Water	90.0000
Acetic acid	10.0000
Additional Stream Parameters	
Density - Aqueous (g/ml)	0.773294
Density - Total (g/ml)	0.773294
Ionic Strength (m-based) - Aqueous (m)	5.17899e-3
Ionic Strength (x-based) - Aqueous (m)	9.02834e-5
pH	2.32267
Standard Liquid Volume - Aqueous (L)	1.07368

Summary

Unit Set: <Custom>

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

Isothermal Calculation
75.0000 °C 1.00000 atm

Phase Amounts
Aqueous 1075.27 g
Vapor 0.0 g
Solid 0.0 g

Aqueous Phase Properties
pH 2.32267
Ionic Strength 9.02834e-5 mol/mol
Density 0.773294 g/ml

Calc. elapsed time: 0.029 sec
Calculation complete

It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created in Example 1 named as *Single Point Calculations*.

1.2. Bubble Point

Liquid boils when its vapor pressure exceeds its confining pressure. Boiling occurs by adding heat (isobaric boiling) or reducing confining pressure (isothermal boiling). Either way, the effect is the same: a vapor phase forms. Stream Analyzer calculates this phenomenon using a calculation type called **Bubble Point**. Since the OLI does not assume an air phase, the confining pressure acts like a plunger on a liquid's surface. The pressure the plunger exerts is the pressure specified in the software.

With the software, the temperature or pressure is adjusted such that a very small amount of vapor will form (i.e. 1×10^{-10} of the total stream amount in gmoles). This is another way of saying that the bubble point calculation is a determination of the boiling point. Usually we determine the temperature at which a solution will boil. If the pressure is set to 1 atm, then we calculate the **Normal Boiling Point**. If we set a constant temperature, then we determine the bubble point pressure.

Example 3: Calculating the Bubble Point of a 1 M Acetone Solution

In this example, we are going to compute the bubble point of a 1 M Acetone solution, by changing the temperature (isobaric) and then the pressure (isothermal). Additionally, you will learn how to change the **Inflows** units from moles to moles/L (M).

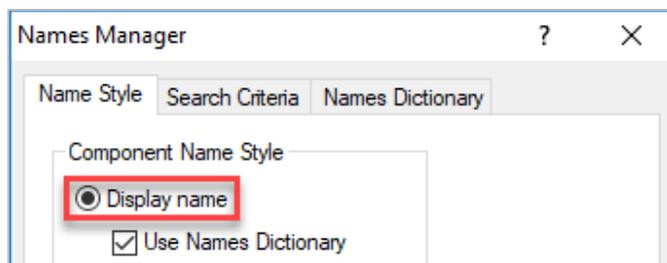
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Bubble Point Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	1 L
Calculation Sub-type	Bubble Point	Temperature	25 °C
Stream Name	Acetone Bubble Point	Pressure	1 atm
Name Style	Display Name	Water	Calculated
Unit Set	Custom	Acetone	1 mol/L
Framework	MSE		

Calculating the Bubble Point Temperature (Isobaric)

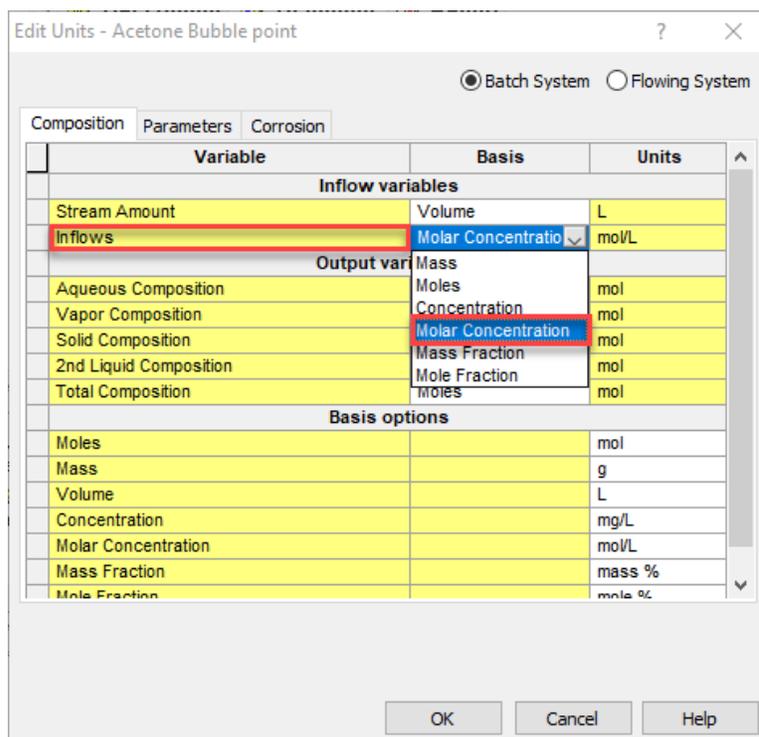
1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Acetone Bubble Point*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** Icon, and select the **Display Name** option, and click **OK**



5. Click on the hyperlink **mol** next to **Stream Amount**

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
Water	55.5082

6. This will open the **Units Manager**. Under **Inflows**, select the option of **Molar Concentration**. It will automatically set the Stream amount as **Volume** in **Liters**. Then click **OK**.



7. Type **Acetone** in the white cell below H2O inflows grid, and press **<Tab>** or hit **<Enter>**, and then enter the value **1.0 mol/L** in the next cell.
8. Go to the **Add Calculation** button and select **Single Point** calculation

9. Select **Bubble point** as Type of Calculation.
10. Change the **SinglePoint** name to **Bubble Point Temperature** using the <F2> key
11. A new section appears in the grid, called **Calculation Parameters**. By default, the Temperature Bubble Point calculation is selected. For this calculation leave the default calculation: **Temperature**

Note: In the drop-down arrow you have the option to select Bubble Point **Temperature** or Bubble Point **Pressure**.

Variable	Value
Stream Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Calculate	Temperature
Inflows	
Water	Temperature
	Pressure
Acetone	1.00000

Note: There are also two dots to the left of the Temperature and Pressure rows. The yellow dot represents the “dependent” variable. The temperature value, 25.000 is colored green. This value is now an initial guess, since the final value will be computed. The brown dot adjacent to the Pressure variable indicates that this potentially dependent variable is “fixed”.

12. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key.
13. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the Summary Box. The temperature at the bubble point is computed to be **87.11°C** at 1 atm. Also notice that the **Vapor** amount is $\approx 5.074\text{e-}9$ moles out of the total **Aqueous** amount of 50.74 moles. This is by design; the software sets the amount of vapor at 1/10th the moles of the stream amount.

Unit Set: <Custom>

Automatic Chemistry Model
MSE (H3O+ ion) Databanks:
MSE (H3O+ ion)
Using Helgeson Direct

Bubble Point Calculation
1.00000 atm
87.1143 °C

Phase Amounts
Aqueous 50.7382 mol
Vapor 5.07382e-9 mol
Solid 0.0 mol

Aqueous Phase Properties
pH 6.23654
Ionic Strength 1.04844e-8 mol/mol
Density 0.954131 g/ml

Calc. elapsed time: 0.725 sec

Calculation complete

Calculating the Bubble Point Pressure (Isothermal)

This next calculation computes the bubble point pressure for the same stream.

1. Select the Stream named **Acetone Bubble point**
2. Go to the **Add Calculation** button and select **Single Point** calculation
3. Select **Bubble point** as Type of Calculation.
4. Change the **SinglePoint** name to **Bubble Point Pressure** using the <F2> key
5. Change the Calculate-Temperature row to **Calculate-Pressure**

Calculation Parameters	
Calculate	Pressure
Inflows (mol/L)	
Water	
Acetone	1.00000

6. **Click** on the **Calculate** button or press the <F9> key.
7. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

Review the Summary Box. The bubble point pressure is computed to be **0.0700550** at 25 °C. Also notice that the **Vapor** amount is $\approx 5.278\text{e-}9$ moles out of the total **Aqueous** amount of 52.78 moles.

Unit Set: <Custom>

Automatic Chemistry Model
MSE (H3O+ ion) Databanks:
MSE (H3O+ ion)
Using Helgeson Direct

Bubble Point Calculation
25.0000 °C
0.0700550 atm

Phase Amounts

Aqueous	52.7833 mol
Vapor	5.27833e-9 mol
Solid	0.0 mol

Aqueous Phase Properties
pH 6.99771
Ionic Strength 1.81463e-9 mol/mol
Density 0.990973 g/ml

Calc. elapsed time: 0.047 sec

Calculation complete

1.3. Dew Point

The **Dew Point** is defined as the temperature at which a condensable component of a gas, for example water vapor in the air, starts to condensate into liquid. **OLI Studio: Stream Analyzer** calculates this phenomenon using a calculation type called Dew Point. With the software, the temperature or pressure is adjusted such that a very small amount of liquid will form.

It is frequently useful to determine the temperature or pressure at which a gas will condense. If the pressure is set constant, we calculate the dew point temperature; if the temperature is constant, then we determine the dew point pressure.

Example 4: Calculating the Dew Point of a Simple Sour Natural Gas

In this example, we are going to compute the dew point of a simple sour natural gas, by changing the temperature (isobaric) and then the pressure (isothermal).

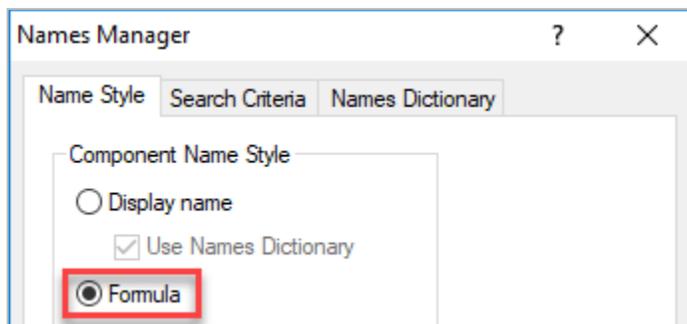
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

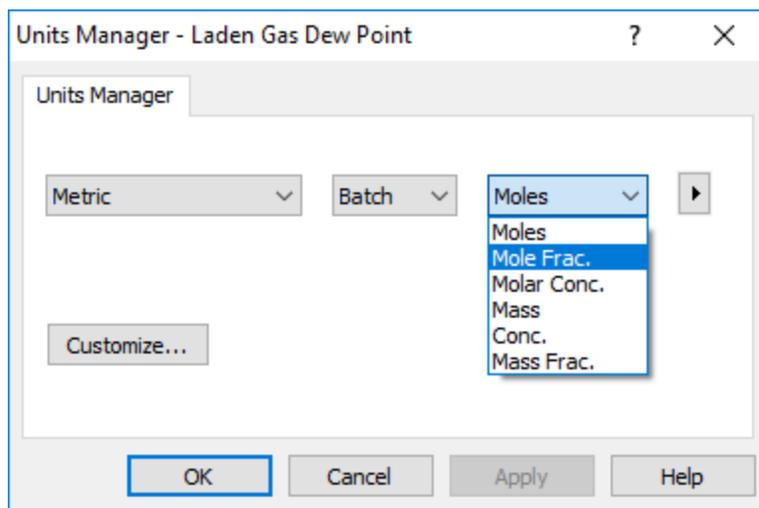
Dew Point Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default – 55.5082 moles
Calculation Sub-type	Dew Point	Temperature	120 °C
Stream Name	Sour Natural Gas Dew Point	Pressure	100 atm
Name Style	Display Formula	H2O	Calculated
Unit Set	Metric, Mole Fraction	CO2	1 mole %
Framework	MSE	CH4	95 mole %
		H2S	3 mole %

Calculating the Dew Point Temperature (Isobaric)

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Sour Natural Gas Dew Point*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** icon, and select the **Formula** option, and click **OK**



5. **Click** on the **Units Manager** icon, and select Metric, Batch, Mole Frac. This will change all inflows to mole %.



6. Enter the composition of the gas given in the table [above](#)
7. Go to the **Add Calculation** button and select **Single Point** calculation
8. Select **Dew point** as Type of Calculation
9. Change the **SinglePoint** name to **Dew Point Temperature** using the <F2> key
10. Keep the Calculate-**Temperature** option

	Variable	Value
Stream Parameters		
	Stream Amount (mol)	55.5082
	Temperature (°C)	120.000
	Pressure (atm)	100.000
Calculation Parameters		
	Calculate	Temperature
Inflows (mole %)		
	H2O	1.00000
	CO2	1.00000
	CH4	95.0000
	H2S	3.00000

11. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
12. Create a **new SinglePoint** and name it **Dew Point Pressure**. Repeat the steps above, and select the Calculate-**Pressure** option
13. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the Summary Box. The calculated dew point temperature is **113.5°C**. The calculated dew point pressure is **129.8 atm**.

Dew Point Temperature

Unit Set: Metric (mole fraction)

Automatic Chemistry Model
MSE (H3O+ ion) Databanks:
MSE (H3O+ ion)
Using Helgeson Direct

Dew Point Calculation
100.000 atm
91.9154 °C

Phase Amounts
Aqueous 5.55082e-5 mol
Vapor 55.5082 mol
Solid 0.0 mol

Aqueous Phase Properties
pH 3.77521
Ionic Strength 3.15475e-6 mol/mol
Density 0.950536 g/ml

Calc. elapsed time: 0.437 sec

Calculation complete

Dew Point Pressure

Unit Set: Metric (mole fraction)

Automatic Chemistry Model
MSE (H3O+ ion) Databanks:
MSE (H3O+ ion)
Using Helgeson Direct

Dew Point Calculation
120.000 °C
472.561 atm

Phase Amounts
Aqueous 1.00000e-6 mol
Vapor 55.5082 mol
Solid 0.0 mol

Aqueous Phase Properties
pH 3.58375
Ionic Strength 5.08513e-6 mol/mol
Density 0.953852 g/ml

Calc. elapsed time: 0.043 sec

Calculation complete

Note: The software sets the amount of liquid to $1/10^6$ of the stream amount for the dew point calculation.

You can study the composition of the acid gases such as CO_2 and H_2S dissolved in the Aqueous phase. After you have calculated the Dew Point Pressure, click on the **Report** Tab. Scroll down or use the **Jump to** option to go to the **Species Output (True Species)**.

Jump to: Species Output (True Species)

Row Filter Applied: Only Non Zero Values
column Filter Applied: Only Non Zero Values

	Total	Liquid-1	Vapor
	mole %	mole %	mole %
CH4	95.0	0.346846	95.0
H2S	3.0	0.305546	3.0
CO2	1.0	0.0429733	1.0
H2O	1.0	99.3036	0.999998
H3O+1	9.16104e-12	5.08513e-4	
HS-1	7.77131e-12	4.31372e-4	
HCO3-1	1.38954e-12	7.71308e-5	
OH-1	1.91059e-16	1.06054e-8	
CO3-2	6.99104e-19	3.88061e-11	
S-2	5.6492e-20	3.13577e-12	
Total (by phase)	100.0	100.0	100.0

The aqueous phase, also known as Liquid-1 in the MSE framework, is shown in the center column. The dissolved CH_4 , H_2S , and CO_2 are 0.347, 0.305, and 0.043 mole % respectively.

1.4. Isochoric (constant volume)

The **Isochoric calculation** fixes the total system **volume** and adjusts the temperature or pressure. This can be understood in a gas-phase from the basis of the Ideal Gas Law:

$$PV = nRT$$

If temperature is the free variable, then the above equation becomes $T = \frac{PV}{nR}$, meaning that for a given volume, pressure, and gas moles, temperature can be obtained.

You will run a calculation, in which the system moles, temperature and volume are defined.

Example 5: Calculating the Total Pressure of a 10 L Vessel Containing Water and Air

In this example, you will add 1 kg water to a 10 L vessel and then fill the void (head space) with Air. The temperature is 25 °C.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Autoclave Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default – 55.5082
Calculation Sub-type	Isochoric	Ambient Temperature	25 °C
Stream Name	Isochoric	H2O	Calculated
Name Style	Display Formula	N2	77 moles
Unit Set	Metric, Moles	O2	21 moles
Framework	AQ	CO2	1 mol
Calculate	Pressure	Ar	0.04 moles
Vessel Volume	10 L		

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Isochoric*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the **gas composition** in the table above
7. Go to the **Add Calculation** button and select **Single Point** calculation
8. Select **Isochoric** as Type of Calculation
9. Change the **SinglePoint** name to **10L Vessel** using the **<F2>** key
10. In the **Calculation Parameters** section set **Total Volume** to **10 L** and **Calculate Pressure**. (To select Pressure, click on the drop-down arrow).

Variable	Value
Stream Parameters	
Stream Amount (mol)	154.548
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Total Volume (L)	10.0000
Calculate	Pressure
Inflows (mol)	
H2O	55.5082
N2	77.0000
O2	21.0000
CO2	1.00000
Ar	0.0400000

- We are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the **Summary Box** or Click on the **Output-Minitab** to see the Results.

The screenshot displays the software interface with the following components:

- Table:** Shows the results of the calculation. The 'Calculation Results (atm)' section is highlighted with a red box, showing a pressure of 305.676 atm.
- Summary Box:** Located on the right, it provides details about the calculation:
 - Type of calculation: Isochoric
 - Unit Set: Metric (moles)
 - Automatic Chemistry Model: Aqueous (H+ ion) Databanks: Aqueous (H+ ion)
 - Using K-fit Polynomials
 - T-span: 25.0 - 225.0
 - *P-span: 1.0 - 201.0
 - * = differs from default.
 - Isochoric Calculation:** 25.0000 °C, 305.676 atm (highlighted with a red box)
 - Phase Amounts: Aqueous 55.6901 mol, Vapor 98.8582 mol, Solid 0.0 mol
 - Aqueous Phase Properties: pH 3.82308, Ionic Strength 2.73634e-6 mol/mol, Density 1.01211 g/ml
- Buttons:** 'Calculate' (green), 'Input', 'Output', 'Advanced', 'Search', 'Add as Stream', and 'Export'.

About **305.7 atm** of pressure are needed to compress the 154.55 moles of gas and liquid into a 10-L volume vessel at 25 °C.

Go to the **Report** tab and view the **Total and Phase Flows (Amount)** table.

Total and Phase Flows (Amounts)

column Filter Applied: Only Non Zero Values

	Total	Aqueous	Vapor
	mol	mol	mol
Mole (True)	154.548	55.6901	98.8582
Mole (App)	154.548	55.6901	98.8582
	g	g	g
Mass	3874.61	1006.11	2868.51
	L	L	L
Volume	10.0001	0.994072	9.00598

The system is 10 L as defined (within the $1/10^6$ tolerance). The water phase makes up slightly less than 1 L and the balance is vapor. At this pressure, about 0.1527 moles of water evaporates, and contributes to the total moles of vapor.

1.5. Vapor Amount and Vapor Fraction

The **vapor amount** and **vapor fraction** calculations are identical in nature to the [Bubble Point](#) calculation, except that instead of the software defining the vapor amount as 1×10^{-10} of the total stream amount, the user defines the vapor size in either mole fraction units (vapor fraction) or mole units (vapor amount). To create a specified amount of vapor (or vapor fraction) the software can adjust the temperature (or pressure).

Example 6: Evaporating a Brine

In this example, you will concentrate a brine via evaporation adjusting the temperature, until reaching a vapor fraction amount of 95 mole %.

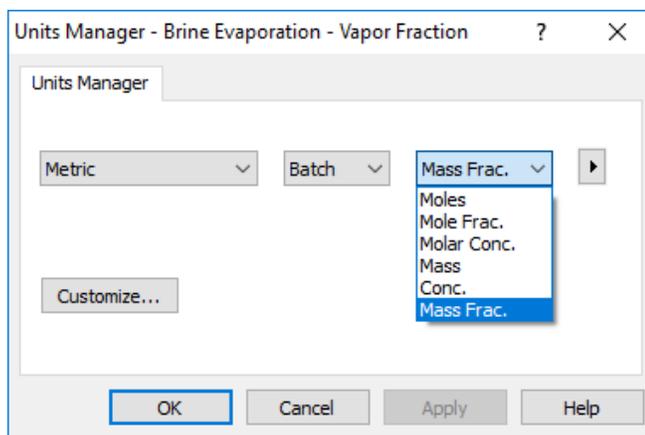
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Vapor Fraction / Vapor Amount Point Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default - 1 kg
Calculation Sub-type	Vapor Fraction	Temperature	25 °C
Stream Name	Brine Evaporation – Vapor Fraction	Pressure	1 atm
Name Style	Display Formula	H2O	Calculated
Unit Set	Metric, Mass Fraction	NaCl	9 mass %
Framework	MSE	CaSO ₄	1 mass %

Calculating the Vapor Fraction Temperature (Isobaric)

13. Add a new **Stream**
14. **Click** on the new Stream and press **<F2>** to change the name to *Brine Evaporation – Vapor Fraction*
15. Select the **MSE** thermodynamic Framework
16. **Click** on the **Names Manager** Icon and select the **Formula** option
17. **Click** on the **Units Manager** Icon, and select Metric, Batch, Mass Frac. This will change all inflows to mass %.



18. Enter the gas composition given in the table [above](#).
19. Go to the **Add Calculation** button and select **Single Point** calculation
20. Select **Vapor Fraction** as Type of Calculation
21. Change the **SinglePoint** name to **Vapor Fraction Temperature** using the <F2> key
22. Enter **95** as the **Vapor Fraction** amount.

Note: The software will convert the 1 kg to mole units and will put 95% of this in the vapor phase.
23. Keep the Calculate-**Temperature** option

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Vapor Fraction (Vapor/Inflow [mol]) (mole %)	95.0000
Calculate	Temperature
Inflows (mass %)	
H2O	90.0000
NaCl	9.00000
CaSO4	1.00000

24. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
25. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the Summary Box. The calculated temperature to put 95% (mole based) of the total stream amount in the vapor phase is **~109°C**, however the results in the summary box are given in mass. Let's go to the **Report**.

Unit Set: Metric (mass fraction)	
Automatic Chemistry Model	
MSE (H3O+ ion) Databanks:	
MSE (H3O+ ion)	
Using Helgeson Direct	
Vapor Fraction Calculation	
1.00000 atm	
108.805 °C	
Phase Amounts	
Aqueous	0.0243143 kg
Vapor	0.882612 kg
Solid	0.0930728 kg
Aqueous Phase Properties	
pH	6.40682
Ionic Strength	0.0990622 mol/mol
Density	1.16798 g/ml
Calc. elapsed time: 0.131 sec	
Calculation complete	

1. Select the **Report** tab and scroll down to **Total and Phase Flow (Amounts)** Table.

Jump to: Total and Phase Flows (Amounts) 

Total and Phase Flows (Amounts)
column Filter Applied: Only Non Zero Values

	Total	Liquid-1	Vapor	Solid
	mol	mol	mol	mol
Mole (True)	51.6887	1.20091	48.9923	1.49547
Mole (App)	51.5708	1.08307	48.9923	1.49547
	kg	kg	kg	kg
Mass	0.999999	0.0243143	0.882612	0.0930728
	L	L	L	cm3
Volume	1518.82	0.0208174	1518.76	41.7748

The apparent moles (**Mole (App)**) are the molecular representation of the system. There is a total of 51.5708 moles in this system, and exactly 95% of this system is in the vapor phase with a total of 48.9923 moles.

1.6. Set pH

The **Set pH** calculation is a useful tool in analyzing or designing a process. It allows you to create a solution that conforms to a premeasured pH. Other applications include designing a system to meet an operational pH or testing the impact of adding an acid or base to a system.

Example 7: Neutralizing Acetic Acid

In this example, you will compute the amount of base titrant required to neutralize a 1 molal acetic acid solution. You will assume a neutral system at 7 pH and 25°C.

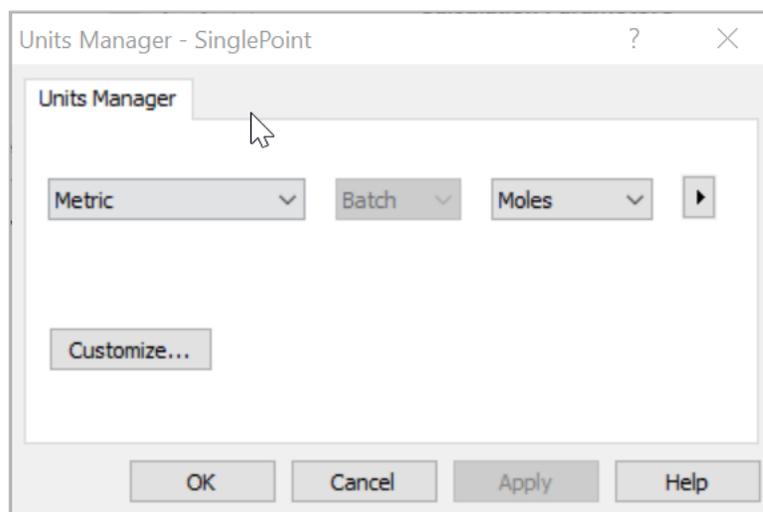
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Set pH Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default
Calculation Sub-type	Set pH	Temperature	25 °C
Stream Name	Neutralizing Acid	Pressure	1 atm
Name Style	Display Formula	H2O	Calculated
Unit Set	Metric, Moles	CH3COOH	1 mol
Framework	AQ		

Setting the pH

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Neutralizing Acid*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles (default units). Click **OK**.



- Enter **1 mol** of **CH₃COOH** as an inflow
- Go to the **Add Calculation** button and select **Single Point** calculation
- Select **Set pH** as Type of Calculation
- Change the **SinglePoint** name to **Neutralizing acetic acid** using the <F2> key

A new grid section named **Calculation Parameters** appears. In this grid the **Target pH** can be defined, as well as the **Acid** and **Basic** titrants. The default titrants are **HCl** and **NaOH** (common) and so no additional specifications are required except to set the pH.

Variable	Value
Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Target pH	0.0
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Inflows (mol)	
H2O	55.5082
CH3COOH	1.00000

Note: The default titrants can be changed by other acids or bases by adding the desired titrant as an inflow. The titrants in the **Set pH** calculation can be also set using the **Specs** button.

Calculation Options

Category: pH

Select an acid and base to adjust to meet the specified pH.

Use Single Titrant Hide Related Inflows **New Inflow**

Acid: CH3COOH, H2O, **HCL**

Base: CH3COOH, H2O, **NAOH**

The default acid and base are already set, so no additional work is required. If a different acid/base is desired, then the **New Inflow** button can be used to find additional components.

10. Enter **7** as the **Target pH** amount
11. Use the default titrants: **HCL** and **NAOH**

Variable	Value
Stream Parameters	
Stream Amount (mol)	56.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Target pH	7.00000
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Inflows (mol)	
H2O	55.5082
CH3COOH	1.00000

12. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
13. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the **Summary Box** or Click on the **Output-Minitab** to see the Results. About **0.997 moles** of NaOH is needed to neutralize 1 mole of acetic acid.

The screenshot displays the software interface with two main panels. The left panel is a table with columns 'Variable' and 'Value'. The right panel is a 'Summary' box with various calculation details.

Variable	Value
Stream Parameters	
Stream Amount (mol)	57.5053
Moles (True) - Aqueous (mol)	58.3044
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Results (mol)	
pH titrant added: NaOH	0.997023
Inflows (mol)	
H2O	55.5082
CH3COOH	1.00000
NaOH	0.997023

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 Using K-fit Polynomials
 T-span: 25.0 - 225.0
 *P-span: 1.0 - 201.0
 * = differs from default.

Set pH Calculation
 25.0000 °C
 1.00000 atm
 Target pH 7.00000
 Acid Titrant: HCl
 Total: 0.0 mol
 Base Titrant: NaOH
 Total: 0.997023 mol
 Added: 0.997023 mol

Phase Amounts
 Aqueous 58.3044 mol
 Vapor 0.0 mol
 Solid 0.0 mol

1.7. Precipitation Point

The **precipitation point** calculation computes the amount of material held in solution at given conditions and forces a very small amount of solid to exist. This calculation could be also called a **solubility calculation**.

Example 8: Determining the Solubility of Calcite (CaCO_3)

Equilibrium based simulators suffer from a potential problem, that the most stable solid will tend to be included over less stable (meta-stable) solids. Such is the case of calcium carbonate. Calcium Carbonate (CaCO_3) is found in nature in many forms. Two common forms are the more thermodynamically stable solids, **Calcite** and the less stable form **Aragonite**.

In this example, we will compute the solubility of CaCO_3 as **Calcite** in a solution containing Ca^{+2} , Mg^{+2} , and Cl^- as well as dissolved CO_2 .

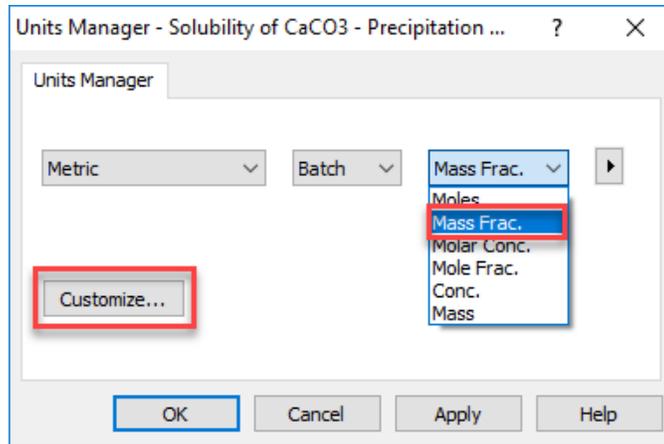
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

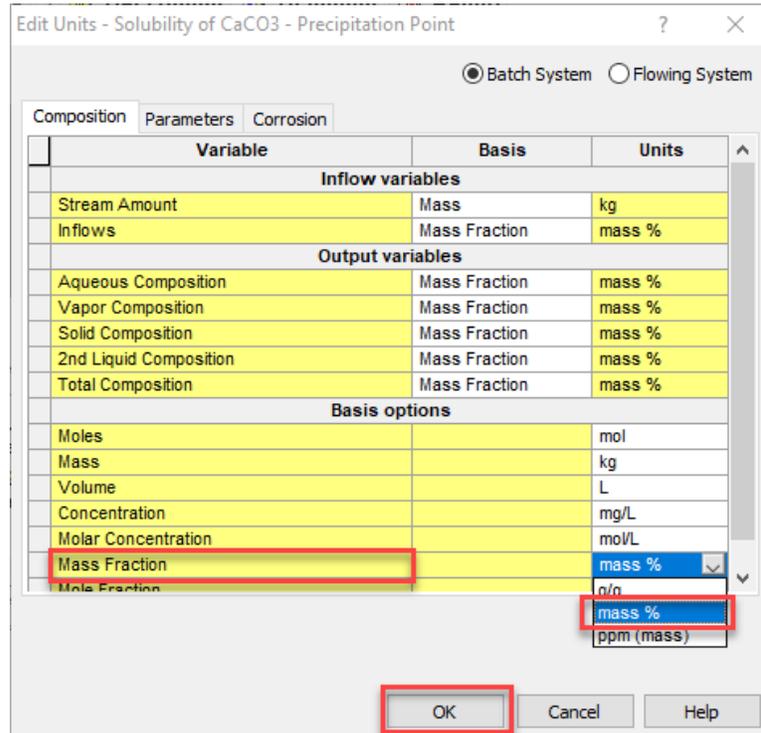
Precipitation Point Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default - 1 kg
Calculation Sub-type	Precipitation Point	Temperature	25 °C
Stream Name	Solubility of CaCO_3 – Precipitation Point	Pressure	1 atm
Name Style	Display Formula	H_2O	Calculated
Unit Set	Metric, Mass Fraction (ppm (mass))	CaCl_2	10870 ppm (mass)
Framework	AQ	MgCl_2	9325 ppm (mass)
		CO_2	431 ppm (mass)
		CaCO_3	0 ppm(mass)

Calculating the Precipitation of Calcite (CaCO_3)

1. Add a new **Stream**
2. **Click** on the new Stream and press <F2> to change the name to *Solubility of CaCO_3 – Precipitation Point*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Mass Frac. This will change all inflows to mass%. However, you need to change the units to ppm (mass), to do this **Click** on the **Customize button**.



6. This will open the **Edit Units** window. **Change** the units from **mass%** to **ppm (mass)**.



- Enter the stream composition given in the table [above](#).
- Go to the **Add Calculation** button and select **Single Point** calculation
- Select **Precipitation Point** as Type of Calculation
- Change the **SinglePoint** name to **Calcite Precipitation** using the <F2> key

At this point you may have noticed that the Calculate button is red, and that there is a **red** text in the Summary Box with instruction that additional specs are needed. The specifications need to be defined in the **Calculation Parameters** grid section.

The screenshot shows the software interface with the following components:

- Navigation Tabs:** Description, Definition, Report, File Viewer.
- Variable Table:**

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Precipitant:	<select>
Adjusted Inflow:	<select>
Inflows (ppm (mass))	
H2O	9.79374e5
CaCl2	10870.0
MgCl2	9325.00
CO2	431.000
CaCO3	0.0
- Summary Box:**

Unit Set: <Custom>

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 Using K-fit Polynomials
 T-span: 25.0 - 225.0
 *P-span: 1.0 - 201.0
 * = differs from default.

Precipitation Point Calculation
 25.0000 °C
 1.00000 atm
 Precipitate: Not specified.
 Adj. Inflow: Not specified.

Calculation not done
**Please select a target solid.
 Please select a variable to adjust.**

11. Select the **CaCO3 (Calcite)** as the **Precipitant**

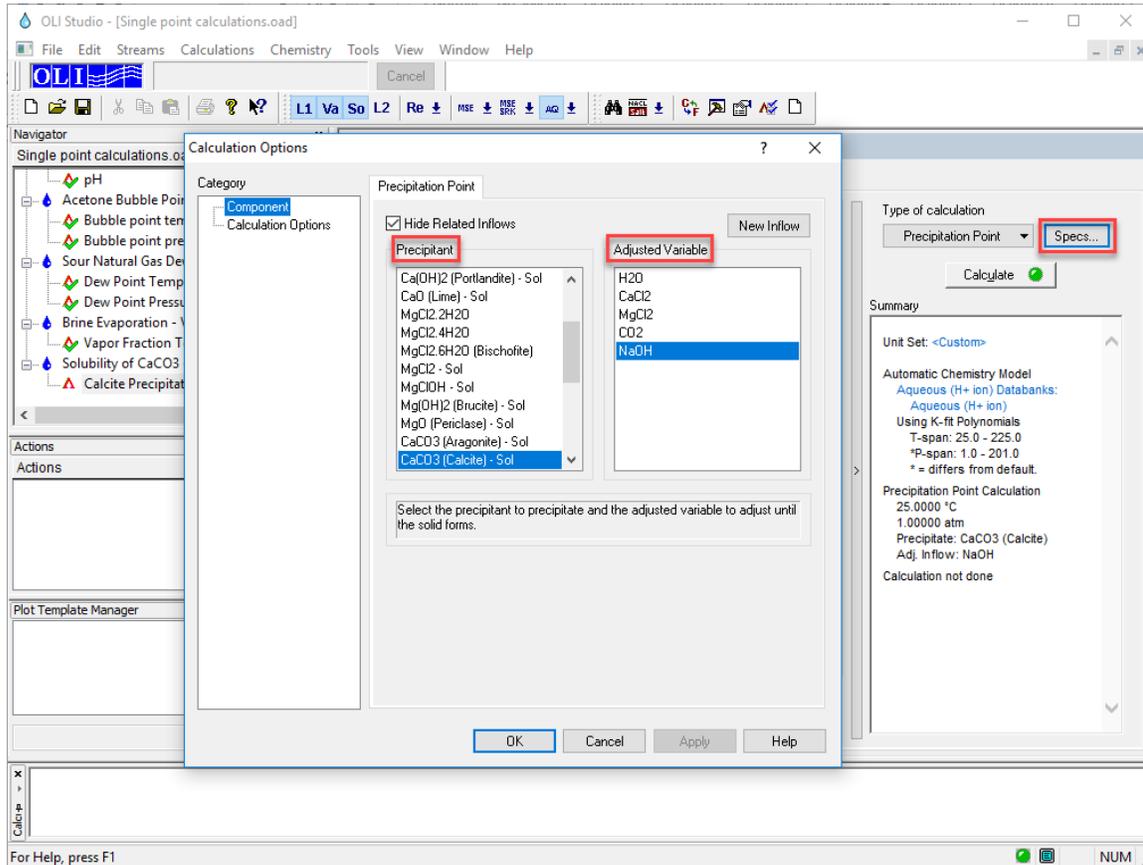
12. Select **NaOH** as the **Adjusted Inflow**

Calculation Parameters	
Precipitant:	CaCO3 (Calcite)
Adjusted Inflow:	CaCO3
Inflows (ppm)	
H2O	9.79374e5
CaCl2	10870.0
MgCl2	9325.00
CO2	431.000
CaCO3	0.0

The **Precipitant** refers to the independent variable – in this calculation, the solid phase selected will precipitate at amount of 1.0×10^{-10} times the stream amount.

The **Adjusted Variable** is the variable to be changed by the software until the solid target amount is achieved.

Note: The precipitation point parameters can be also set using the **Specs** button.



13. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

14. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the **Summary Box** or Click on the **Output-Minitab** to see the Results.

The software calculated that the solubility of CaCO_3 as Calcite in the solution under study is around **~431.15 ppm (mass)**. The pH of this solution is ~5.97.

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00041
Mass - Aqueous (kg)	1.00041
Mass - Solid (kg)	5.46166e-8
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Results (ppm (mass))	
Adjusted Inflow: CaCO3	413.146
Inflows (ppm (mass))	
H2O	9.78970e5
CaCl2	10865.5
MgCl2	9321.15
CO2	430.822
CaCO3	413.146

Type of calculation: Precipitation Point

Calculate

Summary

Unit Set: <Custom>

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 Using K-fit Polynomials
 T-span: 25.0 - 225.0
 *P-span: 1.0 - 201.0
 * = differs from default.

Precipitation Point Calculation
 25.0000 °C
 1.00000 atm
 Precipitate: CaCO3 (Calcite)
 Adj. Inflow: CaCO3
 Total 413.146 ppm (mass)

Phase Amounts
 Aqueous 1.00041 kg
 Vapor 0.0 kg
 Solid 5.46166e-8 kg

Aqueous Phase Properties
 pH 5.96733
 Ionic Strength 0.0107625 mol/mol
 Density 1.01414 g/ml

Input Output

Advanced Search Add as Stream Export

You can also check the results in the **Report Tab**. Click the **Customize** button and Select **Stream Inflows**.

OLI Studio - [Single point calculations.oad*]

File Edit Streams Calculations Chemistry Tools View Window Help

Report Contents

Category

- Report Contents
 - Calculation Summary
 - Stream Inflows
 - Speciation Summary
 - Stream Parameters
 - Total/Phase Flows
 - Scaling Tendencies
 - Species Output
 - Molecular Output
 - Element Balance
 - Species Activity Coe
 - Species Fugacities
 - Partial Pressures
 - Species K-Values
 - Species Mobilities
 - Species Self Diffusiv
 - Vapor Phase Diffusiv
 - Gibbs Free Energy o
 - Gibbs Free Energy o
 - Entropy
 - Entropy - Standard S
 - Reaction Kinetics
 - Redox Equations

Report Contents

To add or remove a section, click the check box. A shaded box means that only part of the component will be printed. To see what's included in a component, click Details.

Sections

- Calculation Summary
- Stream Inflows
- Speciation Summary
- Stream Parameters
- Total/Phase Flows
- Scaling Tendencies
- Species Output
- Molecular Output
- Element Balance
- Species Activity Coefficients
- Species Fugacities
- Partial Pressures
- Species K-Values
- Species Mobilities
- Species Self Diffusivities
- Vapor Phase Diffusivity Matrix

Up Down Select All Clear All

Description

This section displays the stream inflows.

6 of 22 Sections selected

OK Cancel Apply Help

Report File Viewer

Customize Export

1.00026	kg
25.0000	°C
1.00000	atm
6.08996	
0.0106874	mol/mol
0.599793	mol/kg
13.7558	atm
34706.8	µmho/cm
0.0161381	m2/ohm-mol
0.958261	cP
1.07583	
0.988618	L
0.986447	L

Notice that the concentrations have changed slightly. This is to accommodate the additional 413.15 ppm CaCO₃ needed to meet the calculation specifications.

Stream Inflows

Row Filter Applied: Only Non Zero Values

	Input	Output
Species	ppm (mass)	ppm (mass)
H2O	9.79374e5	9.78970e5
CaCl2	10870.0	10865.5
MgCl2	9325.00	9321.15
CO2	431.000	430.822
CaCO3	0.0	413.146

Example 9: Determining the Solubility of Aragonite (CaCO₃)

Calcite is the thermodynamically stable phase of calcium carbonate. **Aragonite**, calcite's orthorhombic polymorph, is about 1.5 times more soluble than calcite⁴. At surface conditions, aragonite spontaneously turns into calcite over geologic time, but at higher pressures aragonite, the denser of the two, is the preferred structure.

In this example, we wish to determine the solubility of the less thermodynamically stable solid, **Aragonite**, independently of the more stable solid **Calcite**. To do this, we need to modify the **solid phases** in the chemistry model and add a new **Databank**.

Starting the Simulation

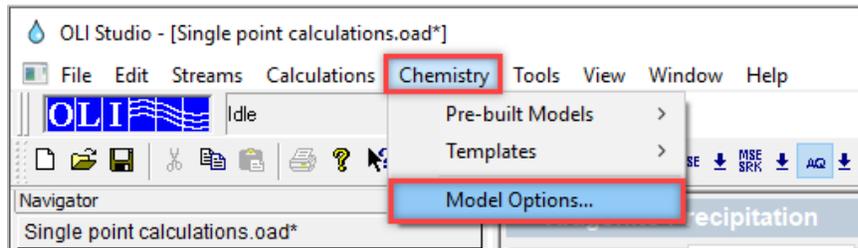
Calculating the Precipitation of Aragonite (CaCO₃)

1. Under the Stream *Solubility of CaCO₃ – Precipitation Point*, **Add a Single Point** calculation
2. Select **Precipitation Point** as Type of Calculation
3. Change the **SinglePoint** name to **Aragonite Precipitation** using the <F2> key
4. Select the **CaCO3 (Calcite)** as the **Precipitant**
5. Select **NaOH** as the **Adjusted Inflow**

Calculation Parameters	
Precipitant:	CaCO3 (Aragonite)
Adjusted Inflow:	CaCO3

⁴ <https://www.sciencedirect.com/topics/earth-and-planetary-sciences/calcite>

6. Click on **Chemistry > Model Options**

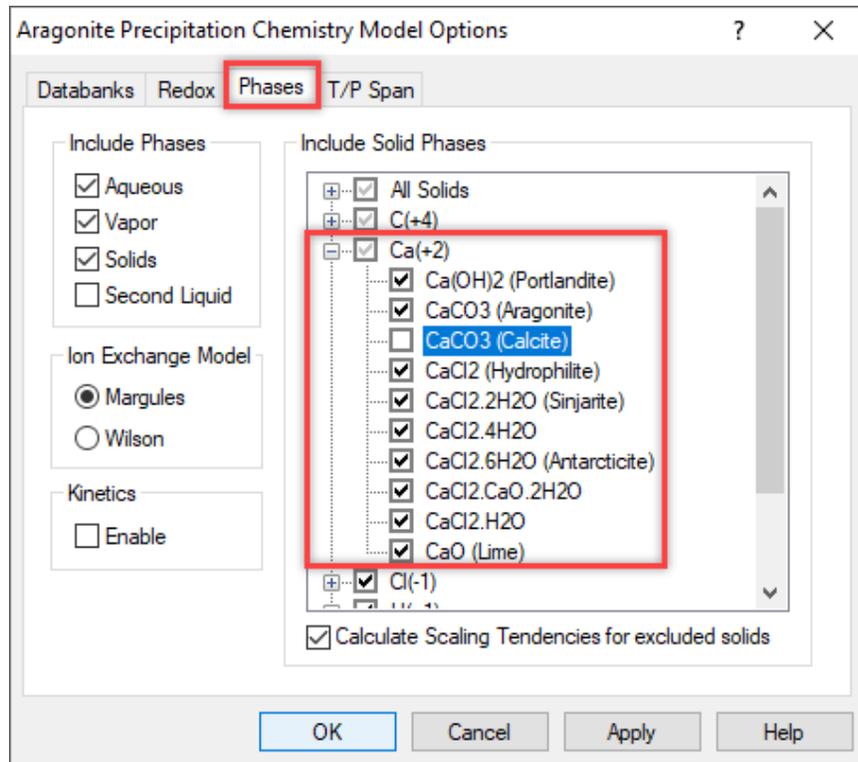


7. Select the **Phases** tab

8. **Click** on the “+” next to the Ca(+2) box to display all the calcium containing solids

9. Scroll down to find CaCO₃ (Calcite) and **uncheck** this solid

10. Click **OK** continue.



Note: The **Include Solid Phases** box lists the solids in the chemistry model. Unchecking these solids will mathematically eliminate the solid from consideration. The Scaling Tendency, however, will still be calculated.

11. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

12. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the **Summary Box** or Click on the **Output-Minitab** to see the Results.

The software calculated that the solubility of CaCO_3 as Aragonite in the solution under study is around **~552.87 ppm (mass)**. The pH of this solution is ~6.21. You can see that the solubility of Aragonite is higher than the solubility of Calcite (~431.15 ppm (mass)).

The screenshot displays a software interface for calculating precipitation. The main window is divided into two panes. The left pane shows a table of variables and their values, while the right pane shows a summary of the calculation.

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00055
Mass - Aqueous (kg)	1.00055
Mass - Solid (kg)	5.46166e-8
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Results (ppm (mass))	
Adjusted Inflow: CaCO_3	552.873
Inflows (ppm (mass))	
H_2O	9.78833e5
CaCl_2	10864.0
MgCl_2	9319.85
CO_2	430.762
CaCO_3	552.873
Solid (ppm (mass))	
CaCO_3 (Aragonite)	1.00000e6

The right pane shows the following summary:

Type of calculation: Precipitation Point

Unit Set: <Custom>

Automatic Chemistry Model
Aqueous (H^+ ion) Databanks:
Aqueous (H^+ ion)
Excluding 1 solid phase
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

Precipitation Point Calculation
25.0000 °C
1.00000 atm
Precipitate: CaCO_3 (Aragonite)
Adj. Inflow: CaCO_3
Total 552.873 ppm (mass)

Phase Amounts
Aqueous 1.00055 kg
Vapor 0.0 kg
Solid 5.46166e-8 kg

Aqueous Phase Properties
pH 6.21344
Ionic Strength 0.0107870 mol/mol

Example 10: Determining the Solubility of Dolomite ($\text{CaMg}(\text{CO}_3)_2$)

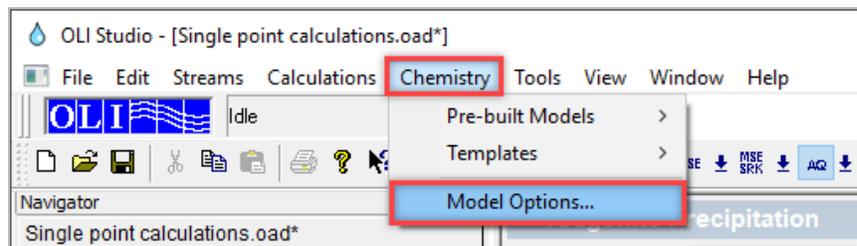
The third carbonate mineral to mention is **Dolomite**, which is something like calcite with a very high concentration of magnesium in it. Under some conditions there can be much more magnesium added in, and when the amount of magnesium becomes roughly the same as the calcium, the resulting mineral is called Dolomite with the following chemical formula: $\text{CaMg}(\text{CO}_3)_2$. The formation of Dolomite is believed to appear in geological time frames.

In the AQ Framework, the Public database does not include Dolomite. To add Dolomite into the Chemistry we need to add the **Geochemical Databank**.

Starting the Simulation

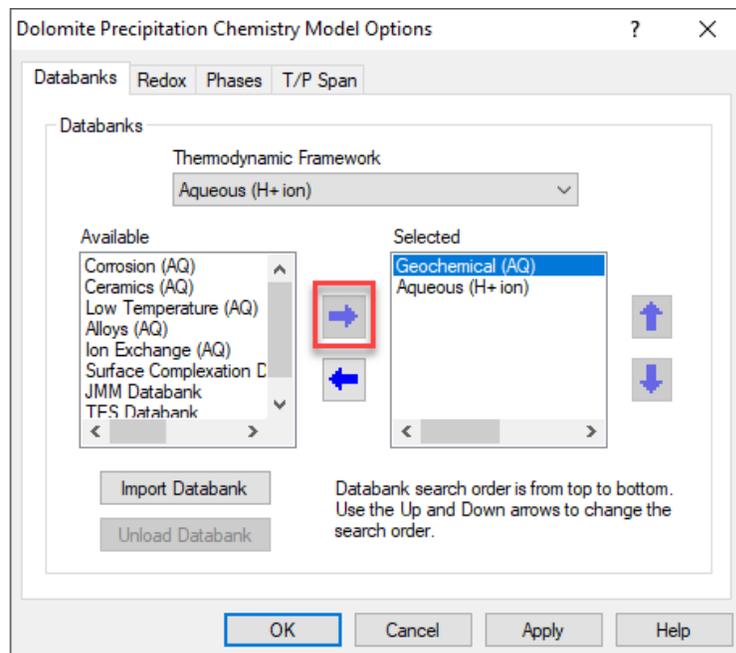
Calculating the Precipitation of Dolomite ($\text{CaMg}(\text{CO}_3)_2$)

1. Under the Stream *Solubility of CaCO_3 – Precipitation Point*, **Add a Single Point** calculation
2. Select **Precipitation Point** as Type of Calculation
3. Change the **SinglePoint** name to **Dolomite Precipitation** using the <F2> key
4. Click on **Chemistry > Model Options**

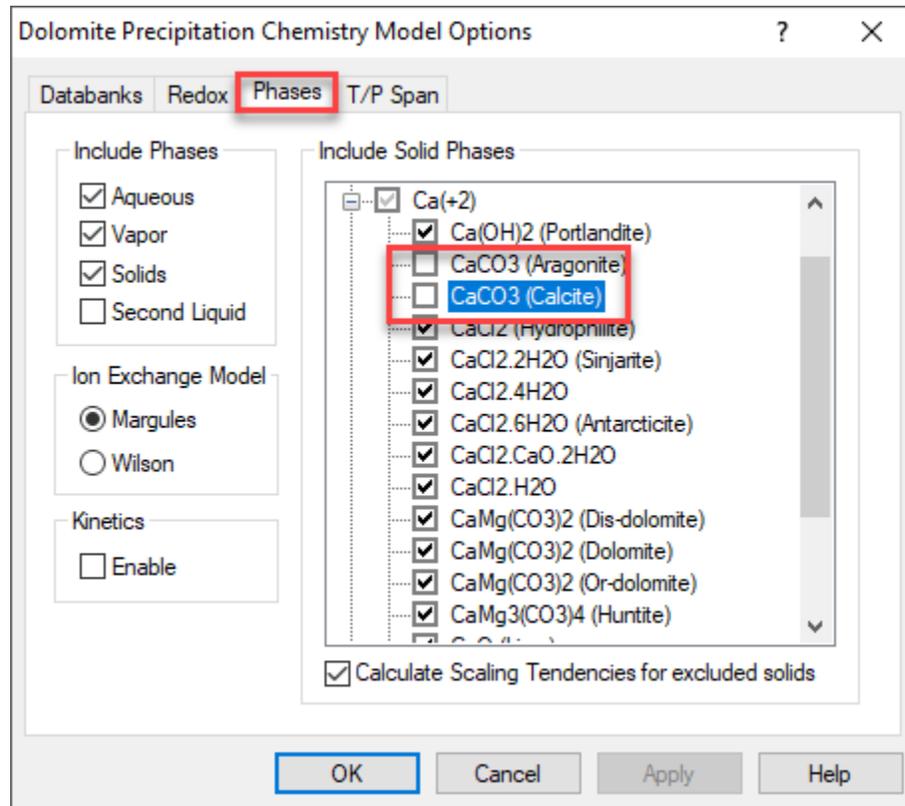


5. In the Databanks Tab, select the **Geochemical (AQ)** Databank. You can double click or use the right arrow to add the databank. Then Click **OK**.

You may have more or less databanks depending on previous installations and imported databanks



6. Select the **Phases** tab
7. **Click** on the “+” next to the Ca(+2) box to display all the calcium containing solids
8. Scroll down to find CaCO₃ (Calcite) and CaCO₃ (Aragonite) and **uncheck** these solids
9. Click **OK** continue.



Note: The **Include Solid Phases** box lists the solids in the chemistry model. Unchecking these solids will mathematically eliminate the solid from consideration. The Scaling Tendency, however, will still be calculated.

10. Select the **CaMg(CO₃)₂ (Dolomite)** as the **Precipitant**
11. Select **CaCO₃** as the **Adjusted Inflow**

Calculation Parameters	
Precipitant:	CaMg(CO ₃) ₂ (Dolomite)
Adjusted Inflow:	CaCO ₃

12. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
13. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the **Summary Box** or Click on the **Output-Minitab** to see the Results.

The software calculated that the solubility of Dolomite in the solution under study is around **~246.84 ppm (mass)**. The pH of this solution is ~5.63.

So far, we know that the solubilities of Calcite, Aragonite, and Dolomite in a $MgCl_2$, $CaCl_2$ and CO_2 containing solution were 413.15, 552.87 and, 246.84 ppm (mass) respectively.

The screenshot displays a software interface with a table of variables and a summary panel. The table is organized into sections: Stream Parameters, Calculation Results (ppm (mass)), Inflows (ppm (mass)), and Solid (ppm (mass)). The 'Calculation Results' section is highlighted with a red box, showing 'Adjusted Inflow: CaCO3' with a value of 246.838. The 'Summary' panel on the right shows the 'Type of calculation' as 'Precipitation Point' and a 'Calculate' button. Below this, the 'Summary' section includes 'Unit Set: <Custom>', 'Automatic Chemistry Model', 'Aqueous (H+ ion) Databanks: Geochemical (AQ) Aqueous (H+ ion)', 'Excluding 2 solid phases', 'Using K-fit Polynomials', 'T-span: 25.0 - 225.0', '*P-span: 1.0 - 201.0', '* = differs from default.', 'Precipitation Point Calculation', '25.0000 °C', '1.00000 atm', 'Precipitate: CaMg(CO3)2 (Dolomite)', 'Adj. Inflow: CaCO3', 'Total 246.838 ppm (mass)', 'Phase Amounts', 'Aqueous 1.00025 kg', 'Vapor 0.0 kg', 'Solid 1.00626e-7 kg', and 'Aqueous Phase Properties', 'pH 5.63236'. The 'Output' button and the 'pH' value are also highlighted with red boxes.

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00025
Mass - Aqueous (kg)	1.00025
Mass - Solid (kg)	1.00626e-7
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Results (ppm (mass))	
Adjusted Inflow: CaCO3	246.838
Inflows (ppm (mass))	
H2O	9.79133e5
CaCl2	10867.3
MgCl2	9322.70
CO2	430.894
CaCO3	246.838
Solid (ppm (mass))	
CaMg(CO3)2 (Dolomite)	1.00000e6

Input **Output**

Advanced Search Add as Stream Export

Type of calculation: Precipitation Point Specs... Calculate

Summary

Unit Set: <Custom>

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Geochemical (AQ)
Aqueous (H+ ion)
Excluding 2 solid phases
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

Precipitation Point Calculation
25.0000 °C
1.00000 atm
Precipitate: CaMg(CO3)2 (Dolomite)
Adj. Inflow: CaCO3
Total 246.838 ppm (mass)

Phase Amounts
Aqueous 1.00025 kg
Vapor 0.0 kg
Solid 1.00626e-7 kg

Aqueous Phase Properties
pH 5.63236

1.8. Composition Point

The **composition point** calculation is used to fix a species value. This calculation is useful when for example you want a target amount of a desired component or to fix an impurity or undesired component below a certain value.

Example 11: Targeting dissolved H₂S in water below 0.001 m

In this example, you will use the composition point calculation to target the amount of molecular H₂S dissolved in water below 0.001 m.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Composition Point Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default – 55.5082
Calculation Sub-type	Composition Point	Temperature	25 °C
Stream Name	Composition Point	Pressure	1 atm
Name Style	Display Formula	H ₂ O	Calculated
Unit Set	Metric, Moles	H ₂ S	0 moles
Framework	AQ	Target H ₂ S-Aq value	0.001 moles

Calculating the Vapor Fraction Temperature (Isobaric)

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Composition Point*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition of the gas given in the table above
7. Go to the **Add Calculation** button and select **Single Point** calculation
8. Select **Composition Point** as Type of Calculation
9. Change the **SinglePoint** name to **H₂S dissolved in water** using the **<F2>** key
10. Set the **Target Species** to **H₂S-Aq** (i.e. the molecular H₂S dissolved in the Aqueous phase)
11. Set the **Target H₂S value** to **0.001** moles
12. Set the **Adjusted Inflow** to **H₂S**

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Target Species:	H2S - Aq
Target H2S Value: (mol)	1.00000e-3
Adjusted Inflow:	H2S
Inflows (mol)	
H2O	55.5082
H2S	0.0

- We are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

The screenshot displays the software interface with the following components:

- Navigation Bar:** Description, Definition, Report, File Viewer.
- Table:**

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5093
Moles (True) - Aqueous (mol)	55.5093
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Results (mol)	
Adjusted Inflow: H2S	1.01019e-3
Inflows (mol)	
H2O	55.5082
H2S	1.01019e-3
- Summary Box:**
 - Type of calculation: Composition Point
 - Calculate button (green checkmark)
 - Unit Set: Metric (moles)
 - Automatic Chemistry Model: Aqueous (H+ ion) Databanks: Aqueous (H+ ion)
 - Using K-fit Polynomials
 - T-span: 25.0 - 225.0
 - *P-span: 1.0 - 201.0
 - * = differs from default.
 - Composition Point Calculation: 25.0000 °C, 1.00000 atm, Target: H2S
 - Fixed at 1.00000e-3 mol
 - Adj. Inflow: H2S
 - Total: 1.01019e-3 mol
 - Phase Amounts: Aqueous 55.5093 mol, Vapor 0.0 mol, Solid 0.0 mol
 - Aqueous Phase Properties: pH 4.99328, Ionic Strength 1.83642e-7 mol/mol
- Buttons:** Input, Output, Advanced, Search, Add as Stream, Export.

According to the calculation, ~0.00101 moles of H₂S were required to create a solution with 0.001 moles of H₂S-aq. The pH of this solution is ~5.0.

You can also go to the **Report** to see the distribution of species under the **Species Output (True Species)** table.

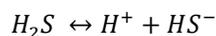
Species Output (True Species)

Row Filter Applied: Only Non Zero Values

column Filter Applied: Only Non Zero Values

	Total	Aqueous
	mol	mol
H ₂ O	55.5082	55.5082
H ₂ S	1.0e-3	1.0e-3
H ⁺	1.01938e-5	1.01938e-5
HS ⁻	1.01928e-5	1.01928e-5
OH ⁻	1.00348e-9	1.00348e-9
S ²⁻	1.391e-13	1.391e-13
Total (by phase)	55.5093	55.5093

You can see that the molecular H₂S is the value that was specified as a target. Notice that the concentration of H⁺ and HS⁻ are nearly identical. This is because the following reactions:



H⁺ is slightly higher because a second reaction, the dissociation of water also contributes to the H⁺ formation.



1.9. Autoclave

An **autoclave** is a high pressure, high temperature hydrometallurgy unit with carefully controlled conditions. From an OLI Software perspective, it is an **isochoric (constant volume) calculation** in which mass, pressure and temperature are allowed to vary.

Autoclave calculations are widely used in the upstream oil and gas applications. When performing corrosion testing, autoclave experiments are essential for simulating downstream conditions, i.e. conditions at high temperatures and pressures. Additionally, it is important to evaluate the corrosivity of production fluids by measuring solution properties, such as pH, and the concentration of aggressive species such as CO₂, H₂S, and chlorides. An autoclave, however, has a constant volume, so it is imperative to know how much material (NaCl solution, CO₂ and H₂S gases) is necessary to add at charging conditions (e.g. at room temperature) in order to reach the desired final specifications, such as partial pressure of CO₂ and H₂S gases.

We will use the Autoclave calculation to calculate partial pressures, fugacities and the final composition of key gases in the aqueous and vapor phases.

For the autoclave calculation 2 examples will be shown:

[Using an Inert Gas](#)

1. [Calculating results at ambient conditions](#)
2. [Increasing the volume of the vessel and its implications](#)
3. [Increasing the final temperature and its implications](#)
4. [Increasing the final pressure and its implications](#)

[Using a Reactive Gas](#)

1. [Calculating results at final conditions](#)
2. [Using a Reactive Gas and a NaOH solution](#)

Example 12: Using an Inert Gas

1. Calculating Results at Ambient Conditions

In this example, you will add 1 kg water to a 2 L autoclave and then fill the void (head space) with N₂. The ambient temperature is 25 °C. The N₂ is presumed to be the gas that remains in the autoclave headspace after sparging (O₂ removal) is completed.

The amount of N₂ added is the combination of N₂ vapor filling the headspace, and N₂ that dissolves in the water (N₂ aqueous). Since N₂ has a low water solubility, this second amount is negligible. H₂O also evaporates, so the headspace will be a mixed gas, N₂ and H₂O.

We can use the **Ideal Gas Law** to estimate the amount of N₂ needed to fill the headspace:

$$PV = nRT$$
$$1 \text{ atm} \times 1 \text{ L} = n \times 0.082057 \frac{\text{L} \cdot \text{atm}}{\text{K} \cdot \text{mol}} \times 298.15 \text{ K}$$
$$n = 0.040874 \text{ moles}$$

Although this estimate does not consider the H₂O that is in the 1 L headspace or the amount of N₂ dissolved in water, it is still an easy approach to get a reasonable estimate.

You will review the results in greater detail here, because part of the goal of this first example it to show where the important variables and properties are.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Autoclave Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default – 55.5082
Calculation Sub-type	Autoclave	Ambient Temperature	25 °C
Stream Name	Autoclave	Final Temperature	25 °C
Name Style	Display Formula	Final Pressure	1 atm
Unit Set	Metric, Moles	Vessel Volume	2 L
Framework	MSE-SRK	H2O	Calculated
Results for	Ambient conditions	N2	0 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Autoclave*
3. Select the **MSE-SRK** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the **N2** as an **inflow**
7. Go to the **Add Calculation** button and select **Single Point** calculation

8. Select **Autoclave** as Type of Calculation
9. Change the **SinglePoint** name to **Autoclave – Inert Gas** using the <F2> key

Note: At this point you may have noticed that the Calculate button is red, and that there is a **red** text in the Summary Box with instruction that additional specs are needed. The specifications need to be defined in the **Calculation Parameters** grid section.

10. Click on the **Specs** button.

The screenshot shows a software interface with a table of variables and a summary box. The table is divided into sections: Stream Parameters, Calculation Parameters, and Inflows (mol). The Calculation Parameters section is highlighted with a red box. The summary box on the right contains a red error message: "Volume of vessel is invalid. Use the specs button to select up to 5 gases to consider." The "Specs..." button in the "Type of calculation" dropdown is also highlighted with a red box.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Ambient: Temperature (°C)	25.0000
Ambient: Pressure (atm)	
Calculation Parameters	
Final Temperature (°C)	0.0
Final Pressure (atm)	
Vessel Volume (L)	0.0
Compute results at which condition	Ambient
Inflows (mol)	
H2O	55.5082
N2	0.0

Summary

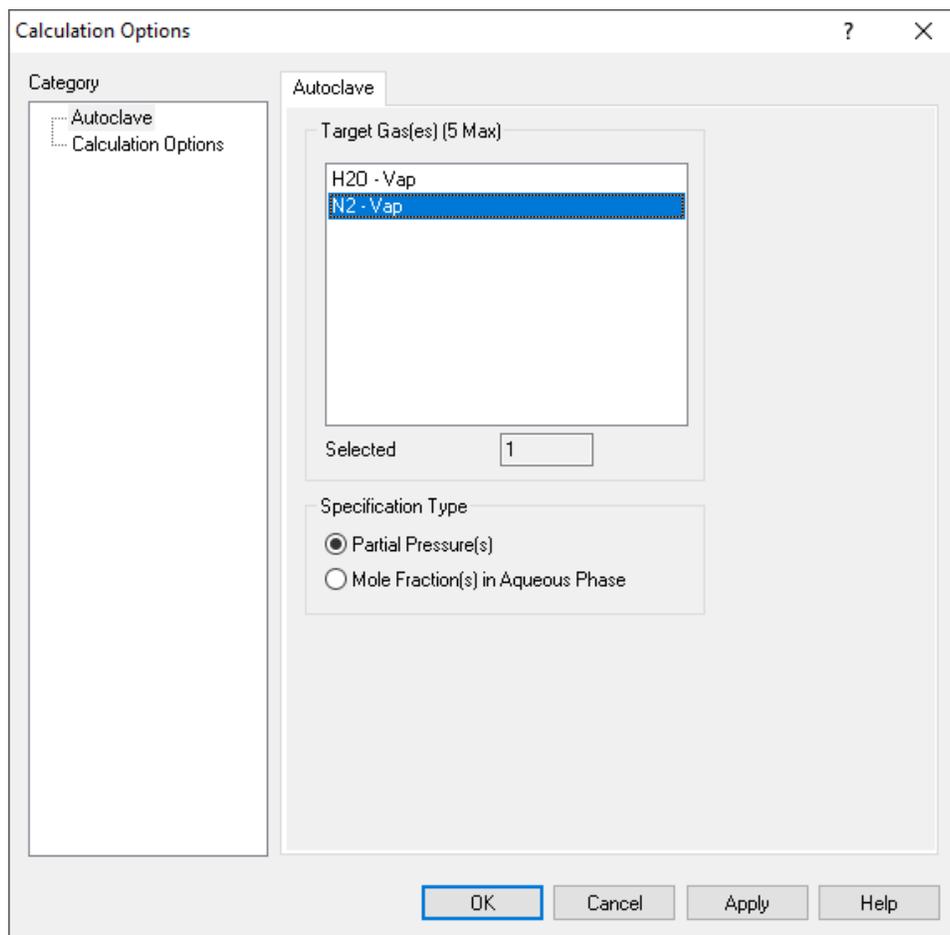
Unit Set: Metric (moles)

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 Using K-fit Polynomials
 T-span: 25.0 - 225.0
 *P-span: 1.0 - 201.0
 * = differs from default.

Autoclave Calculation
 Specifications:
 Ambient Temperature 25.0000 °C
 Final Temperature 0.0 °C
 Final Pressure
 Vessel Volume 0.0 L

Calculation not done
 Volume of vessel is invalid.
 Use the specs button to select up to 5 gases to consider.

11. This will open the **Calculation Options** window to set up the target gas. Select **N2-Vap** and make sure to select the specification type **Partial Pressure** (default). Click **OK**.



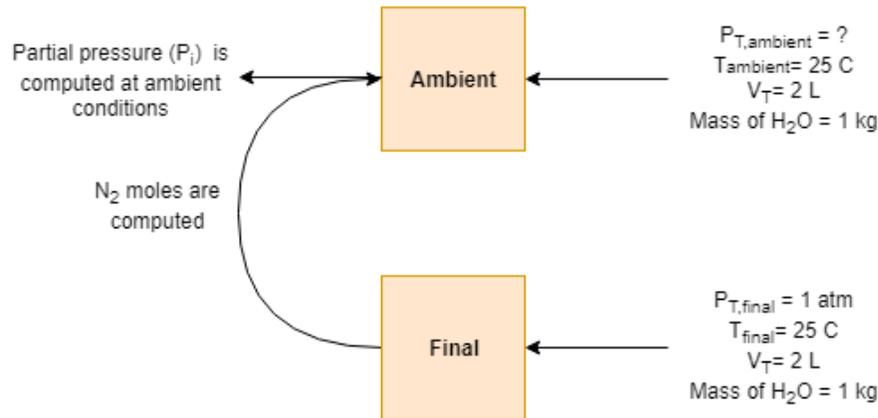
12. Set the **Final Temperature** to **25°C**, the **Final Pressure** to **1 atm** and the **Vessel Volume** to **2 L**
 13. Set the **compute results** at **Ambient** Conditions

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Ambient: Temperature (°C)	25.0000
Ambient: Pressure (atm)	
Calculation Parameters	
Final Temperature (°C)	25.0000
Final Pressure (atm)	1.00000
Vessel Volume (L)	2.00000
Partial Pressure: N2 (atm)	
Compute results at which condition	Ambient

At this point the system is defined as 1 kg H₂O (55.5082 moles) at an ambient temperature of 25 °C. The partial pressure of N₂ will be calculated at a final temperature, 25 °C and pressure, 1 atm in a 2 L vessel.

Note: The Autoclave calculation pathway

When performing an **autoclave calculation**, the software will perform two computations: First, at the final conditions, and the second one at ambient (initial) conditions. It will compute the amount (in moles) of N₂ needed to create a 1 atm pressure at final conditions. It will then use this N₂ to compute the pressure at ambient conditions. The calculation pathway is showed in the image below.



14. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

15. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

The screenshot shows the software interface with a table of results and a summary panel. The table has two columns: 'Variable' and 'Value'. The 'Output' button is highlighted with a red box.

Variable	Value
Stream Parameters (mol)	
Stream Amount	55.5483
Moles (True) - Liquid-1 (mol)	55.5076
Moles (True) - Vapor (mol)	0.0407594
Calculation Results	
Ambient Temperature (°C)	25.0000
Ambient Pressure (atm)	1.00000
Final Temperature (°C)	25.0000
Final Pressure (atm)	1.00000
Vessel Volume (L)	2.00001
Partial Pressure: N2 (atm)	0.968642
Condition that results were computed f	Ambient
Inflows (mol)	
H2O	55.5082
N2	0.0400796

Summary Panel:

- Type of calculation: Autoclave
- Unit Set: Metric (moles)
- Automatic Chemistry Model: MSE-SRK (H3O+ ion) Databanks
- Second Liquid phase: Using Helgeson Direct
- Autoclave Calculation Results for ambient conditions:
 - Ambient Temperature: 25.0000 °C
 - Ambient Pressure: 1.00000 atm
 - Final Temperature: 25.0000 °C
 - Final Pressure: 1.00000 atm
 - Vessel Volume: 2.00000 L
 - N2: 0.968642 atm
- Phase Amounts:
 - Aqueous: 55.5076 mol
 - Vapor: 0.0407594 mol
 - Solid: 0.0 mol
 - 2nd Liquid: 0.0 mol
- Aqueous Phase Properties:
 - pH: 6.99756

The calculated ambient pressure is 1 atm. It is identical to the final pressure, which is not surprising, since the ambient and final temperatures were defined at the same value, and by design, the autoclave calculation uses the identical inflows for ambient and final conditions.

The amount of N₂ added is 0.0400796 moles, which produces a ~0.9686 atm partial pressure. The computed N₂ inflow compares to the Ideal Gas value of 0.040874 moles, a ~2% deviation.

Let's review the distribution of N₂ in the liquid and vapor phase in the **Report** tab. Scroll down to the last table named **Element Distribution**.

The last row is N (which is representing the molecular nitrogen). The distribution is 98.5% in the vapor phase and 1.5% in the liquid phase. Also notice that around 0.0023% of the water has evaporated (see the H(+1) and O(-2) rows).

Element Distribution

	Total	Total	Liquid-1	Vapor
	mol	mole %	% of Total	% of Total
H(+1)	111.016	66.6346	99.9977	2.30264e-3
O(-2)	55.5082	33.3173	99.9977	2.30264e-3
N	0.0801591	0.0481133	1.49278	98.5072

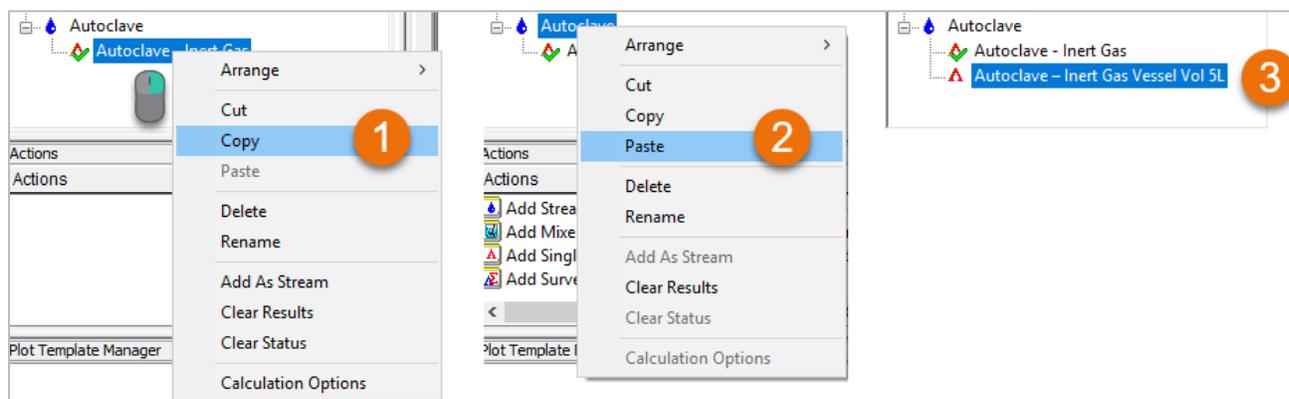
These results infer two effects:

1. As the final pressure (P_T) increases, additional N₂ will dissolve in the water, shifting the fraction of nitrogen to the liquid.
2. As the total autoclave volume (V_T) increases relative to the input liquid (which stays constant), additional water will evaporate, shifting the water to the vapor. This case will be shown next.

2. Increasing the Vessel Volume to 5 L

You are going to use the same case that you built up in the example above, with the only difference that you will change the **Vessel Volume**.

1. **Right click** on the *Autoclave – Inert Gas* single point calculation and select **copy**
2. Selecting the stream named **Autoclave**, right click on it and select **paste**
3. Select the copied stream and name it *Autoclave – Inert Gas Vessel Vol 5L*



Change the **Vessel Volume** to **5 L** and **Calculate** <F9>

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Ambient: Temperature (°C)	25.0000
Ambient: Pressure (atm)	
Calculation Parameters	
Final Temperature (°C)	25.0000
Final Pressure (atm)	1.00000
Vessel Volume (L)	5.00000
Partial Pressure: N2 (atm)	
Compute results at which condition	Ambient
Inflows (mol)	
H2O	55.5082
N2	0.0

Type of calculation
Autoclave Specs...
Calculate

Summary
Unit Set: Metric (moles)
Automatic Chemistry Model
MSE-SRK (H3O+ ion) Databanks:
MSE-SRK (H3O+ ion)
MSE (H3O+ ion)
Second Liquid phase
Using Helgeson Direct
Autoclave Calculation
Specifications:
Ambient Temperature 25.0000 °C
Final Temperature 25.0000 °C
Final Pressure 1.00000 atm
Vessel Volume 5.00000 L
N2
Calculation not done

At this point the system is defined as 1 kg H₂O (55.5082 moles) at an ambient temperature of 25 °C. The partial pressure of N₂ will be calculated at a final temperature, 25 °C and pressure, 1 atm in a 5 L vessel.

It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

The screenshot displays a software interface with a table of variables and values, a summary box, and navigation buttons.

Variable	Value
Stream Parameters (mol)	
Stream Amount	55.6671
Moles (True) - Liquid-1 (mol)	55.5037
Moles (True) - Vapor (mol)	0.163399
Calculation Results	
Ambient Temperature (°C)	25.0000
Ambient Pressure (atm)	1.00000
Final Temperature (°C)	25.0000
Final Pressure (atm)	1.00000
Vessel Volume (L)	4.99998
Partial Pressure: N2 (atm)	0.968642
Condition that results were computed f	Ambient
Inflows (mol)	
H2O	55.5082
N2	0.158874

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model
MSE-SRK (H3O+ ion) Databanks:
MSE-SRK (H3O+ ion)
MSE (H3O+ ion)
Second Liquid phase
Using Helgeson Direct

Autoclave Calculation
Results for ambient conditions:
Ambient Temperature 25.0000 °C
Ambient Pressure 1.00000 atm
Final Temperature 25.0000 °C
Final Pressure 1.00000 atm
Vessel Volume 5.00000 L
N2 0.968642 atm

Phase Amounts
Aqueous 55.5037 mol
Vapor 0.163399 mol
Solid 0.0 mol
2nd Liquid 0.0 mol

Aqueous Phase Properties
pH 6.99756

The moles of liquid are now 55.5037. The reduction of 0.0039 moles (compared to the case of 2 L which was 55.5076 moles) is because this amount of H₂O evaporated into the larger headspace. This phase distribution is important to modeling the autoclave system properly, especially at elevated conditions as will be seen in the next example.

The amount of N₂ required to fill the 4-L headspace is 0.1589 moles; this amount is ~4-times greater than the first case, which is expected for gas with a low water solubility.

3. Increasing the Final Temperature

In this example, you will add 1 kg water to a 5 L autoclave and then fill the void (head space) with N₂. The ambient temperature is 25 °C, and the final conditions will be 1 atm and 100 °C.

The purpose of this example is to raise the H₂O partial pressure relative to N₂. In the 5 L case above, the N₂ inflow is 0.1634 moles. As temperature increases, the H₂O vapor pressure increases, and the amount of N₂ required to fill the vapor void will decrease.

You are going to use the same case that you built up in the example above, with the only difference that you will change the **Final Temperature** to **25 °C**.

1. **Copy** the *Autoclave – Inert Gas Vessel Vol 5L* single point calculation and **paste** under the **Autoclave** Stream.
2. **Name it** *Autoclave – Inert Gas Tf=100C*
3. Change the **Final Temperature** to **100°C** and **Calculate** <F9>

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Ambient: Temperature (°C)	25.0000
Ambient: Pressure (atm)	
Calculation Parameters	
Final Temperature (°C)	100.000
Final Pressure (atm)	50.0000
Vessel Volume (L)	5.00000
Partial Pressure: N2 (atm)	
Compute results at which condition	Ambient
Inflows (mol)	
H2O	55.5082
N2	0.0

At this point the system is defined as 1 kg H₂O (55.5082 moles) at an ambient temperature of 25 °C. The partial pressure of N₂ will be calculated at a final temperature, 100 °C and pressure, 50 atm in a 5 L vessel.

It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

The screenshot displays a software interface with a main table and a summary panel on the right. The main table is divided into sections: Stream Parameters (mol), Calculation Results, and Inflows (mol). The Inflows section shows H2O and N2. The N2 row is highlighted with a red border. The summary panel on the right provides a detailed overview of the calculation, including the unit set (Metric (moles)), the automatic chemistry model (MSE-SRK (H3O+ ion) Databanks), and the results for ambient conditions. The summary also lists phase amounts and aqueous phase properties.

Variable	Value
Stream Parameters (mol)	
Stream Amount	55.5087
Moles (True) - Liquid-1 (mol)	55.5031
Moles (True) - Vapor (mol)	5.54762e-3
Calculation Results	
Ambient Temperature (°C)	25.0000
Ambient Pressure (atm)	0.0339414
Final Temperature (°C)	100.000
Final Pressure (atm)	1.00000
Vessel Volume (L)	5.00009
Partial Pressure: N2 (atm)	2.67276e-3
Condition that results were computed f	Ambient
Inflows (mol)	
H2O	55.5082
N2	4.38508e-4

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model
MSE-SRK (H3O+ ion) Databanks:
MSE-SRK (H3O+ ion)
MSE (H3O+ ion)
Second Liquid phase
Using Helgeson Direct

Autoclave Calculation
Results for ambient conditions:
Ambient Temperature 25.0000 °C
Ambient Pressure 0.0339414 atm
Final Temperature 100.000 °C
Final Pressure 1.00000 atm
Vessel Volume 5.00000 L
N2 2.67276e-3 atm

Phase Amounts
Aqueous 55.5031 mol
Vapor 5.54762e-3 mol
Solid 0.0 mol
2nd Liquid 0.0 mol

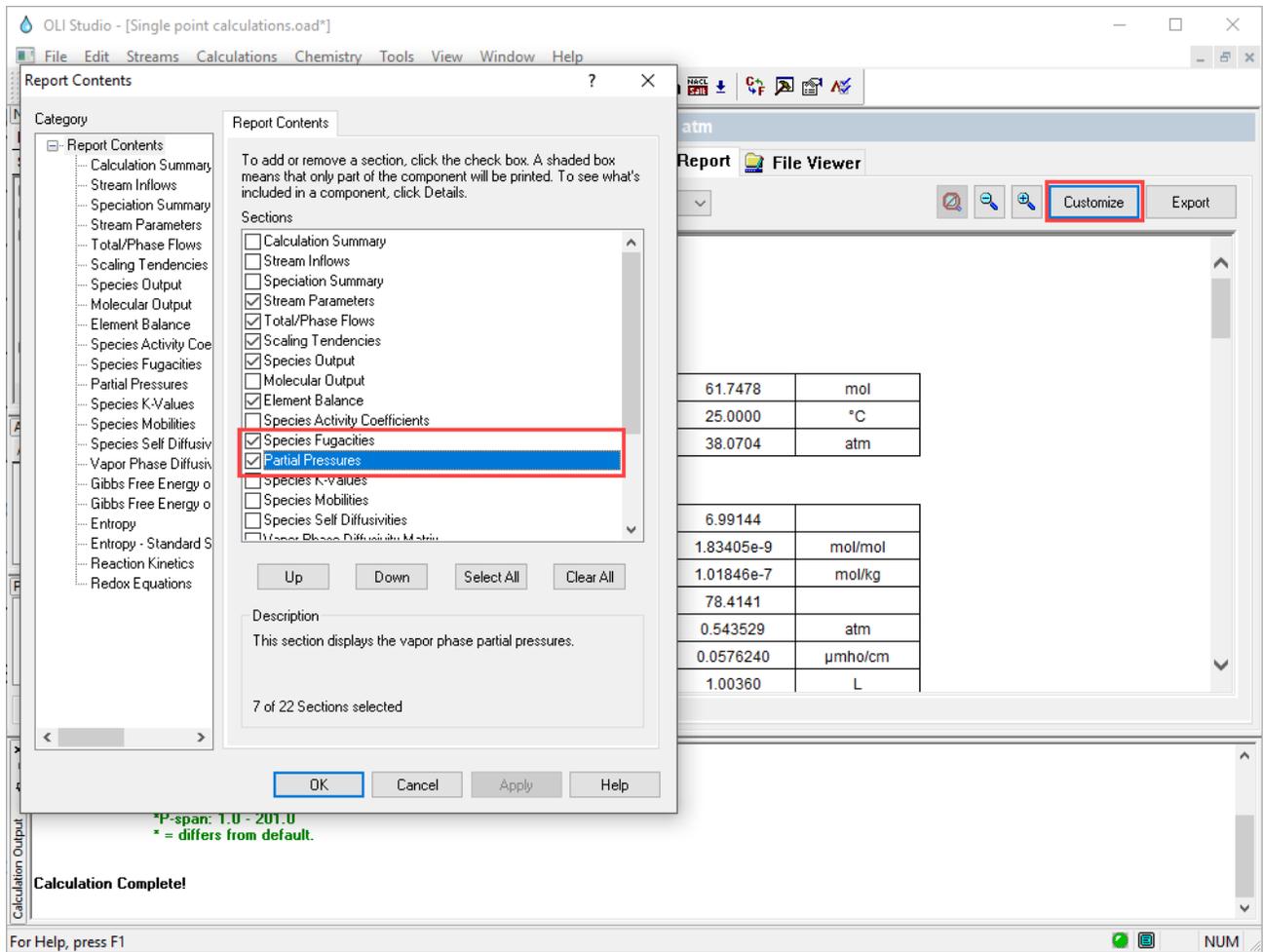
Aqueous Phase Properties
pH 6.99772

The amount of N₂ added is very small (~0.0004 moles). This is to be expected, because the vapor pressure of pure water at 100 °C is 1 atm. Therefore, a negligible amount of N₂ is needed to raise the pressure. Notice also that the calculated ambient pressure is 0.0339 atm. The vapor pressure of pure water at 25° C is 0.0313.

The results above imply that the autoclave will have a vacuum pressure at the ambient temperature, and when heated to 100 °C will reach atmospheric pressure.

In autoclave testing, it is also of utmost importance to study and understand the partial pressures and fugacities of key gases at the final conditions. You need to enable these properties to be shown in the **Report**.

Go to the **Customize** button and enable both the **Species Fugacities** and the **Partial Pressures** options, and then click **OK**.



Notice that the **Fugacity** and **Partial Pressure** of N₂ are nearly identical. This is expected since at low pressure the fugacity approaches its partial pressure.

Species Fugacities

Row Filter Applied: Only Non Zero Values

Species	atm
H2O	0.0312529
N2	2.67376e-3

Partial Pressures

Row Filter Applied: Only Non Zero Values

Species	atm
H2O	0.0312686
N2	2.67276e-3

4. Increasing the Final Pressure

In this example, you will add 1 kg water to a 5 L autoclave and then fill the void (head space) with N₂. The ambient temperature is 25 °C, and the final conditions will be 100 atm and 100 °C.

You are going to use the same case that you built up in the example above, with the only difference that you will change the **Final Pressure** to **100 atm**.

1. **Copy** the *Autoclave – Inert Gas Tf=100C* single point calculation and **paste** under the **Autoclave** Stream.
2. **Name it** *Autoclave – Inert Gas Pf=100 atm*
3. Change the **Final Pressure** to **100 atm** and **Calculate** <F9>

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Ambient: Temperature (°C)	25.0000
Ambient: Pressure (atm)	
Calculation Parameters	
Final Temperature (°C)	100.000
Final Pressure (atm)	100.000
Vessel Volume (L)	5.00000
Partial Pressure: N2 (atm)	
Compute results at which condition	Ambient
Inflows (mol)	
H2O	55.5082
N2	0.0

At this point the system is defined as 1 kg H₂O (55.5082 moles) at an initial temperature of 25 °C. The partial pressure of N₂ will be calculated at a final temperature of 100 °C and a final pressure of 100 atm in a 5 L vessel.

It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

The screenshot displays a software interface with a main table of results and a summary box on the right. The main table is organized into sections: Stream Parameters (mol), Calculation Results, and Inflows (mol). The summary box on the right provides a detailed overview of the calculation, including the unit set, chemistry model, and phase amounts.

Variable	Value
Stream Parameters (mol)	
Stream Amount	67.8251
Moles (True) - Liquid-1 (mol)	55.5441
Moles (True) - Vapor (mol)	12.2810
Calculation Results	
Ambient Temperature (°C)	25.0000
Ambient Pressure (atm)	75.6205
Final Temperature (°C)	100.000
Final Pressure (atm)	100.000
Vessel Volume (L)	5.00000
Partial Pressure: N2 (atm)	75.5829
Condition that results were computed for	Ambient
Inflows (mol)	
H2O	55.5082
N2	12.3169

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model
MSE-SRK (H3O+ ion) Databanks:
MSE-SRK (H3O+ ion)
MSE (H3O+ ion)
Second Liquid phase
Using Helgeson Direct

Autoclave Calculation
Results for ambient conditions:
Ambient Temperature 25.0000 °C
Ambient Pressure 75.6205 atm
Final Temperature 100.000 °C
Final Pressure 100.000 atm
Vessel Volume 5.00000 L
N2 75.5829 atm

Phase Amounts
Aqueous 55.5441 mol
Vapor 12.2810 mol
Solid 0.0 mol
2nd Liquid 0.0 mol

Aqueous Phase Properties
pH 6.98517
Innic. Strength 1.85708e-9 mol/mol

The computed ambient pressure $P_{T,A}$ is 75.6205 atm. Of this total, 75.5829 atm is N_2 ($P_{N_2}=75.5829$ atm) and 0.0376 atm is H_2O ($P_{H_2O}=0.0376$ atm). Thus, to create a 100 atm final pressure, the autoclave would need to be charged with N_2 at a regulator pressure of 75.6205 atm.

According to the calculation, the amount of N_2 in the autoclave is 12.3169 moles. This amount of N_2 plus the 55.5082 moles of H_2O produces a final pressure of 100 atm in a 5 L autoclave at 100 °C.

Let's study the partial pressure and fugacity of N_2 at these final conditions. Remember, you need to enable these properties to be shown in the **Report**.

Go to the **Customize** button and enable both the **Species Fugacities** and the **Partial Pressures** options, and then click **OK**.

For comparison purposes, the **Species Fugacities** and the **Partial Pressures** for 100 °C and 1 atm, and 100 °C and 100 atm are shown.

100 °C and 1 atm

Species Fugacities

Row Filter Applied: Only Non Zero Values

Species	atm
H2O	0.0312529
N2	2.67376e-3

100 °C and 100 atm

Species Fugacities

Row Filter Applied: Only Non Zero Values

Species	atm
H2O	0.033019
N2	75.9152

Partial Pressures

Row Filter Applied: Only Non Zero Values

Species	atm
H2O	0.0312686
N2	2.67276e-3

Partial Pressures

Row Filter Applied: Only Non Zero Values

Species	atm
H2O	0.0376507
N2	75.5829

Notice that at low pressures, the partial pressures and fugacities values of both H₂O and N₂ are nearly identical. At the higher pressure, i.e. 100 atm, the partial pressures and fugacities of H₂O and N₂ start to differ.

The cause of this deviation is the *non-ideal effects of high pressures on gas molecules as they are forced closer together*. At low pressures, gas molecules are too far apart to interact. As pressure increases, the average distance between two molecules decrease, until at short range, intermolecular attractive forces begin to impact the molecular properties. The impact of this effect is quantified in the fugacity term. Notice that fugacity and partial pressure have the same units, atm.

Thus, when reviewing these two tables, the partial pressure can be seen as the idealized gas property at high pressures (which does not take into account intermolecular forces). The fugacity is the real gas property at this pressure. The non-ideal effect of pressure is therefore encapsulated in the following relationship:

$$\varphi = \frac{\text{Fugacity}}{\text{Partial Pressure}} = \frac{f}{p_i}$$

Where,

φ is the fugacity coefficient

At low pressures, a gas molecule fugacity (f) approaches its partial pressure (p_i), i.e. $f \rightarrow p_i$ or $\varphi = 1$.

Example 13: Using and Reactive Gas

1. Calculating Results at Final Conditions

In this example, you will add 1 kg water to a 2 L autoclave and then fill the void (head space) with CO₂. The ambient temperature is 25 °C.

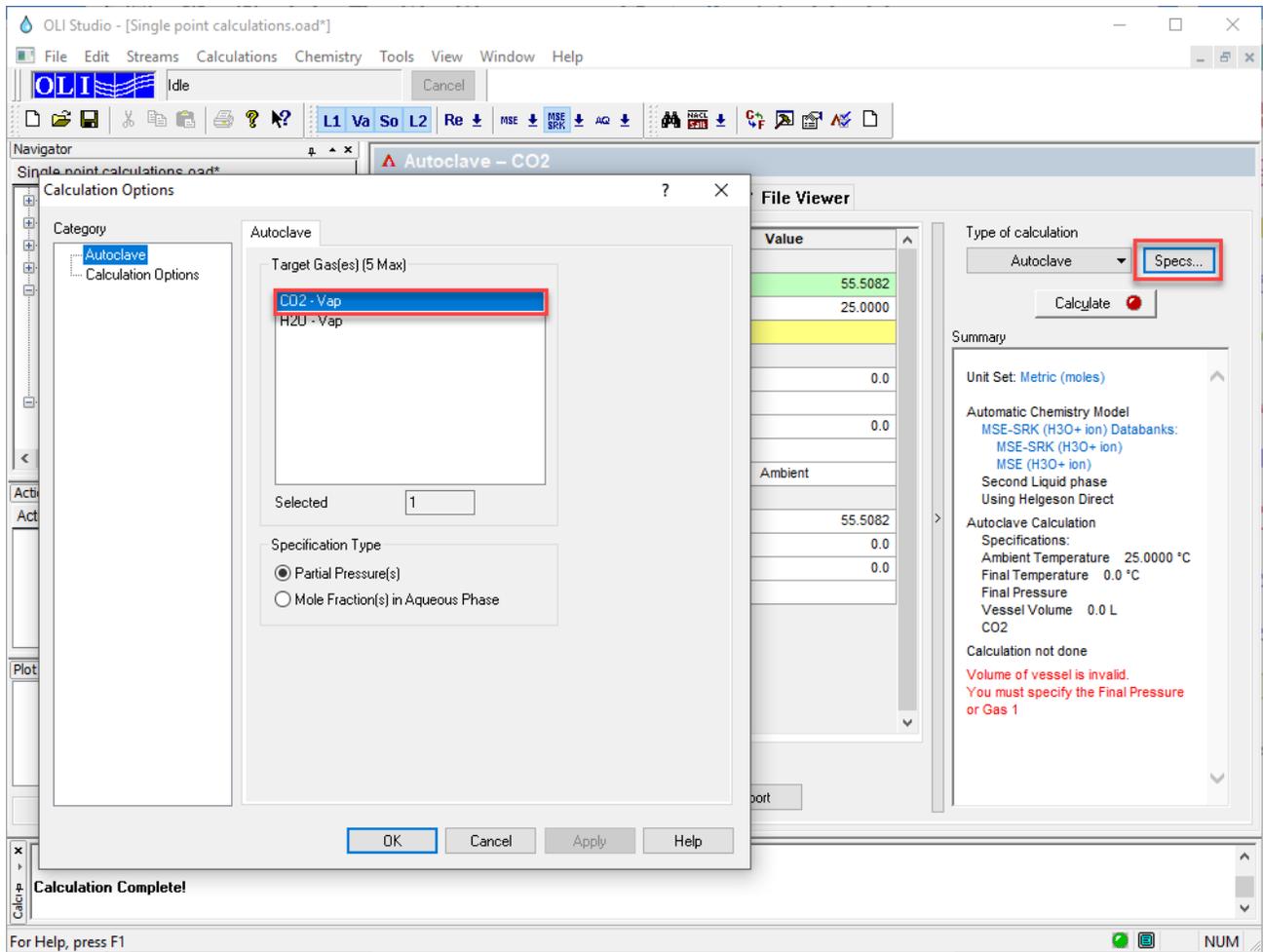
You will then modify the case further by adding NaOH so that additional CO₂ dissolves in water to form bicarbonate.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Autoclave Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default – 55.5082
Calculation Sub-type	Autoclave	Ambient Temperature	25 °C
Stream Name	Autoclave	Final Temperature	25 °C
Name Style	Display Formula	Final Pressure	1 atm
Unit Set	Metric, Moles	Vessel Volume	2 L
Framework	MSE-SRK	H2O	Calculated
Results for	Final Conditions	CO2	0 moles
		NaOH	0 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Autoclave Reactive Gas*
3. Select the **MSE-SRK** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the **CO2 and NaOH** as **inflows**
7. Go to the **Add Calculation** button and select **Single Point** calculation
8. Select **Autoclave** as Type of Calculation
9. Change the **SinglePoint** name to **Autoclave – CO2** using the **<F2>** key
10. Click on the **Specs** button. This will open the **Calculation Options** window to set up the target gas.
11. Select **CO2** and make sure to select the specification type **Partial Pressure** (default). Click **OK**.



- Set the **Final Temperature** to **25°C**, the **Final Pressure** to **1 atm** and the **Vessel Volume** to **2 L**
- Set the **compute results** at **Final** Conditions. Click on the cell to enable the drop-down arrow.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Ambient: Temperature (°C)	25.0000
Ambient: Pressure (atm)	
Calculation Parameters	
Final Temperature (°C)	25.0000
Final Pressure (atm)	1.00000
Vessel Volume (L)	2.00000
Partial Pressure: CO2 (atm)	
Compute results at which condition	Ambient
Inflows	
H2O	Final
CO2	Ambient
NaOH	0.0

At this point the system is defined as 1 kg H₂O (55.508 moles) at an ambient temperature of 25 °C. The partial pressure of CO₂ will be calculated at a final temperature, 25 °C and pressure, 1 atm in a 2 L vessel.

14. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

15. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

The screenshot displays a software interface with a table of variables and values on the left, and a summary panel on the right.

Variable	Value
Stream Parameters (mol)	
Stream Amount	55.5808
Moles (True) - Liquid-1 (mol)	55.5397
Moles (True) - Vapor (mol)	0.0409453
Calculation Results	
Final Temperature (°C)	25.0000
Final Pressure (atm)	1.00000
Vessel Volume (L)	2.00003
Partial Pressure: CO ₂ (atm)	0.968445
Condition that results were computed for	Final
Inflows (mol)	
H ₂ O	55.5082
CO ₂	0.0725216

Summary Panel:

- Type of calculation: Autoclave
- Unit Set: Metric (moles)
- Automatic Chemistry Model: MSE-SRK (H₃O+ ion) Databanks: MSE-SRK (H₃O+ ion), MSE (H₃O+ ion)
- Second Liquid phase: Using Helgeson Direct
- Autoclave Calculation Results for final conditions:
 - Ambient Temperature 25.0000 °C
 - Final Temperature 25.0000 °C
 - Final Pressure 1.00000 atm
 - Vessel Volume 2.00000 L
 - CO₂ 0.968445 atm

A total amount of 0.0725 moles of CO₂ added was computed by the software to set the autoclave total pressure to 1 atm. For comparison, the same scenario in Example 12-1 [Analyzing the Results](#) required 0.04 moles of N₂. The difference is the amount of CO₂ that dissolved in the water. CO₂ is more soluble than N₂ in water.

To analyze the CO₂ distribution in more detail, go to the **Report** Tab, and Scroll down until you find the **Element Distribution** table.

Element Distribution

	Total	Total	Liquid-1	Vapor
	mol	mole %	% of Total	% of Total
H(+1)	111.016	66.5797	99.9977	2.32766e-3
O(-2)	55.6533	33.3768	99.8552	0.144823
C(+4)	0.0725216	0.0434932	45.3222	54.6778

The **Element Distribution** table contains three rows, H(+), O(-2), and C(+4). These are the elements of H₂O and CO₂. If you compare the C(+4) in the liquid and vapor phases, you will see that about 45.3% of the CO₂ dissolved in the water phase. By comparison, 1.5% of the added N₂ dissolved in water at the same condition (see Example 12-1).

2. Using a Reactive Gas and a NaOH solution

In this example, you will further modify the chemistry by adding NaOH so that additional CO₂ dissolves in water to form bicarbonate. This will increase the gas requirement.

Starting the Simulation

You are going to use the same case that you built up in the example above, with the only difference that you will add the **0.1 moles of NaOH**.

1. **Copy** the *Autoclave – CO₂* single point calculation and **paste** under the **Autoclave Stream**.
2. **Name it** *Autoclave – CO₂ – NaOH*
3. Change the **composition** of **NaOH** to **0.1 moles** and **Calculate** <F9>

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.6082
Ambient: Temperature (°C)	25.0000
Ambient: Pressure (atm)	
Calculation Parameters	
Final Temperature (°C)	25.0000
Final Pressure (atm)	1.00000
Vessel Volume (L)	2.00000
Partial Pressure: CO ₂ (atm)	
Compute results at which condition	Final
Inflows (mol)	
H ₂ O	55.5082
CO ₂	0.0
NaOH	0.100000

At this point the system is defined as 1 kg H₂O (55.508 moles) and 0.1 moles of NaOH at an ambient temperature of 25 °C. The partial pressure of CO₂ will be calculated at a final temperature, 25 °C and final pressure, 1 atm in a 2 L vessel.

4. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

Inflows (mol)	
H ₂ O	55.5082
CO ₂	0.171600
NaOH	0.100000

The CO₂ inflow is calculated to be 0.1716 moles. This is exactly 0.1 moles more than the calculation with only CO₂ (Example 13-1) and results from the acid-base reaction with the 0.1 moles of NaOH.

To see the different species that have formed in solution go to the **Report** tab and select the **Species Output (True Species)**.

Species Output (True Species)

Row Filter Applied: Only Non Zero Values

column Filter Applied: Only Non Zero Values

	Total	Liquid-1	Vapor
	mol	mol	mol
H2O	55.5083	55.507	1.28477e-3
Na+1	0.1	0.1	
HCO3-1	0.0998917	0.0998917	
CO2	0.0716542	0.0320887	0.0395654
CO3-2	5.42505e-5	5.42505e-5	
H3O+1	2.3994e-7	2.3994e-7	
OH-1	6.87229e-8	6.87229e-8	
NaOHCO3-2	2.76574e-14	2.76574e-14	
NaOH	3.90126e-15	3.90126e-15	
Total (by phase)	55.7799	55.7391	0.0408502

You can see that ~0.1 moles of bicarbonate (HCO_3^-) have been formed. This reaction is increasing the CO_2 gas requirement to reach a total final pressure of 1 atm.

1.10. Custom

In the calculations that we have seen so far, variables were predefined. For instance, we selected either temperature or pressure as a fixed value in order to find the dew point pressure or dew point temperature. With the **Custom** calculation, however, you have the option to choose which parameters to set at fixed values and which parameters to keep as variables, to calculate the desired information, such as, for example, to investigate the solubility of gases in solution.

Example 14: Solubility of Oxygen in Water

With a custom calculation, we are going to calculate the solubility of O₂ in water at 25°C and 1 atm.

Starting the Simulation

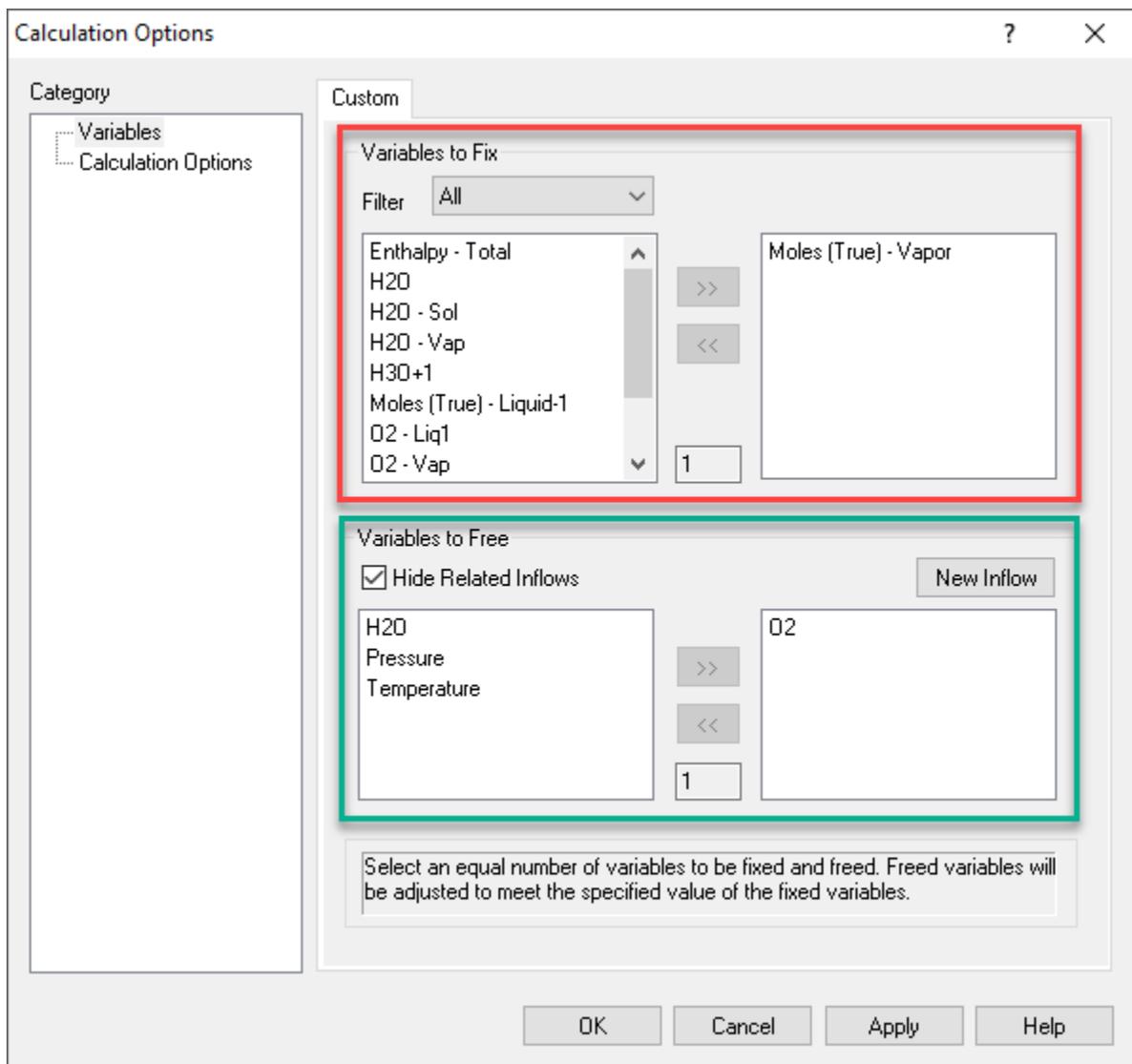
Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Custom Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Default – 1kg
Calculation Sub-type	Custom	Temperature	30 °C
Stream Name	Custom Calculation	Pressure	4 atm
Name Style	Display Formula	H ₂ O	Calculated
Unit Set	Metric, Mass fraction – ppm (mass)	O ₂	0 mol
Framework	MSE		

Setting the pH

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Custom Calculation*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Mass Frac. This will change all inflows to mass %.
6. **Click** on the **Customize** button. This opens the Edit Units window.
7. Under **Basis Options** change mass fraction from **mass %** to **ppm (mass)**
8. Enter **O₂** as an inflow and **0** moles
9. Change the **T** to **30 °C** and **P** to **4 atm**
10. Go to the **Add Calculation** button and select **Single Point** calculation
11. Select **Custom** as Type of Calculation
12. Change the **SinglePoint** name to **Oxygen Solubility** using the **<F2>** key
13. Select the **Specs** button. This will open the **Calculation Options window**

Note: In the Calculation Options window, you have the option to select the **Variables to Fix** and the **Variables to Free**. In this example, the Variable to Fix is the number of Moles (True) of Vapor which will be given a small value of 1×10^{-7} moles. You can interpret this as the first bubble of vapor formed, indicating that the aqueous phase is saturated. The Variable to Free is the inflow of oxygen, in order to achieve saturation.



14. In the **Variables to Fix** section, select **Moles (True) Vapor**, by double clicking or using the >> button.
15. In the **Variables to Free** section, select **O2** as the inflow. Then click OK.

This will add a **Calculation Parameters** sections, where the Target (Variable to Fix) and the Adjusted Inflow (Variable to Free) are shown. The Target has a brown dot in front of it indicating that is fix value, and the Adjusted Inflow is in green indicating that the software will adjust this value.

The screenshot displays a software interface with a main table and a summary panel on the right.

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00000
Temperature (°C)	30.0000
Pressure (atm)	4.00000
Calculation Parameters	
● Target: Moles (True) - Vapor (mol)	0.0
Adjusted: O2 (ppm (mass))	0.0
Inflows (ppm (mass))	
H2O	1.00000e6
Adjusted: O2	

Summary Panel:

- Type of calculation: Custom
- Calculate button (with a red error icon)
- Unit Set: <Custom>
- Automatic Chemistry Model
- MSE (H3O+ ion) Databanks: MSE (H3O+ ion)
- Using Helgeson Direct
- Custom Calculation
- Fixed variable: Moles (True) - Vapor, target: 0.0 mol
- Free variable: O2
- Calculation not done
- Moles (True) - Vapor must be greater than 0.0.**

Input section at the bottom contains buttons: Advanced, Search, Add as Stream, Export.

- Fix the Moles (True) Vapor to $1e^{-7}$
- We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
- It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

Review the Summary Box or Click on the Output-Minitab to see the results.

The screenshot displays a software window with a main table and a summary panel on the right. The main table has columns for 'Variable' and 'Value'. It is organized into sections: 'Stream Parameters', 'Calculation Results', and 'Inflows (ppm (mass))'. The 'Adjusted: O2' row in the 'Inflows' section is highlighted with a red box. The summary panel on the right contains various calculation details, including 'Unit Set: <Custom>', 'Automatic Chemistry Model', 'MSE (H3O+ ion) Databanks', 'Using Helgeson Direct', 'Custom Calculation', 'Fixed variable: Moles (True) - Vapor, target: 1.00000e-7 mol', 'Free variable: O2, total: 146.938 ppm (mass)', 'Phase Amounts', 'Aqueous Phase Properties', and 'Calc. elapsed time: 1.053 sec'. A red box highlights the 'Custom Calculation' section in the summary panel. At the bottom of the main window, there are buttons for 'Input', 'Output', 'Advanced', 'Search', 'Add as Stream', and 'Export'. The 'Output' button is also highlighted with a red box.

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00015
Mass - Liquid-1 (kg)	1.00015
Mass - Vapor (kg)	3.18493e-9
Temperature (°C)	30.0000
Pressure (atm)	4.00000
Calculation Results	
Target: Moles (True) - Vapor (mol)	1.00000e-7
Inflows (ppm (mass))	
H2O	9.99854e5
Adjusted: O2	146.938

Summary

Unit Set: <Custom>

Automatic Chemistry Model
MSE (H3O+ ion) Databanks:
MSE (H3O+ ion)
Using Helgeson Direct

Custom Calculation
Fixed variable:
Moles (True) - Vapor, target:
1.00000e-7 mol
Free variable:
O2, total:
146.938 ppm (mass)

Phase Amounts
Aqueous 1.00015 kg
Vapor 3.18493e-9 kg
Solid 0.0 kg

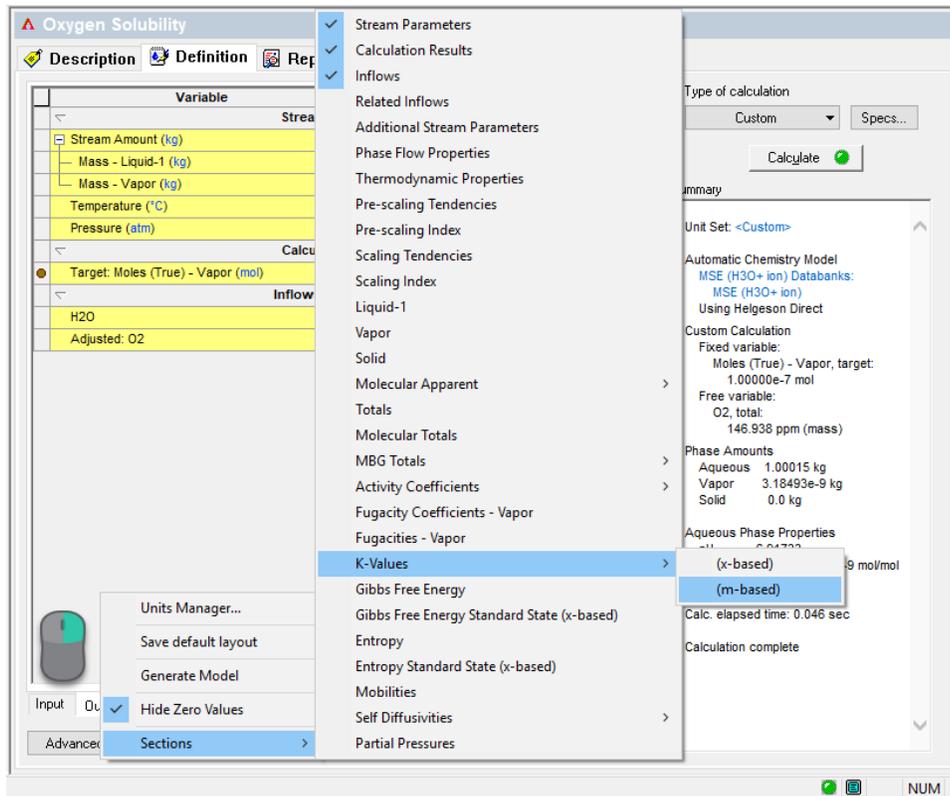
Aqueous Phase Properties
pH 6.91733
Ionic Strength 2.18165e-9 mol/mol
Density 0.995710 g/ml

Calc. elapsed time: 1.053 sec
Calculation complete

At 30°C and 4 atm the solubility of O₂ in water is 146.94 ppm (mass)

To get an estimate of the Henry's constant, you can study the K-values reported by the software.

Right click on the gray area, go to **Sections>K-values>m-based**.



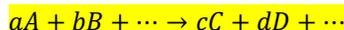
The reciprocal of K_{O2VAP} : $O2VAP=O2AQ$ will give you an estimate of the Henry's constant.

K-Values - (m-based)	
KH2O: 2H2O=H3OION+OHION	1.46564e-14
KH2OPPT: H2OPPT=H2O	1.32964
KH2OVAP: H2OVAP=H2O	23.8182
KO2VAP: O2VAP=O2AQ	1.15985e-3

1.11. Reaction Kinetics

Most of the chemistry and calculations that we have presented so far assumes equilibrium. However, chemical reactions vary in speed as they occur. Some can occur instantaneously, while others can take years to reach equilibrium. The speed of a chemical reaction is given by the **Reaction Rate**, which is a measure of the change in concentration of the reactants or the change in concentration of the products per unit time.

For the stoichiometric reaction below:



The reaction rate is defined as:

$$\text{rate} = -\frac{1}{a} \left(\frac{d[A]}{dt} \right) = -\frac{1}{b} \left(\frac{d[B]}{dt} \right) = \frac{1}{c} \left(\frac{d[C]}{dt} \right) = \frac{1}{d} \left(\frac{d[D]}{dt} \right)$$

We can describe the kinetics of a chemical reaction by using a **Rate Law**, which is an expression that relates the concentration of each reactant raised to an exponent that reflects the reaction order (which is determined experimentally) and the **rate constant, k** , (a proportionality constant between reaction rate and concentration).

The general rate law is generally expressed as:

$$\text{Rate} = k [A]^s [B]^t$$

Where $s + t$ gives us the reaction order of the reaction. s and t are not the same as the stoichiometric coefficients a and b .

The reaction **rate constant** units are specific for the overall reaction order, since we always want the units of the rate to be concentration units per unit of time, e.g., M/s.

Reaction order	Units
0	M/s
1	1/s
2	1/(M•s)

The rate constant, k , is dependent on the temperature at which the reaction takes place. Its dependence with temperature can be studied using the Arrhenius Equation, as shown below.

$$k = A \exp \left(-\frac{E_a}{RT} \right)$$

where: k = Reaction rate constant (*units depend on reaction order*)

A = Arrhenius frequency factor (*has same units as k*)

E_a = Activation energy $\left(\frac{\text{joule}}{\text{gmole}} \right)$

R = Universal gas constant $\left(8.314 \frac{\text{joule}}{\text{gmole K}} \right)$

T = Temperature (K)

There are two different ways to enter rate laws reaction kinetics in OLI Studio: Stream Analyzer

1. **Standard Rate Law** which uses the Arrhenius equation for the reaction rate constant k , referred to as STD type within the software.
2. **Non-Standard Rate Law**, referred to as SPEC type within the software.

In this section, we will show you how to set up both types of reaction kinetics.

The reaction kinetics is enabled Under the Chemistry menu > Model Options > Phases > Kinetics

1.11.1. Standard Rate Law

The Standard Rate Law (STD) considers both the forward and reverse reaction rates, the individual species reaction orders, and the forward and reverse reaction constants (determined using the Arrhenius Equation).

For the reaction below:



where: a, b, \dots, c, d are stoichiometric coefficients

A, B, \dots are reactant species

C, D, \dots are product species

The rate law is of the form:

$$Rate = (k_f a_A^{r_1} a_B^{r_2} \dots - k_r a_C^{p_1} a_D^{p_2})$$

where:

$Rate$ = Reaction rate $\frac{mol}{h}$

k_f = Forward reaction rate constant (units depend on reaction order)

k_r = Reverse reaction rate constant (units depend on reaction order)

a_A, a_B, \dots = Activities of reactant species $\left(\frac{mol}{m^3}\right)$

$r_1, r_2 \dots$ = Reaction order of individual reactant species
(normally from experimental data. Default is stoichiometric coefficients: a, b, \dots)

a_C, a_D, \dots = Activities of product species $\left(\frac{mol}{m^3}\right)$

p_1, p_2, \dots = Reaction order of individual product species
(normally from experimental data. Default is stoichiometric coefficients: c, d, \dots)

Within the software the naming of the constants defined above is the following:

OLI Keyword	Description
KF	Forward reaction rate constant
KR	Reverse reaction rate constant
AF	Forward reaction Arrhenius factor
AR	Reverse reaction Arrhenius factor
BF	Forward reaction activation energy divided by the universal gas constant (K)
BR	Reverse reaction activation energy divided by the universal gas constant (K)
ER_i	Reaction order of reactant species i
EP_i	Reaction order of product species i

Thus, when specifying a standard rate expression, the user must define one of the following: (1) The Arrhenius frequency factors (AF and AR), and reaction activation energies divided by the universal gas constant (BF and BR) or, (2) the reaction rate constants (KF and KR) directly. In addition, the user can specify the individual

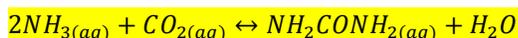
species order coefficients for the forward and reverse reactions if these differ from the stoichiometric coefficients (which are the default).

When defining the reaction order for a species, the order in which the species appears in the reaction equation must be defined (i.e., subscript *i*) with a sequential number, for either the reactant or product species. Hence, the first reactant is identified with the number 1, the second, 2 and so on. Similarly, the product species are identified with the integers 1, 2, 3, etc.

If any of the keywords are not defined, the software assumes a default value for that variable. These default values are assumed to be zero for the reaction rate constants, Arrhenius factors, and activation energies (divided by the universal gas constant). For the species reaction order coefficients, the reaction stoichiometric values are assumed. To complete the standard rate expression definition, the reaction temperature and initial reactant molality are included in the process stream composition definition.

Example 15: Reaction of Ammonia and Carbon Dioxide

In this example, we are going to consider the reaction of ammonia and carbon dioxide to form urea and water, according to the following reaction:



This reaction will take place in a plug flow reactor at 200°C and 100 atm, with a total residence time of 100 hours.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Single Point Calculation with Reaction Kinetics Enabled			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Calculated
Calculation Sub-type	Isothermal	Temperature	200 °C
Stream Name	Standard Rxn Kinetics	Pressure	100 atm
Single Point Name	Rxn Ammonia/CO2	Water	55.5082
Name Style	Display OLI Name (TAG)	CO2	2 moles
Unit Set	Metric, Moles	NH3	2 moles
Framework	AQ	UREA	0 moles
Kinetics	Enabled		
Kinetics Holdup Time	100 hours		
Number of Kinetic Steps	10		

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Standard Rxn Kinetics*
3. Select the **AQ** thermodynamic Framework

4. Click on the **Names Manager** icon, and select the **OLI Name (TAG)** option, and click **OK**.



5. Click on the **Units Manager** icon, and select Metric, Batch, Moles.

6. Enter the stream composition, temperature and pressure given in the table above.

7. Go to the **Add Calculation** button and select **Single Point** calculation

8. Select **Isothermal** (default) as Type of Calculation.

9. Change the **SinglePoint** name to **Rxn Ammonia/CO2** using the <F2> key

So far, we have created an Isothermal calculation. Now, we are going to enable the **Reaction Kinetics** option at the **Single Point Level**.

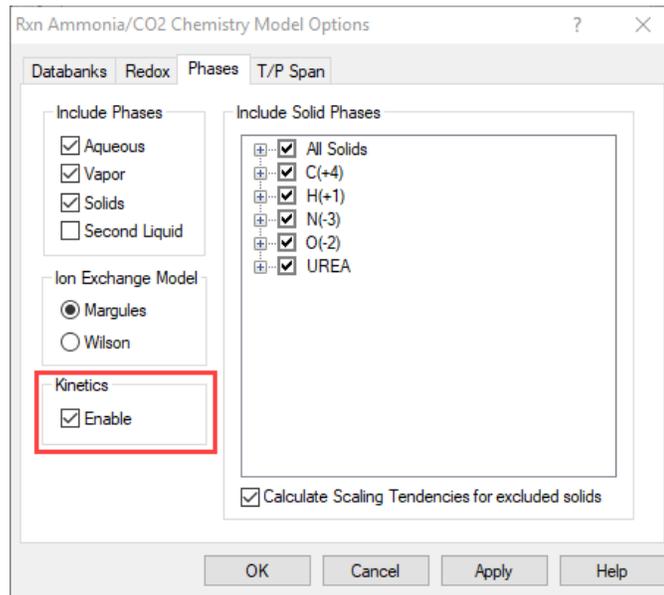
10. To enable reaction kinetics, make sure that you are at the **Single Point Level** by clicking on the Single Point icon, and then go to **Chemistry menu > Model Options**. This will open the **Chemistry Model** window.

The screenshot shows the OLI Studio interface with the following components:

- Navigator:** A list of calculations, with '1.11.1. Arrhenius Rxn Kinetics' and 'Rxn Ammonia/CO2' highlighted.
- Chemistry Menu:** Open, showing 'Model Options...' selected.
- Chemistry Model Window:** Open, showing 'Stream Parameters' and 'Inflows (mol)'.

Variable	Value
Stream Parameters	
Stream Amount (mol)	59.5082
Temperature (°C)	200.000
Pressure (atm)	100.000
Inflows (mol)	
H2O	55.5082
CO2	2.00000
NH3	2.00000
UREA	0.0
- Summary:** Shows 'Type of calculation: Isothermal' and 'Unit Set: Metric (moles)'. It also lists 'Automatic Chemistry Model' and 'Aqueous (+ ion) Databanks: Aqueous (H+ ion)'. The calculation is currently 'not done'.

11. Select the **Phases** tab and check the **Kinetics** box. Then click **OK**.



A new grid section named **Calculation Parameters** appears. In this grid the **Kinetics Holdup Time**, and the **Number of Kinetic Steps** can be defined. The default values are 2 h and 2 steps respectively.

12. Change the **Kinetics Holdup Time** to **100** hours and the **Number of Kinetic Steps** to **10**.

Variable	Value
Stream Parameters	
Stream Amount (mol)	59.5082
Temperature (°C)	200.000
Pressure (atm)	100.000
Calculation Parameters	
Kinetics Holdup Time (hr)	100.000
Number of Kinetic Steps	10
Inflows (mol)	
H2O	55.5082
CO2	2.00000
NH3	2.00000
UREA	0.0

Kinetics Holdup time is equivalent to **Residence Time**. The **Number of Kinetic Steps** is equivalent to Δt , thus Kinetics Holdup time = $\sum \Delta t$.

Note: Kinetics Holdup Time vs Number of Kinetic Steps

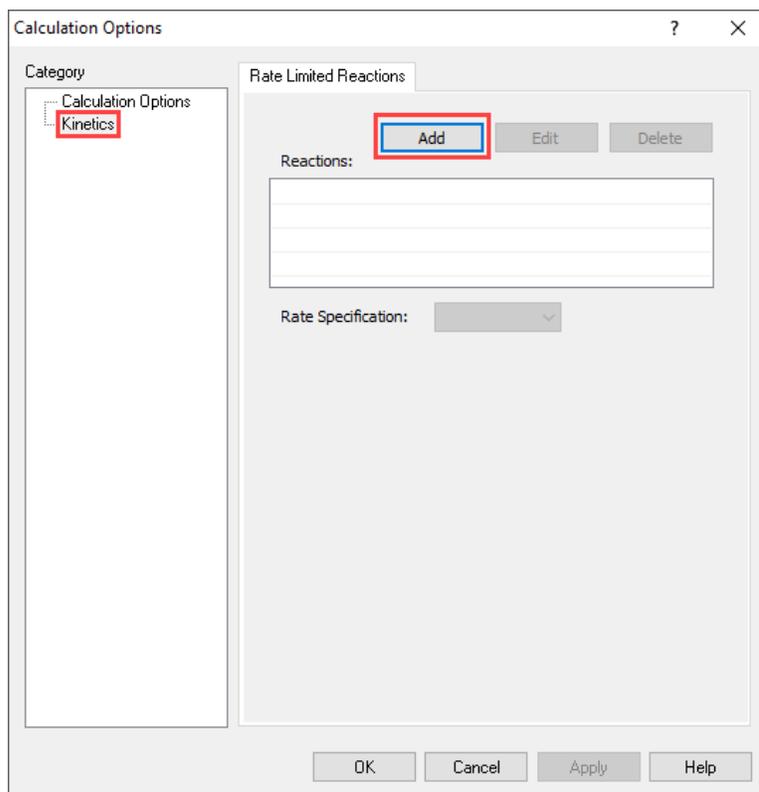
For processes that have reaction kinetics, the software needs to know how the concentration of the reactants (or products) change over time during the reaction, which is given by the **rate law**. It is necessary to divide the total residence time into small steps. Adding more steps decreases the error; however, as you increase the number of stages, the computational time increases.

Now, our next step is to define the reaction kinetics.

13. Click on the **Specs** button. This will open the **Survey Options Window**.

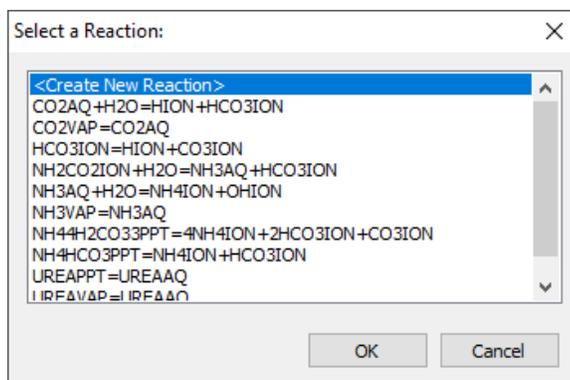
14. Select **Kinetics** under the Category window

15. Click the **Add** button to add a new reaction. This will open the **Select a Reaction Window**.



You will be given a list of reactions which are already in the chemistry model. For our example, we need to create a new reaction.

16. Select the option **Create a New Reaction**, and then click **OK**.



This enables the option to enter a new reaction.

17. **Type** the following reaction: $2\text{NH}_3\text{AQ}+\text{CO}_2\text{AQ}=\text{UREAAQ}+\text{H}_2\text{O}$ and then hit **Enter**. The window will update.

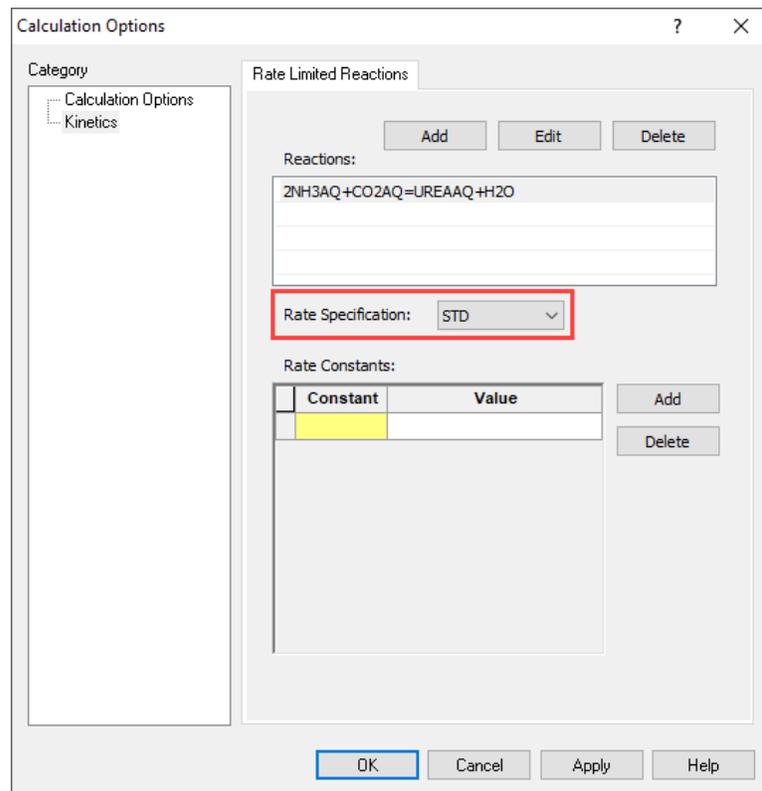
Note: You must use the OLI Tag Name for this step, and additionally specify the phase of the reactants and products. Water is a special case; it is written only as H_2O .

As a general rule:

- For an aqueous phase: AQ
- For a vapor/gas phase: VAP
- For a solid phase: PPT
- For a hydrated solid: $\text{SOLIDNAME}\cdot n\text{H}_2\text{O}$, where n is the hydration number
- For an ion: ION

You can find the OLI TAG Name of your specific species using the [Component Search Tool](#).

18. Select the STD (Standard Rate Reaction Kinetics) as the Rate Specification



Now, let's start entering the rate constants.

Remember, the forward and reverse reactions have the same format. The rate is the following:

$$R = k_f[\text{NH}_3]^2[\text{CO}_2] - k_r[\text{NH}_2\text{CONH}_2]$$

For this example, the forward rate constant (KF) is a constant value equal to 2000.

And, the reverse rate constant (KR) is defined as follows:

$$KR = AR e^{\frac{-BR}{T}}$$

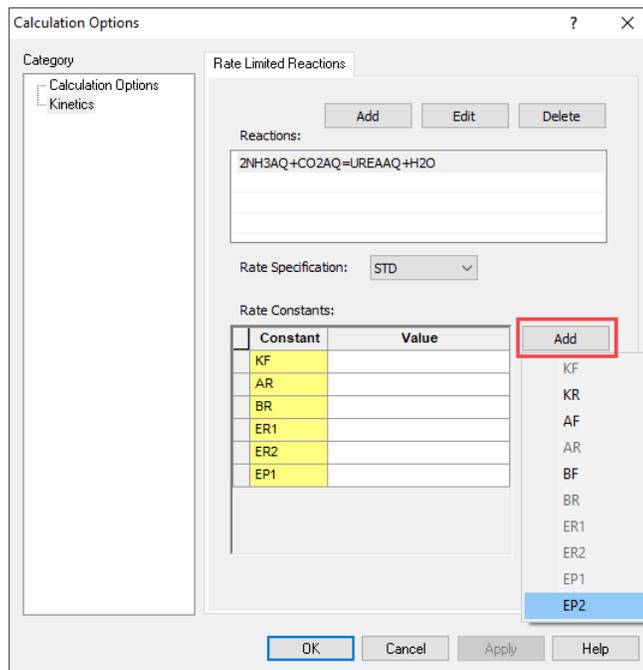
$$KR = 1.2 \times 10^{-10} e^{\frac{-3480.78}{T}}$$

A summary of the Reaction Rate Parameters is given in the table below (These parameters were created for illustration purposes, do not use them for any real design work).

Parameters	Value	Comment
KF	2000	Forward Rate Constant
KR	Calculated	Reverse Rate Constant
AF		Not needed
AR		1.2×10^{-10}
BF		Not needed
BR	3480.78	Determined from $BR = \frac{E_a}{RT} = \frac{28939.9}{8.3142}$
ER1	2	This is the exponent of reactant 1 [NH3] ²
ER2	1	This is the exponent of reactant 2 [CO2]
EP1	1	This is the exponent of product 1 in the mechanism. In this case [NH2CONH2]
EP2	0	H2O does not participate in the reaction

Now that we have identified the parameters needed, we can add them.

19. Click on the **Add** button and select the parameters needed.



20. **Type** the constant values, and then click **OK**.

Calculation Options

Category: Kinetics

Rate Limited Reactions

Reactions:

Rate Specification: STD

Rate Constants:

Constant	Value
KF	2000
AR	1.2e-10
BR	3480.78
ER1	2
ER2	1
EP1	1
EP2	0

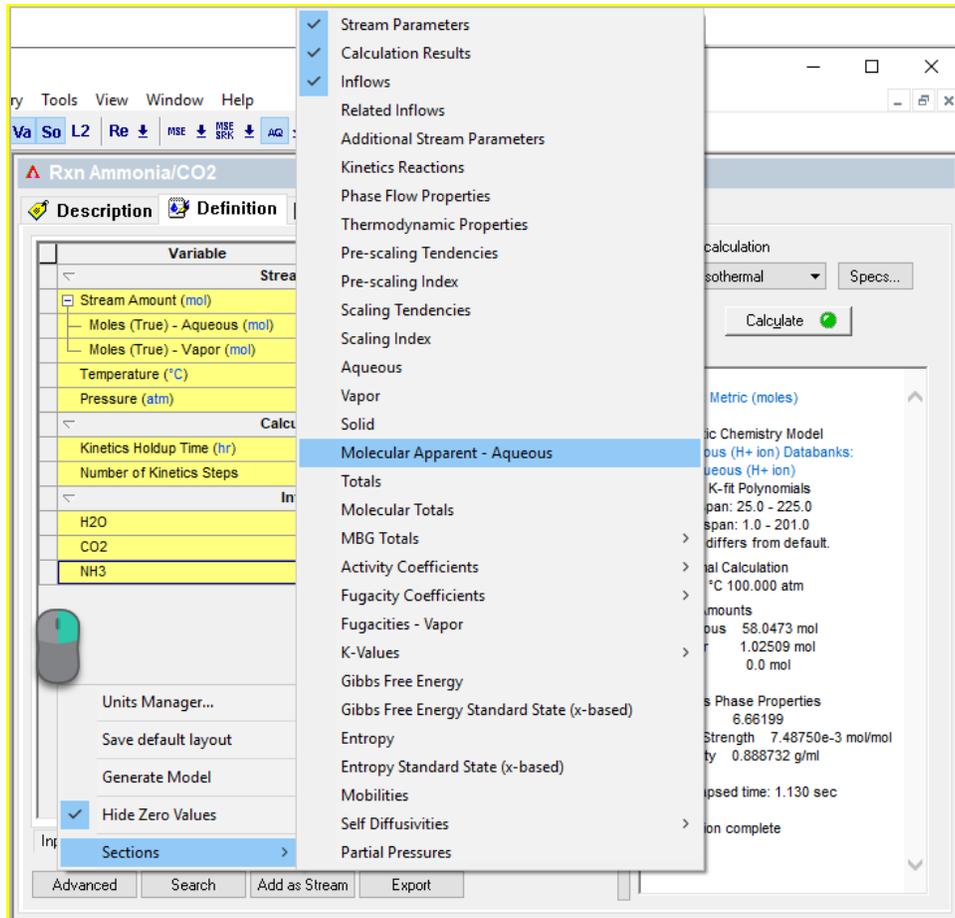
Buttons: Add, Edit, Delete, OK, Cancel, Apply, Help

21. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key.

22. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Single Point Calculations*.

Analyzing the Results

1. Click on the **Output-Minitab** to see the Results.
2. Right click on the gray area and select **Sections> Molecular Apparent - Aqueous**



About **0.002 moles** of Urea had been formed with a total residence time of 100 hours.

Molecular Apparent - Aqueous (mol)	
H2O	55.2950
NH3	1.95686
CO2	1.22715
UREA	2.09657e-3

You can make changes on the residence time, reaction conditions or the rate of reaction to maximize the production of urea.

1.11.2. Non-standard Rate Law

Non-Standard Rate Law, also referred to as SPEC type within the software. These reactions do not follow the Arrhenius kinetics.

Example 16: Ammonia Hydrolysis

In this example we are using simpler chemistry. We are going to study the hydrolysis of ammonia.



For this reaction we know the forward rate constant (k_f) but need to constrain the reverse reaction to the thermodynamic equilibrium constant. This implies that we are going to replace an existing equation within the software.

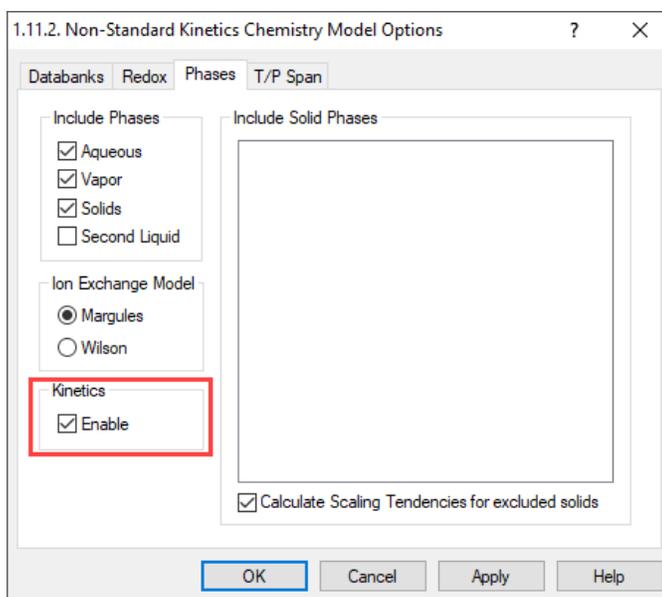
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Single Point Calculation with Reaction Kinetics Enabled			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Single Point Calculation	Stream Amount	Calculated
Calculation Sub-type	Isothermal	Temperature	25 °C
Stream Name	Non-Standard Rxn Kinetics	Pressure	1 atm
Single Point Name	Ammonia Hydrolysis	Water	55.5082
Name Style	Display OLI Name (TAG)	NH3	0.1 moles
Unit Set	Metric, Moles		
Framework	AQ		
Kinetics	Enabled		

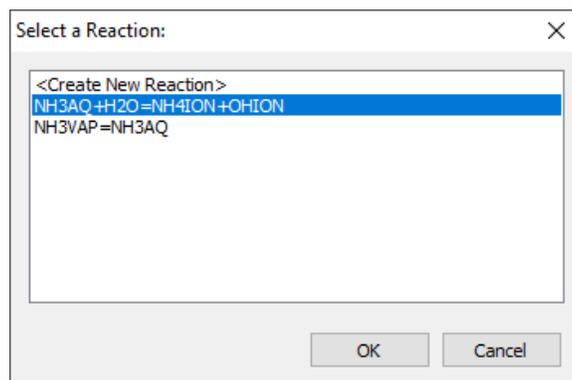
1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Non-Standard Rxn Kinetics*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon, and select the **OLI Name (TAG)** option, and click **OK**.
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles.
6. **Enter** the stream composition, temperature and pressure given in the table above.
7. Go to the **Add Calculation** button and select **Single Point** calculation
8. Select **Isothermal** (default) as Type of Calculation.
9. Change the **SinglePoint** name to **Ammonia Hydrolysis** using the **<F2>** key

- To enable reaction kinetics, make sure that you are at the *Single Point Level* by clicking on the Single Point icon, and then go to **Chemistry menu > Model Options**. This will open the **Chemistry Model** window.
- Select the **Phases** tab and check the **Kinetics** box. Then click **OK**.

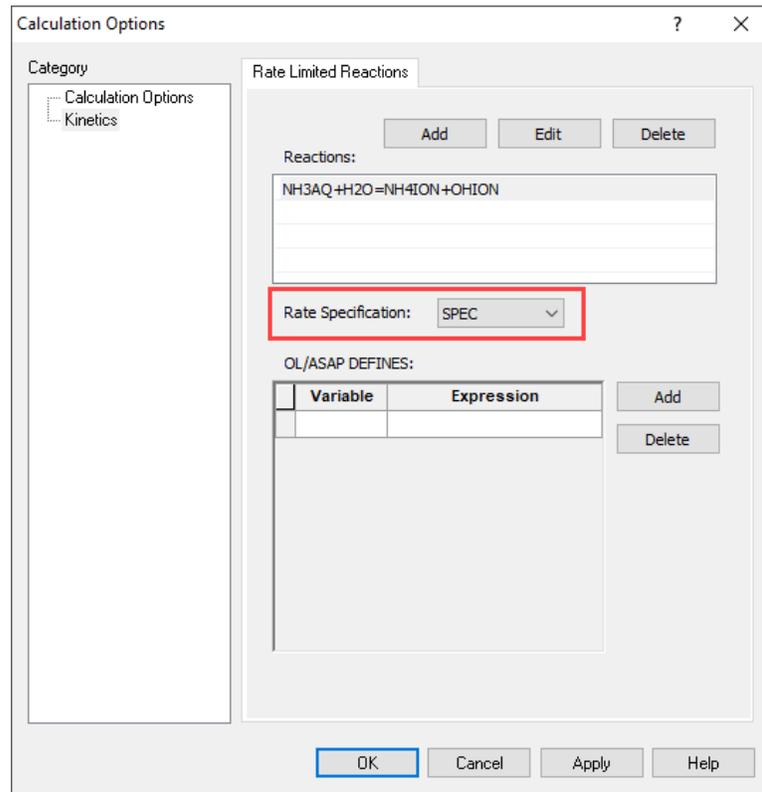


Now, our next step is to define the reaction kinetics.

- Click on the **Specs** button. This will open the **Survey Options Window**.
- Select **Kinetics** under the Category window
- Click the **Add** button to add a new reaction. This will open the **Select a Reaction** Window.
- Select the first reaction: $\text{NH}_3\text{AQ} + \text{H}_2\text{O} = \text{NH}_4\text{ION} + \text{OHION}$, and then click **OK**.



16. Select the SPEC as the Rate Specification.



For this example, the forward and reverse reaction rates are the following:

$$Rate_f = k_f \cdot \gamma_{NH_3,aq} [NH_{3,aq}] \cdot \gamma_{H_2O} [H_2O] \quad \text{where } k_f = 3$$

$$Rate_r = k_r \cdot \gamma_{NH_4^+} [NH_4^+] \cdot \gamma_{OH^-} [OH^-] \quad \text{where } k_r = \frac{k_f}{K_{eq}}$$

Thus, the total rate is given by:

$$Rate = Rate_f - Rate_r$$

$$Rate = k_f \cdot \gamma_{NH_3,aq} [NH_{3,aq}] \cdot \gamma_{H_2O} [H_2O] - k_r \cdot \gamma_{NH_4^+} [NH_4^+] \cdot \gamma_{OH^-} [OH^-]$$

These is where things get difficult. You now need to speak "OLI". We have some rules for SPEC type equations.

We now need to turn these values into “OLI” terms⁵.

We can define any variable we want. We have some variables that you will need to use. Any concentration variable such as $[\text{NH}_{3\text{aq}}]$ is defined as the natural log and is designated with the letter “L”. So $[\text{NH}_{3\text{aq}}]$ is used as LNH3AQ.

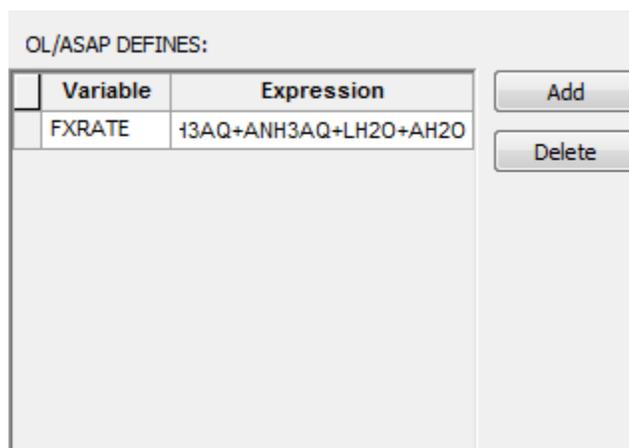
Similarly, activity coefficients γ are also taken as the natural log. So, γ_{OH^-} is written as $\text{Log}_e \gamma_{\text{OH}^-} = \text{AOHION}$.

KEQ is the thermodynamic equilibrium constant for the equation. AH2O is special in the Aqueous thermodynamic framework in that it is the variable $\text{Ln}(a_{\text{H}_2\text{O}})$.

We now need to add these variables to the kinetics window⁶:

Variable	Expression
FXRATE	LNH3AQ+ANH3AQ+LH2O+AH2O
RXRATE	LNH4ION+ANH4ION+LOHION+AOHION
KF1	3
KR1	KF1/KEQ
RATE1	(KF1*EXP(FXRATE)-KR1*EXP(RXRATE))*VOLLIQ/1000

17. Change the **Kinetics Holdup Time** to **100** hours and the **Number of Kinetic Steps** to **10**.

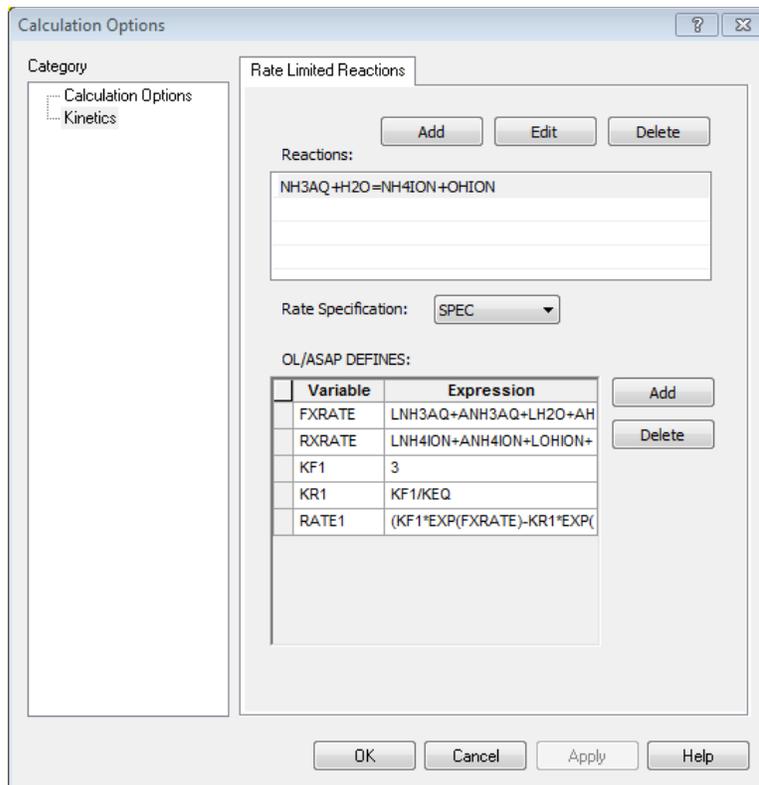


⁵ Commonly referred to as ASAP variables.

⁶ Copy and paste from this document can make this step easier

You will notice in the image above that we have scrolled to the end. That is ok. Click the **Add** button to continue with the equations. It is important that you keep the order correct. You see what we are using previously defined variables in subsequent equations.

Complete the remainder of the variables.



The completed equations

The variable VOLLIQ is the volume of the liquid phase in Liters. OLI requires the rate to be in mol/m³ we need to divide by 1000.

Click the **OK** button.

Like the previous example, this is a plug-flow reactor with a holdup time of 100 hours and 10 steps.

Now **Calculate**

Once the calculation is complete you can click the **Output** mini tab and add the *Aqueous* section (not molecular aqueous):

The screenshot shows a software interface with a main table of results and a summary panel on the right.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.6082
Moles (True) - Aqueous (mol)	55.6082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Results	
Kinetics Holdup Time (hr)	100.000
Number of Kinetics Steps	10
Inflows (mol)	
H2O	55.5082
NH3	0.100000
Aqueous (mol)	
H2O	55.5077
NH3	0.0994574
OHION	5.42587e-4
NH4ION	5.42587e-4
HION	1.97028e-11

Summary Panel:

- Type of calculation: Isothermal
- Unit Set: Metric (moles)
- Automatic Chemistry Model: AQ (H+ ion) Databanks: Public
- Isothermal Calculation: 25.0000 °C 1.00000 atm
- Phase Amounts:
 - Aqueous: 55.6082 mol
 - Vapor: 0.0 mol
 - Solid: 0.0 mol
- Aqueous Phase Properties:
 - pH: 10.7171
 - Ionic Strength: 9.75731e-6 mol/mol
 - Density: 0.996159 g/ml
- Calc. elapsed time: 0.387 sec
- Calculation complete

You can see that some ammonium ion has been created. It is interesting to see what the equilibrium condition would be.

Create another single point isothermal calculation and run it without any reaction kinetics. Here are results below:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.6082
Moles (True) - Aqueous (mol)	55.6082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
NH3	0.100000
Aqueous (mol)	
H2O	55.5069
NH3	0.0986221
OHION	1.37789e-3
NH4ION	1.37789e-3
HION	7.99755e-12

The reaction kinetics have forced the back reaction to be dominant. In the equilibrium case, approximately

1.3×10^{-3} moles of NH_4^+ have been created. By limiting the forward reactions, we allow the back reaction to take place and that only formed 5.4×10^{-4} moles of NH_4^+

You can find a completed and worked example here: [Chapter 12 – Non-standard Reaction Kinetics](#)

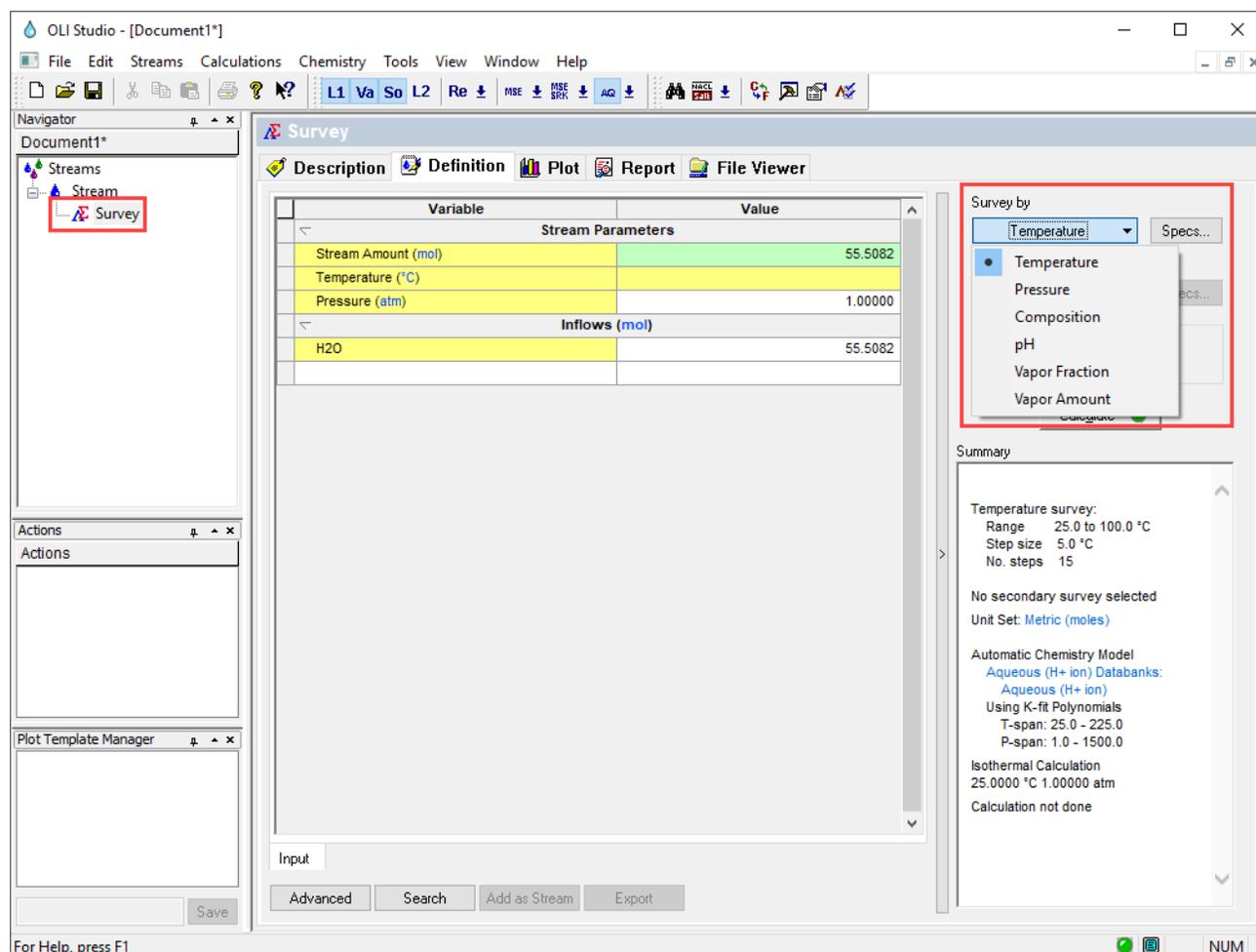
Section 2. Survey Calculations

Survey calculations are single point calculations strung together in series. They are also referred to as multiple point calculations.

There are three different ways to set up surveys:

1. **Single Survey:** These calculations allow the user to designate one independent variable. The predefined single surveys include survey by Temperature, Pressure, Composition, pH, Vapor Fraction and Vapor Amount.
2. **Dual Survey:** These calculations allow the user to designate two independent variables.
3. **Survey by changing the single point calculation type:** By default, the isothermal calculation is selected for survey calculations. If the user wants to study the solubility of a salt in solution, it is possible to change the survey from **Isothermal** to the **Precipitation Point** calculation type.

In this section, you will learn how to set up **survey types** and introduce some additional features to get the most out of your simulation results.



The screenshot shows the OLI Studio interface with the Survey configuration window open. The 'Survey by' dropdown menu is open, showing options: Temperature (selected), Pressure, Composition, pH, Vapor Fraction, and Vapor Amount. The main window displays a table of variables and values for a survey.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082

Summary:

Temperature survey:
Range 25.0 to 100.0 °C
Step size 5.0 °C
No. steps 15

No secondary survey selected
Unit Set: Metric (moles)

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
P-span: 1.0 - 1500.0

Isothermal Calculation
25.0000 °C 1.00000 atm
Calculation not done

2.1. Single Surveys

An introduction to single surveys is given here. We will illustrate, in detail, the steps necessary to conduct this type of calculation. The example below was designed to be used as a guide for future reference.

Example 17: Removal of Nickel from Wastewater

This case study is a typical wastewater treatment problem, the removal of a trace heavy metal ion (nickel) from a water stream in which the presence of another chemical (cyanide) significantly alters the treatment strategy. In this case, we are considering precipitation as an approach to removal of the nickel.

The wastewater in this case study contains nickel ions at a concentration of 0.002 m (or moles/ 1 kg H₂O). The existing treatment strategy is to precipitate the nickel ions as Nickel Hydroxide (Ni(OH)₂). The soluble nickel remaining after precipitation needs to be less than 1 ppm, which is the maximum contaminant level allowed.

During the course of the plant operation, some cyanide ion is inadvertently added to the waste stream. The soluble nickel is now more than 1ppm. Sulfide salts were then added to hopefully precipitate the nickel and once again achieve the design specification.

This example will be divided into three different scenarios:

1. [Scenario 1: Wastewater without Additives](#)
2. [Scenario 2: Wastewater with Cyanide Content](#)
3. [Scenario 3: Wastewater with Sulfide Salts](#)

The power of the Stream Analyzer becomes apparent when we are seeking to study the chemistry of individual streams. For this specific example a Survey by **pH** will be used.

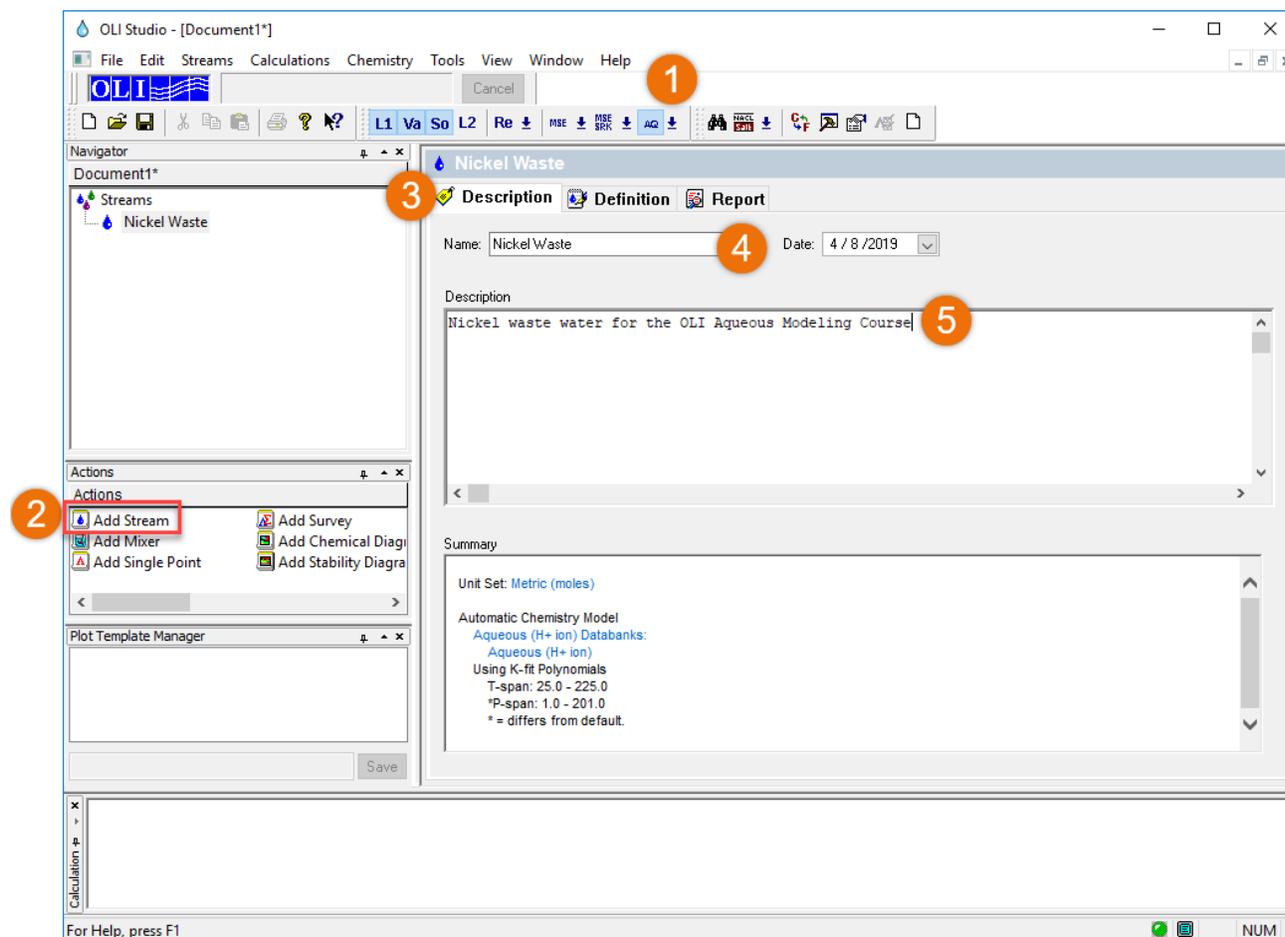
Scenario 1: Wastewater without Additives

We begin by starting the Stream Analyzer Program. This may be accomplished by **clicking** on the OLI Studio: Stream Analyzer icon or by using the Start button and finding **OLI Studio** under *Programs*, which will take you to the New window where you start creating your calculations.



1. Select the **AQ-Databank** (The default databank)
2. Click on **Add Stream** icon (in the actions panel). This will display the **Definition** window. We should add some descriptive information about this stream, so we can later identify the stream
3. Click on the **Description** tab. This will display the description information
4. Replace the name **Stream** with the name **Nickel Waste**. It is advisable to change the name of the stream from the default name. You may be entering many streams and will need to sort them out later
5. Add the following text to the **Description** box: “*Nickel waste water for the OLI Aqueous Modeling Course*”

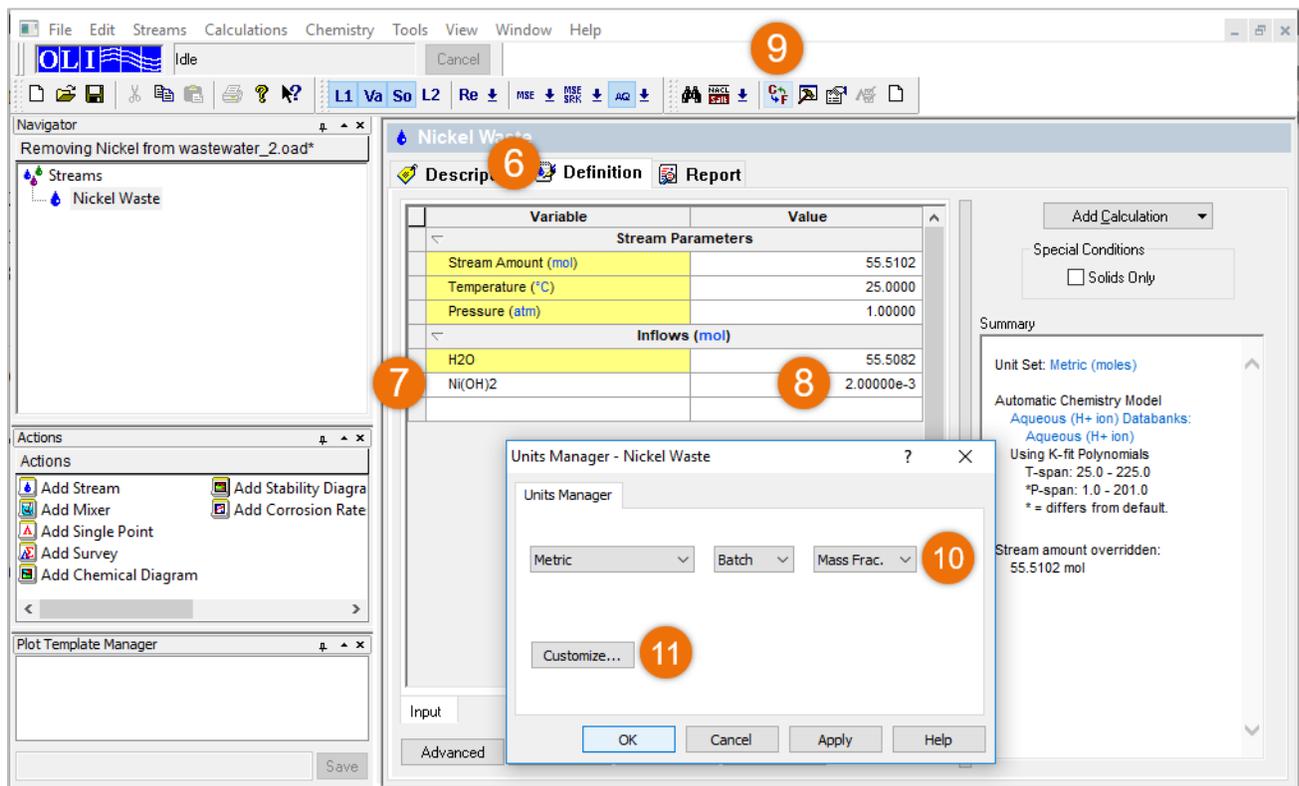
Note: The summary box will contain additional information as the calculations proceed. This information maybe the name of additional databases or chemistry models imported from other OLI software packages. The filled-out window should look like the figure below.



6. Click on the **Definition** tab to start defining the wastewater stream
7. Click in the white box in the grid below the **Inflows** line. Add the formula **Ni(OH)₂**
8. Click in the white box next to the species you just entered and enter the value **0.002**. Press **<Enter>** to update the list

Note: Stream Analyzer will automatically change the name of the species to the selected display name. In this instance, the name you entered was **Ni(OH)₂** but it may have changed to a different form. If it changed you can specify which display name to use in the [Names Manager](#) icon 

9. For the output results, we want output units in **ppm**. To change the output units, click on the [Units Manager](#) icon . This will open a new window.
10. Change moles to Mass Frac. Using the drop-down arrow
11. Click on the **Customize** button. The **Units Manager** window will appear.



The screenshot shows the OLI software interface with the 'Nickel Waste' stream definition window. The 'Definition' tab is active, displaying a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5102
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
Ni(OH) ₂	2.00000e-3

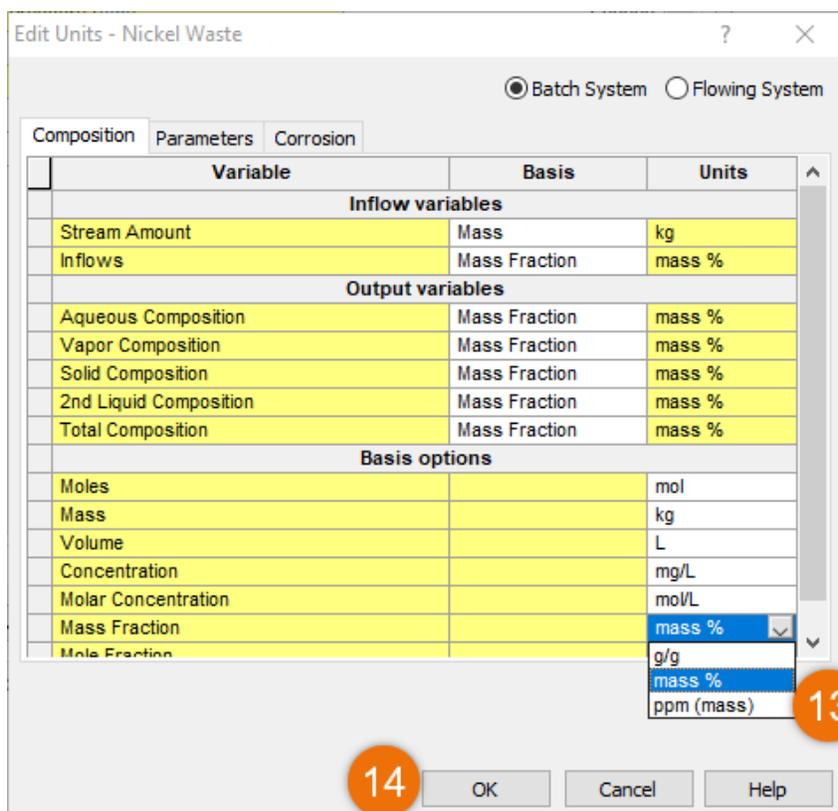
The 'Units Manager - Nickel Waste' dialog box is open, showing the following settings:

- Unit Set: Metric (moles)
- Automatic Chemistry Model: Aqueous (H+ ion) Databanks: Aqueous (H+ ion)
- Using K-fit Polynomials
- T-span: 25.0 - 225.0
- *P-span: 1.0 - 201.0
- * = differs from default.
- Stream amount overridden: 55.5102 mol

The 'Units Manager' dialog box has three dropdown menus: 'Metric', 'Batch', and 'Mass Frac.'. The 'Customize...' button is highlighted.

12. Change the Mass Fraction Units to ppm (mass)

13. Click OK



Our primary interest in this application is finding the optimum pH for nickel removal. To create a plot of Ni^{+2} as function of pH, we will need to run a pH survey.

Creating a pH Survey to find the optimum pH for nickel removal

Click on the **Nickel Waste** stream icon in the tree view on the left-hand side of the window. This will bring you back to the top of the series of calculations by displaying just the stream information.

1. Click on the **Add Calculation** button
2. Select **Survey**

The screenshot shows a software interface with a 'Nickel Waste' stream selected. The 'Add Calculation' menu is open, and the 'Survey' option is highlighted. The 'Nickel Waste' stream information is displayed in a table.

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00019
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (ppm (mass))	
H2O	9.99815e5
Ni(OH)2	185.335

The 'Add Calculation' menu options are:

- Single Point
- Survey
- Chemical Diagram
- Stability Diagram
- Corrosion Rates

The 'Automatic Chemistry Model' section shows:

- Aqueous (H+ ion) Databanks: Aqueous (H+ ion)
- Using K-fit Polynomials
- T-span: 25.0 - 225.0
- *P-span: 1.0 - 201.0
- * = differs from default.

You can now add descriptive information about this calculation.

3. Enter a new **Survey name: Base Survey**. You can also double click on 'Survey' to change the name
4. Enter a **Description: Base pH survey without additives**.

Since we do not want a temperature survey which is the default, we will need to change the survey type.

5. Click on the **Definition** tab to do the survey calculation.
6. Click on the **Survey by** button
7. Select **pH**

Note: The default acid titrant and the base titrant are already defined (HCl and NaOH). We are now ready to begin the calculations.

The screenshot shows the software interface for configuring a survey. The main window displays a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00019
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Target pH	
Use Single Titrant	No
pH Acid Titrant	HCl
pH Base Titrant	NaOH
Inflows (ppm (mass))	
H2O	9.99815e5
Ni(OH)2	185.335
HCl	0.0
NaOH	0.0

The Summary panel on the right shows the following details:

pH survey:
Acid - HCl
Base - NaOH
Range 0.0 to 14.0
Step size 1.0
No. steps 14

No secondary survey selected
Unit Set: <Custom>

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

We should now save our work. It is very frustrating to work for a long period of time and forget to save our work. So please save.

8. Select **File**

9. Select **Save As** from the menu. Give the name *Removing nickel from wastewater*

10. Click on the **Calculate** button

The screenshot shows the OLI Studio interface for a simulation titled "[Removing Nickel from wastewater_2.oad]". The File menu is open, and the "Save As..." option is selected, indicated by a red circle with the number 9. The "Save As..." option is also highlighted in blue, with a red circle containing the number 10. The main window displays a table of simulation parameters and a Survey panel on the right. The Survey panel has "pH" selected in the "Survey by" dropdown, and the "Calculate" button is highlighted with a red circle containing the number 11. The table below shows the following data:

Variable	Value
Stream Parameters	
Amount (kg)	1.00019
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
pH	
Single Titrant	No
Liquid Titrant	HCL
Gaseous Titrant	NAOH
Inflows (ppm (mass))	
1	9.99815e5
2	185.335

The program will run for a short time. When the orbit disappears, check the summary box to see if the calculation is complete. In the tree-view, you can expand the survey to see if all the points converged.

The screenshot displays the OLI software interface for configuring a Base Survey. The main window is titled "Base Survey" and contains several panels:

- Navigator:** Shows a tree view of the survey configuration. A red box highlights the "Base Survey" folder, which contains a list of target pH values from 0.0 to 9.0, each with a green checkmark indicating convergence.
- Configuration Panel:** Contains a table of parameters and control options.

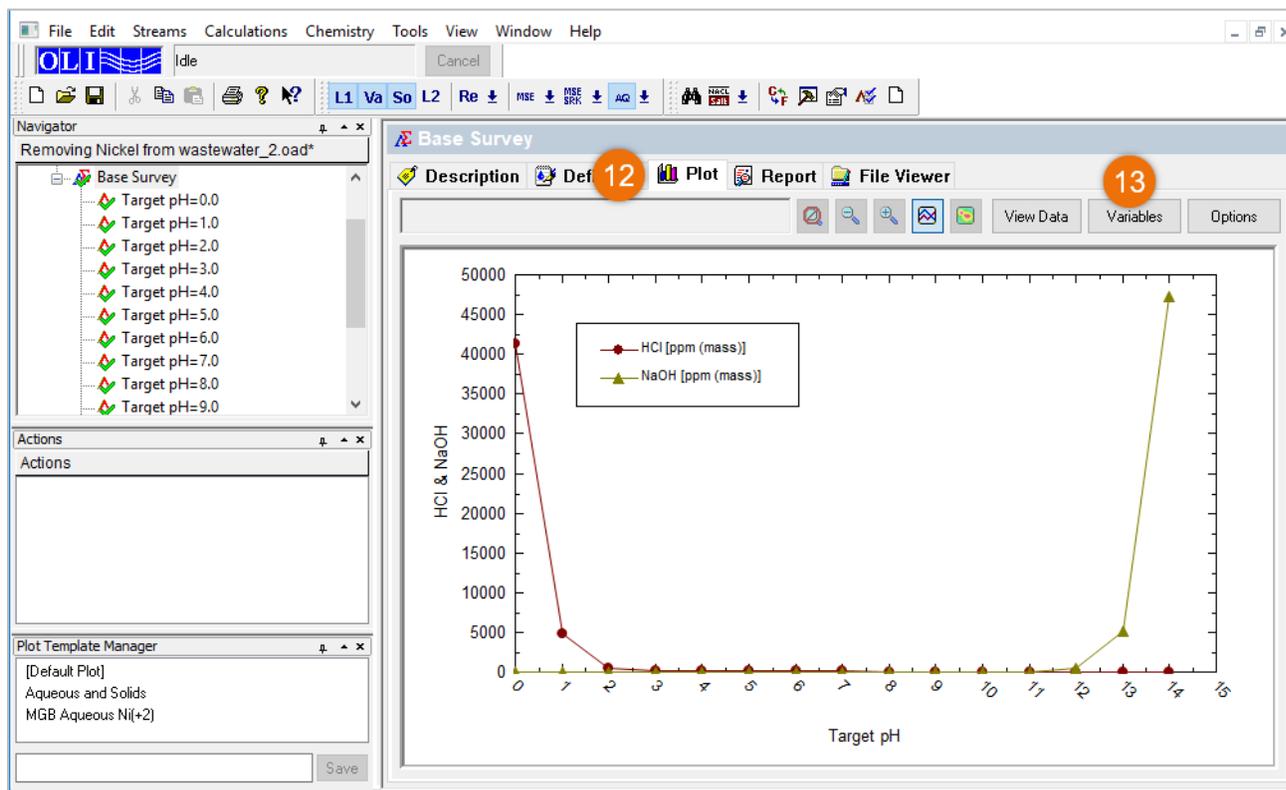
Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00019
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Target pH	
Use Single Titrant	No
pH Acid Titrant	HCl
pH Base Titrant	NaOH
Inflows (ppm (mass))	
H2O	9.99815e5
Ni(OH)2	185.335
HCl	0.0
NaOH	0.0
- Summary:** Provides a summary of the survey configuration:
 - pH survey: Acid - HCl, Base - NaOH
 - Range: 0.0 to 14.0
 - Step size: 1.0
 - No. steps: 14
 - Unit Set: <Custom>
 - Automatic Chemistry Model: Aqueous (H+ ion) Databanks: Aqueous (H+ ion)

The bottom status bar displays the message "Calculation Complete!" in a red box, along with the text "For Help, press F1" and "NUM".

We can now obtain some graphical results.

11. Click on the **Plot** tab

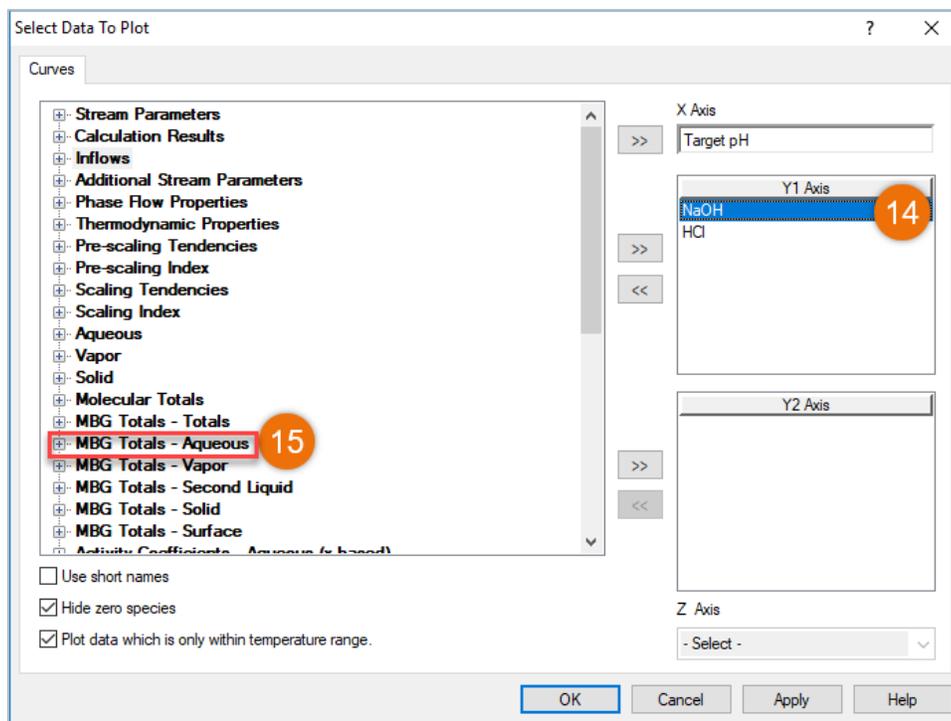
12. Click on the **Variables** button



This will open a new window. The **NaOH** and **HCl** variables in the Y-Axis box should be displayed.

13. **Select** them and then **Click** on the left double-arrow (**<<**) button which will remove **NaOH** and **HCl** from the list. You can also select and double click to remove them.
14. Scroll down the left-hand window to find **MBG Totals - Aqueous** and expand the list by clicking the **+** box.

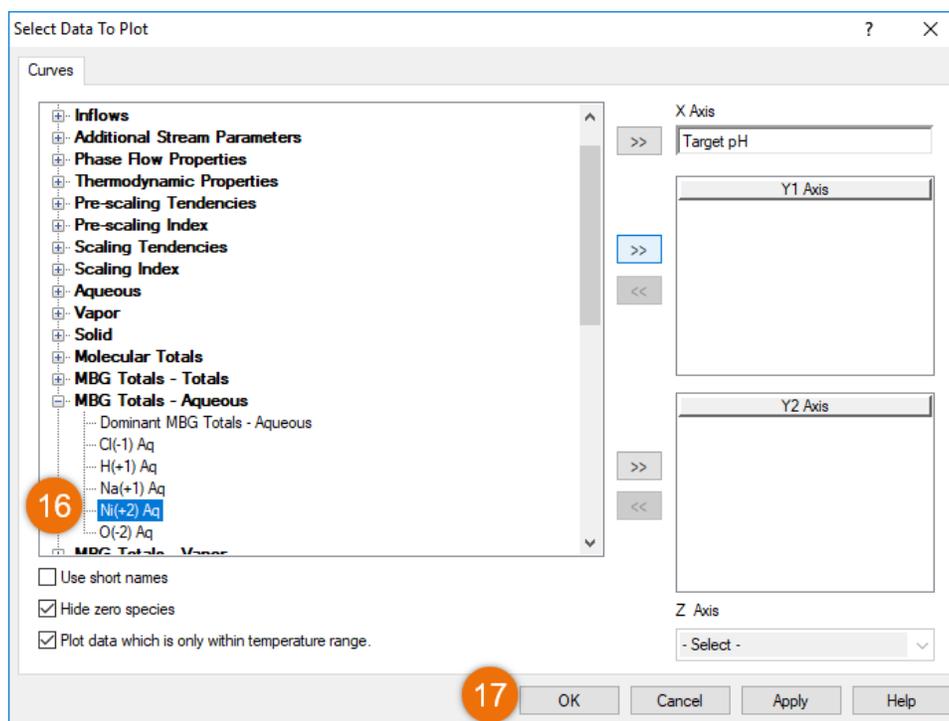
Note: MGB is an abbreviation for Material Balance Groups. The **MGB** variable is a sum of all the species for that material in the phase requested.



The grid updates to show the **MGB** totals available to display. In this case we desire the Nickel(+2) species. in this case all the **Ni(+2) Aq** variable is a sum of all nickel containing ions in the aqueous phase in solution. Any solids are excluded from the summation.

15. **Double-Click** the **Ni(+2)** item or select it and use the **>>** button.

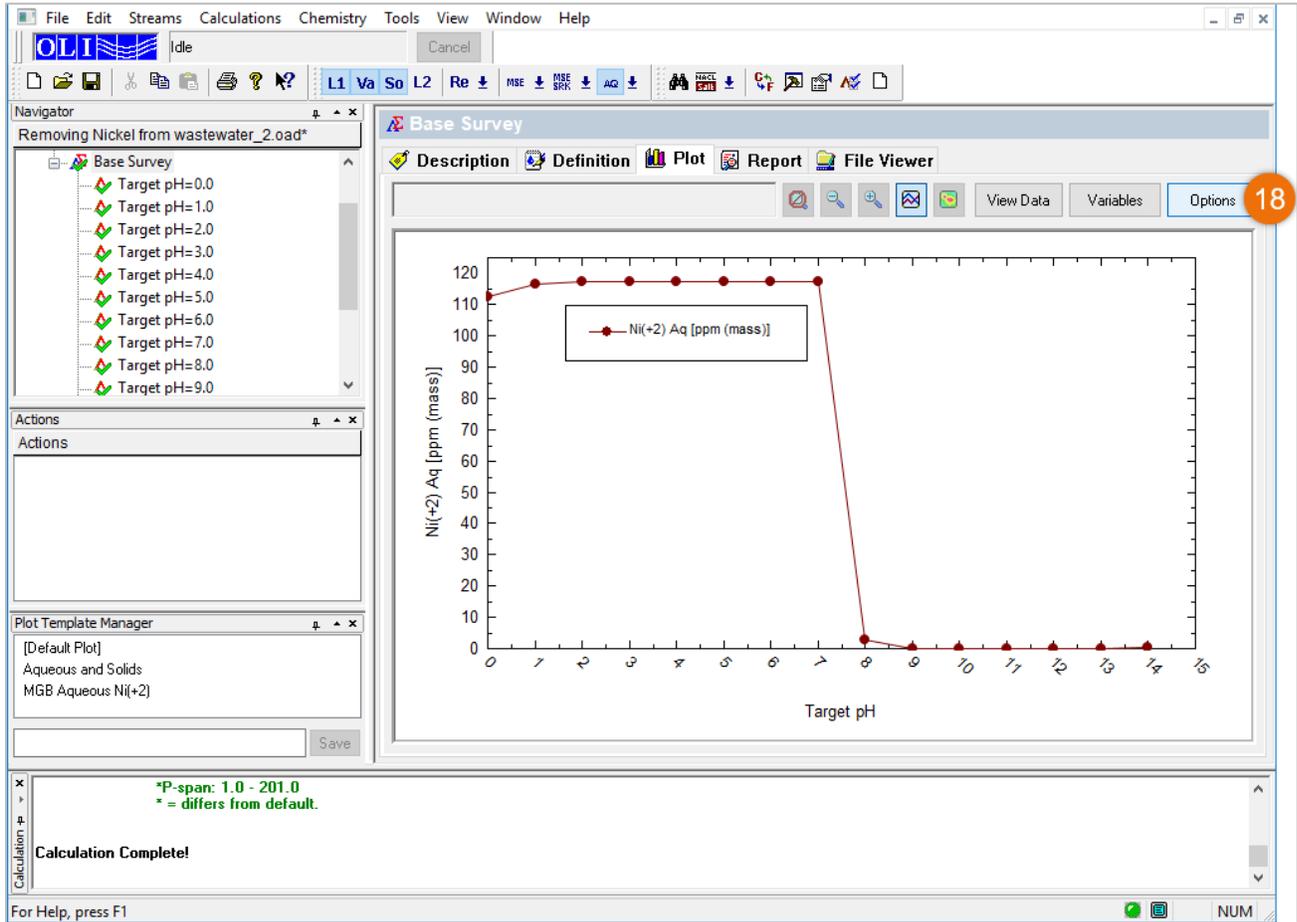
16. **Click** on the **OK** button.



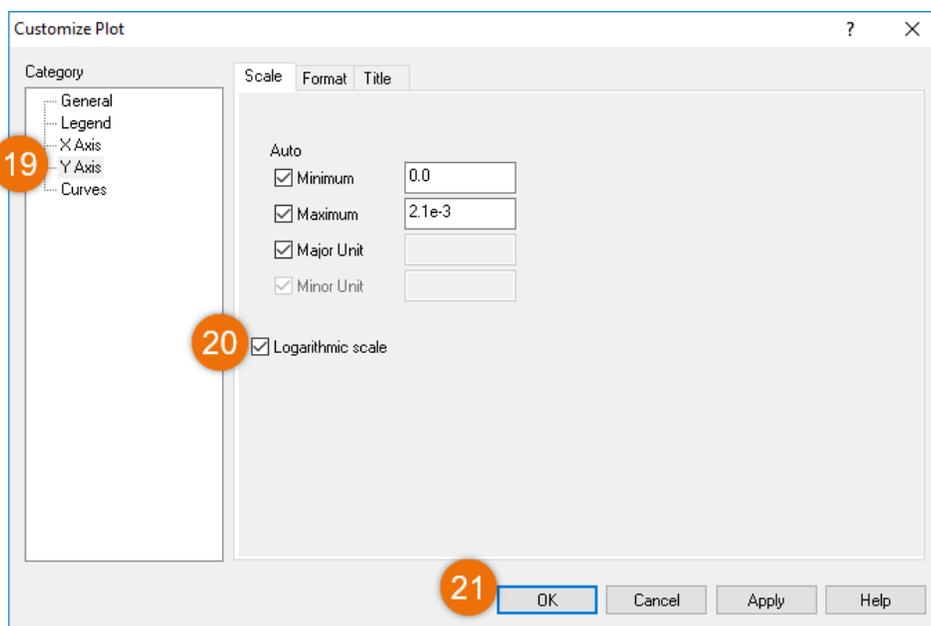
You will see the new plot.

For many calculations, the values on the plot extend over a very large range of numbers. The default linear axis may not capture all the details we require.

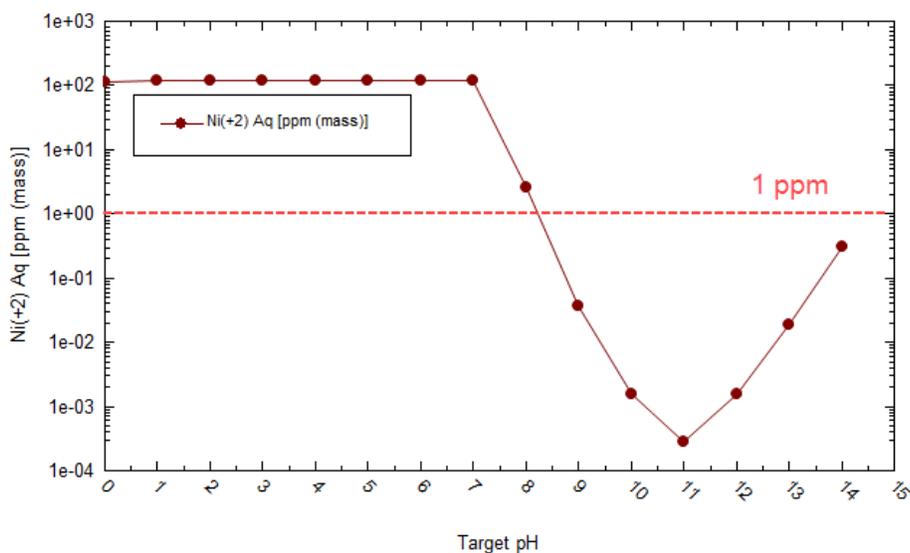
17. Above the plot window locate and select the **Options** button. This opens a new window.



18. Select **Y-Axis** from the Category List
19. **Check** the Logarithmic Scale Box
20. **Click** on the **OK** box



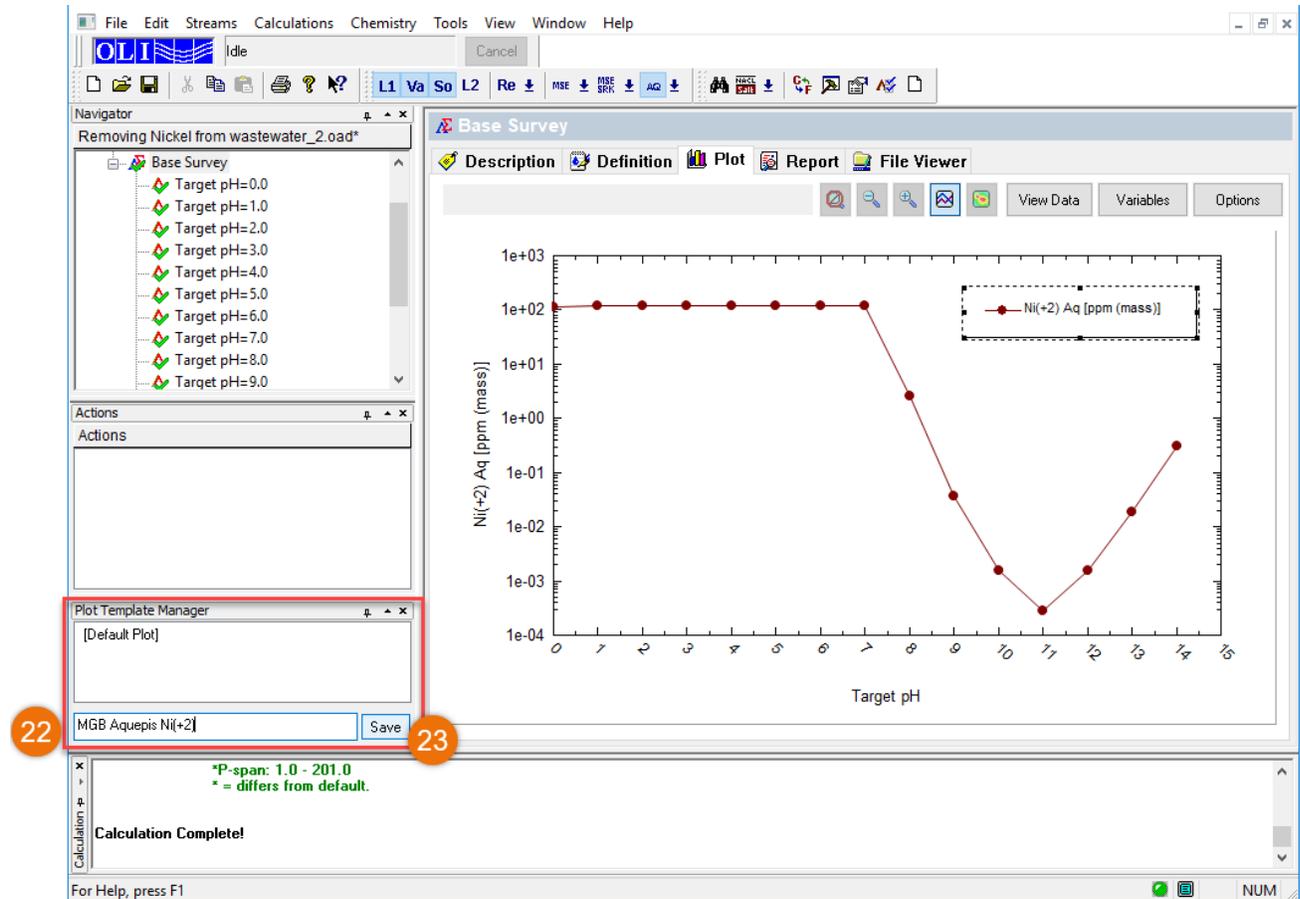
The modified plot is then displayed. The limit of 1 ppm for Ni^{2+} is approximately 2×10^{-5} moles. Above $\text{pH}=9$, we are several orders of magnitude below this limit. Additionally, you can see that a minimum amount of Ni^{2+} in the aqueous phase seems to occur in the $\text{pH}=11$ range. This is the result of nickel solids forming and leaving the aqueous phase.



Note: The red line was put as a reference. it was not plot with the software.

Let's make the plot shown above the default plot. To do that we are going to use the Plot Template Manager Tool.

21. Save the description in the left-hand corner panel named **Plot Template Manager**. Type **MBG Aqueous Ni(+2)** as the name in this case.
22. Click **Save**



Now there will be two plots on that list now. First is default and second is **MBG Aqueous Ni(+2)**. You are now able to see these plot conditions for any other analyzer object in this case when you add survey for that object.

What else is important in this solution?

23. Click once more on the **Variables** button

24. **Add** the following **Aqueous** species to the plot. (you may need to scroll up or down to find all the species):

Ni(OH)₂

NiOH+1

Ni+2

Ni(OH)₃₋₁

25. **Add** the following **Solids** species to the plot:

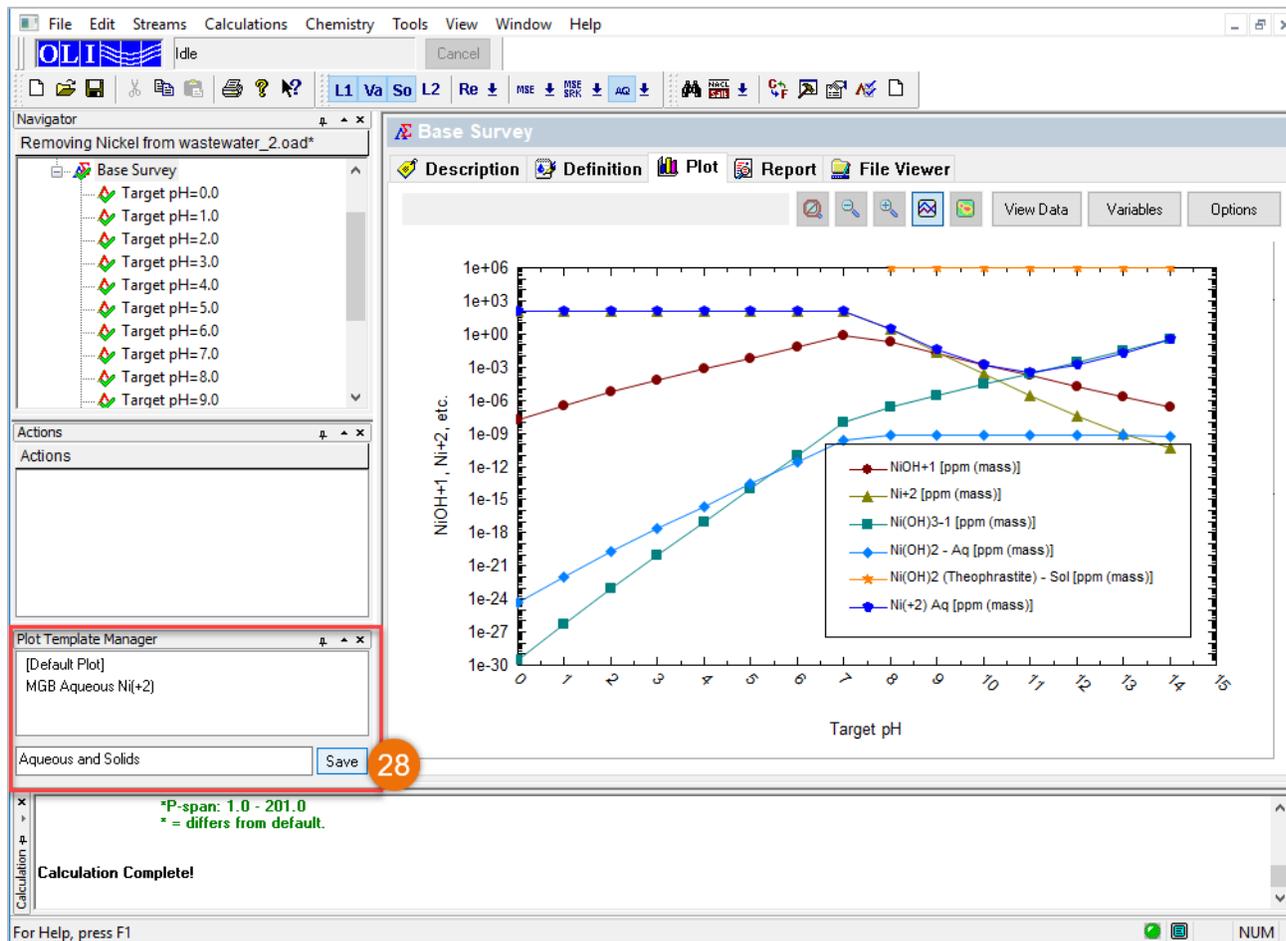
Ni(OH)₂

26. **Click** on the **OK** button when done

The screenshot shows the OLI software interface. The main window is titled "Base Survey" and has a menu bar with "File", "Edit", "Streams", "Calculations", "Chemistry", "Tools", "View", "Window", and "Help". The "Variables" button in the top right corner is highlighted with a red circle labeled "24". A "Select Data To Plot" dialog box is open in the center, with a red circle labeled "25" over the "Aqueous" section. The "Aqueous" section is expanded, and the "Y1 Axis" list contains the following species: NiOH+1, Ni+2, Ni(OH)3-1, Ni(OH)2 - Aq, Ni(OH)2 (Theophrastite) - Sol, and Ni(+2) Aq. The "X Axis" is set to "Target pH". The "Y2 Axis" is empty. The "Z Axis" is set to "- Select -". The "OK" button at the bottom of the dialog box is highlighted with a red circle labeled "27". The "Solid" section is highlighted with a red circle labeled "26". The "Aqueous" section is highlighted with a red circle labeled "25".

You can see that the soluble nickel (**Ni(+2) Aq**) is a summation of the other species. The large drop in the value is because most of the nickel leaves the aqueous solution as Ni(OH)₂-Solid at pH values greater than 7.0 with a maximum near pH=11.

27. Let's save this as a default plot as well in the Plot Template Manager as **Aqueous and Solids**



Scenario 2: Wastewater with Cyanide Content

The real importance of aqueous speciation modeling of this treatment is only really appreciated if we introduce the cyanides, which brings us to the real waste treatment problem.

For this scenario, you will repeat many of the same steps as in [Scenario 1](#). We recommend that you create new calculations below the **Nickel Waste** stream. This will keep the core composition the same without affecting the results of other calculations.

Please follow these steps for this scenario. Please note that we will only show the screens that are substantially different from those that you have already seen.

Creating a pH Survey to find the optimum pH for nickel removal

1. **Click** on the **Nickel Waste** stream in the tree view in the left-hand window
2. This will display the **Actions** pane in the bottom left corner of the Stream Analyzer window. **Click** on the **Add Survey** icon in the Actions pane

The screenshot shows the Stream Analyzer software interface. The left pane (Navigator) shows a tree view with 'Streams' containing 'Nickel Waste' and 'Base Survey'. A red circle with the number '1' is placed over 'Nickel Waste'. The bottom-left pane (Actions) shows a list of actions: 'Add Stream', 'Add Mixer', 'Add Single Point', 'Add Survey', 'Add Chemical', 'Add Stability', and 'Add Corrosion'. A red circle with the number '2' is placed over 'Add Survey'. The main window displays the 'Nickel Waste' stream configuration. The 'Description' tab is active, showing a table of variables and values. The table is divided into 'Stream Parameters' and 'Inflows (ppm (mass))'. The 'Inflows' table has two rows: 'H2O' with a value of 9.99815e5 and 'Ni(OH)2' with a value of 185.335. The right pane shows the 'Summary' section with 'Unit Set: <Custom>' and 'Automatic Chemistry Model' details. The bottom status bar shows 'For Help, press F1' and 'NUM'.

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00019
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (ppm (mass))	
H2O	9.99815e5
Ni(OH)2	185.335

3. Click on the **Description** Tab, and change the *Name* and *Description* in the **Description** tab.

Name: **Waste Survey with CN**

Description: **pH survey with both Nickel and CN**

4. Click on the **Definition** Tab

5. Add **NaCN** to the grid with a value of **490 ppm**

6. Click on the **Survey By** button and select **pH**. Note that HCl and NaOH are the default titrants and are automatically added

7. Click on the **Calculate** button.

The screenshot shows the software interface for configuring a survey. The main window is titled "Waste Survey with CN". The "Description" tab is active, showing the following information:

Variable	Value
Stream Parameters	
Stream Amount (kg)	1.00019
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Target pH	
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NaOH
Inflows (ppm (mass))	
H2O	9.99325e5
Ni(OH)2	185.335
NaCN	490.000

The "Survey by" dropdown is set to "pH". The "Calculate" button is highlighted with a green checkmark. The "Summary" panel on the right shows the following information:

pH survey:
Acid - HCLIN
Base - NaOH
Range 0.0 to 14.0
Step size 1.0
No. steps 14

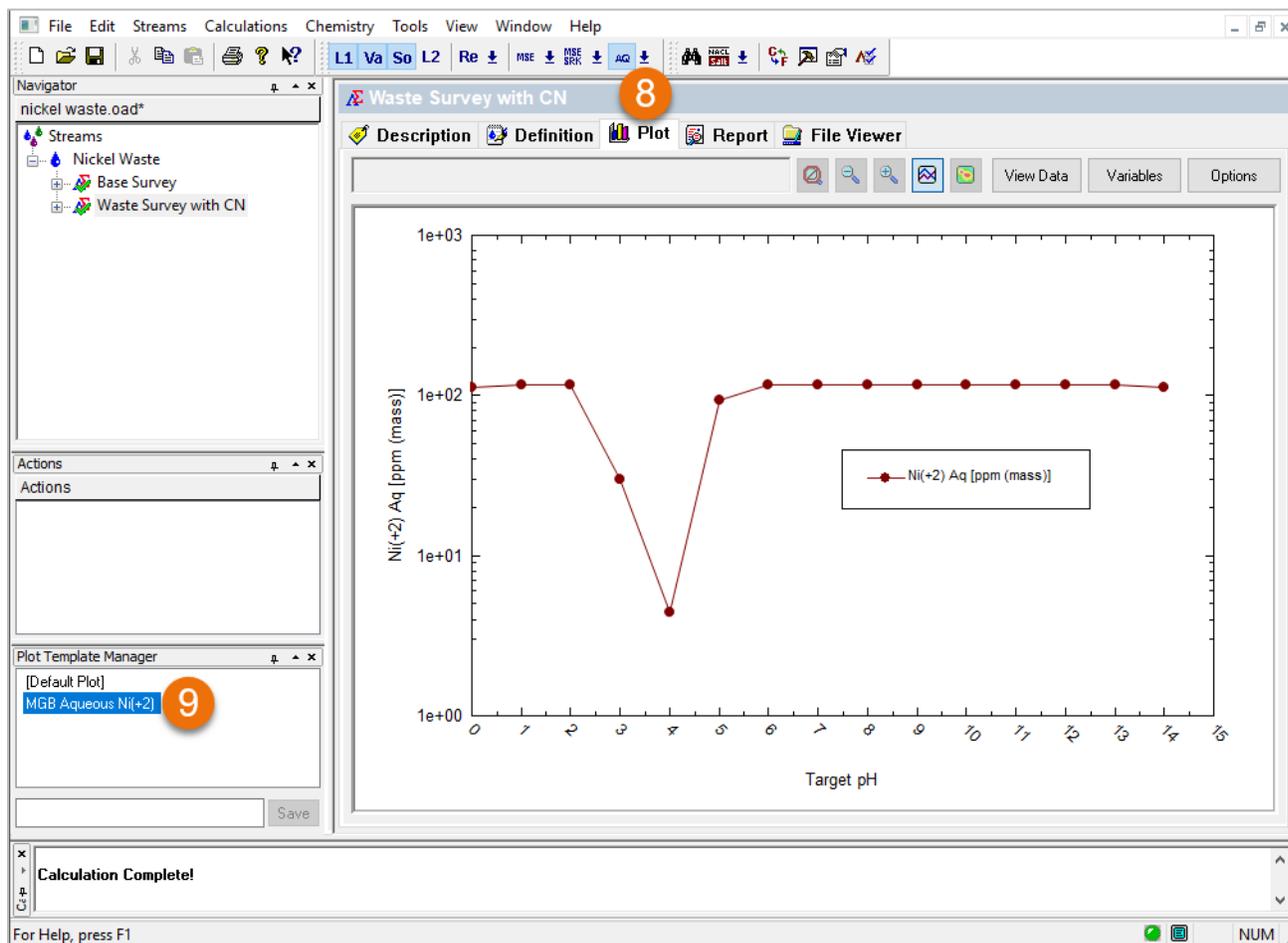
No secondary survey selected
Unit Set: <Custom>

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Using K-fit Polynomials
T-span: 25.0 - 225.0
*P-span: 1.0 - 201.0
* = differs from default.

Set pH Calculation

Let's review the results.

8. Click on the **Plot** tab
9. Go to the **Plot Template Manager** tool, and click on MGB Aqueous Ni(+2)



The results have changed very dramatically. The new optimum pH for Ni removal is around 4.0, rather than 11. However, the lowest total Ni remaining in solution is now around 4 ppm which is well over 1 ppm.

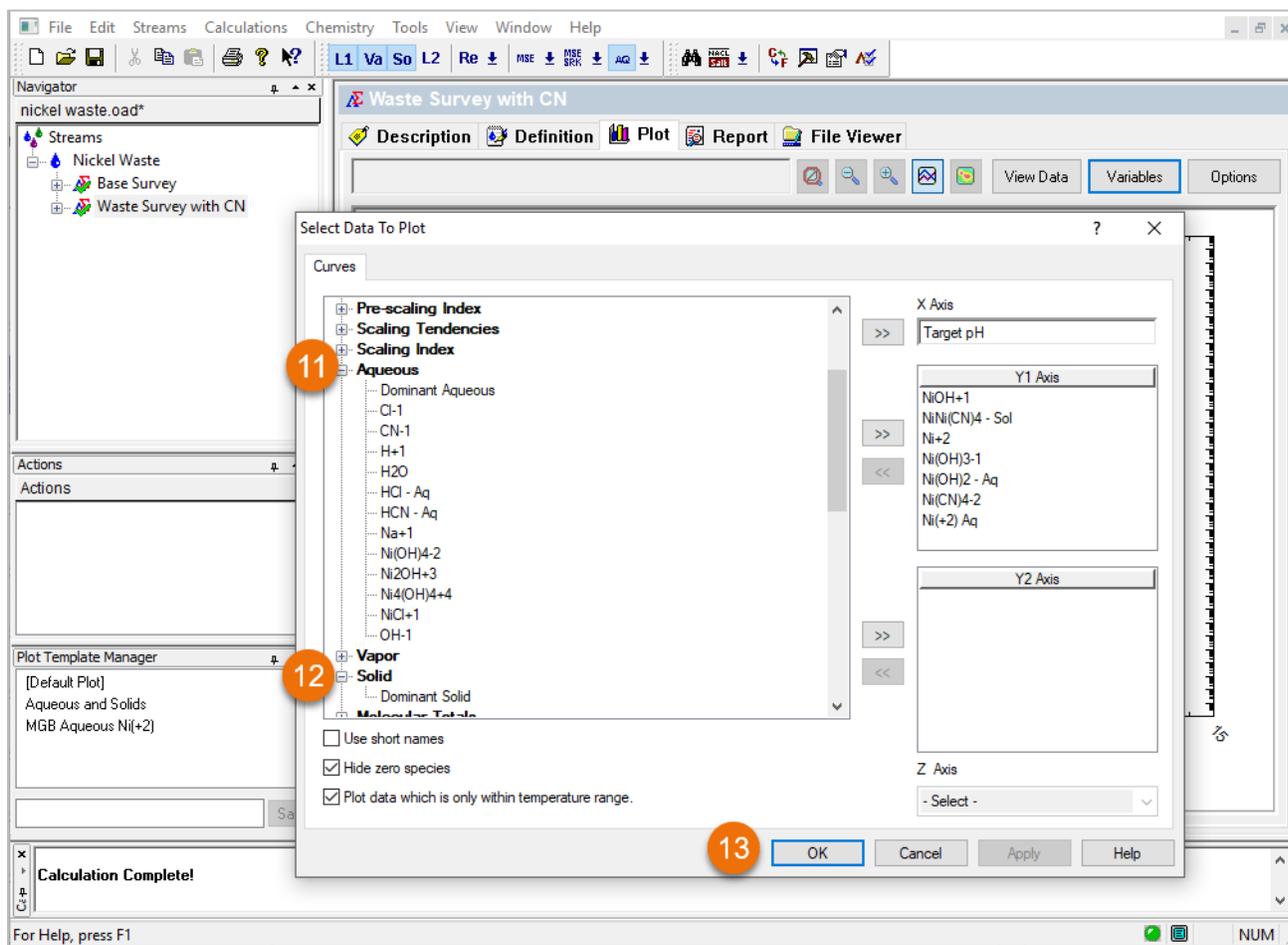
Let's analyze why this is happening. We can now modify the plot to display more variables. Select the **Aqueous and Solids** plot saved in the **Plot Template Manager**.

10. Click on **Variables**

11. **Add** the following new **Aqueous** species: Ni(CN)₄-2

12. **Add** the following new **Solid** species: NiNi(CN)₄-Solid

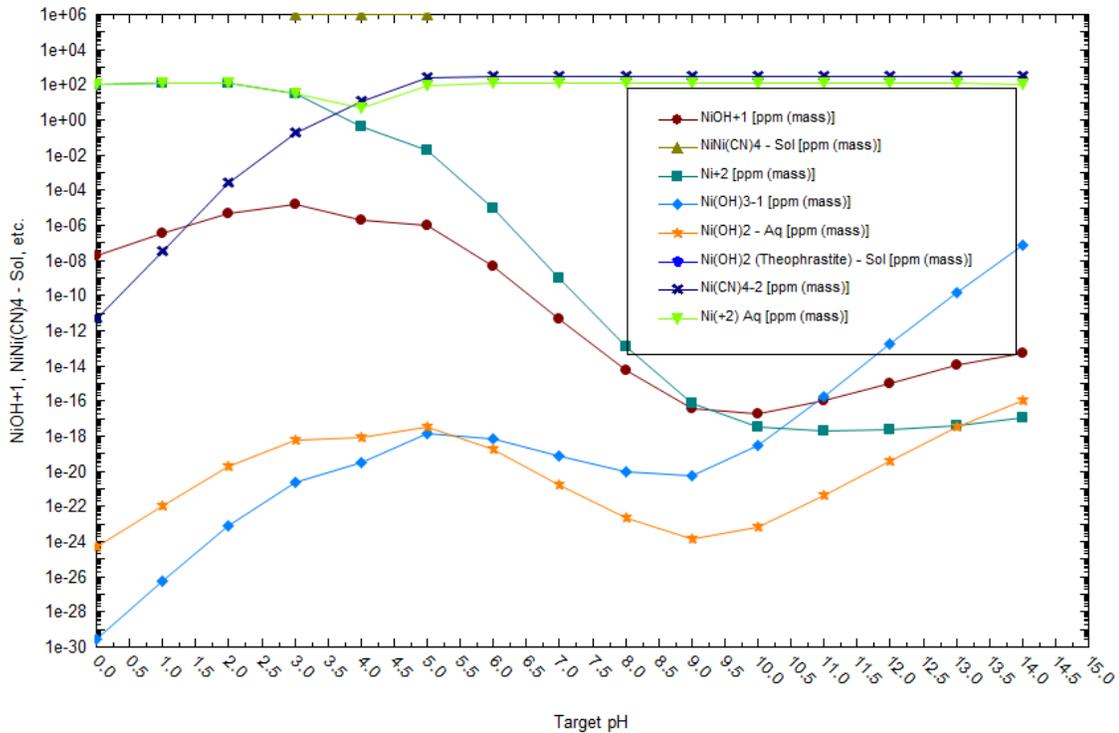
13. **Click OK**



Let's analyze the results.

The culprit is the $\text{Ni}(\text{CN})_4^{2-}$ complex of nickel and cyanide. Basically, the plot of the total Ni in solution and the $\text{Ni}(\text{CN})_4^{2-}$ complex overlap over the interval pH=5 to 12. This means that virtually all nickel in solution is in the form of this complex.

This complex thus holds the Ni in solution and does not allow the nickel hydroxide to even form. Instead, a much weaker precipitate, the $\text{NiNi}(\text{CN})_4$ salt forms over a narrow range of pH with 4.0 being the optimum.



Scenario 3: Wastewater with Sulfide Salts

We can now try to influence nature by introducing a source of sulfide. We do this because nearly all metal sulfide salts are highly insoluble.

Create a new single point calculation and a survey as you did in the previous two scenarios.

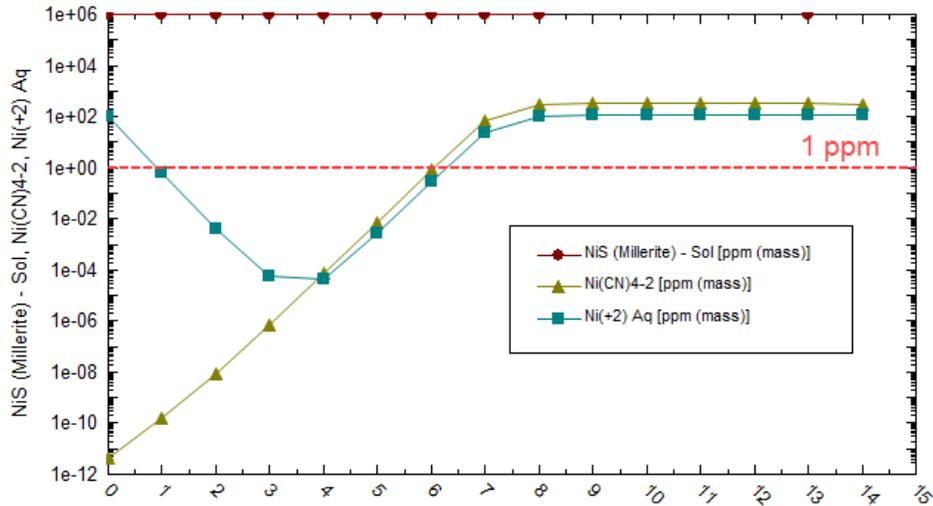
Add **490 ppm** of **NaCN**

Add **340 ppm** of **H2S**

For the survey case, use the plot template manager to start off with the MBG– Aqueous (Ni+2) and then add the following variables:

1. **Aqueous** Species: $\text{Ni}(\text{CN})_4^{2-}$
2. **Aqueous** Species: Ni^{+2}

3. Solid Species: NiS-Solid



The results reflect a "power struggle" between the $\text{Ni}(\text{CN})_4^{2-}$ which is holding the nickel in solution and the NiS solid which clearly has a greater tendency to form than the $\text{Ni}(\text{CN})_4$ solid. As a result, our optimum pH is still around 4.0 and we are now around 10^{-5} ppm total nickel in solution which is a bit below 1 ppm.

This would be a good time to **save** your work. You may use the **File/Save As...** menu item or use the **Save icon** on the toolbar.

Final Thoughts...

Aqueous speciation modeling can teach us a great deal about complex chemical systems and the interactions of individual species.

The actual removal achieved with sulfide may not be quite enough to satisfy the regulations. This is useful information to have. In addition, with the power of Stream Analyzer, one could now explore alternative treatment methods such as ion exchange.

Although such a simulation is beyond the scope of this demonstration, consider how vital it is to know that the dominant species to be exchanged (removed from solution) is an anion $\text{Ni}(\text{CN})_4^{2-}$ and not the cation (Ni^{+2}) as the conventional wisdom might dictate.

Click here for a completed OLI Analyzer file for this tour: [Chapter 03 Tour](#)

2.1.1. Temperature Survey

The default single survey calculation is the Survey by **Temperature**. The software computes solution properties based on a known composition and pressure at different temperatures.

Example 18: Studying a Four-phase mixture and its Partitioning

The purpose of this first example is to present the basic Temperature survey. You will study how a four-phase mixture partitions as a function of temperature. The system composition will be basic, containing one primary phase component, H₂O (liquid), CH₄ (gas), Decane (organic), and NaCl (solid). Each component will partition each of the other three phases.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Temperature Survey Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Calculated
Stream Name	Temperature Survey	Temperature Range	25-100 °C
Survey Name	4-Phase Partitioning	Step Size	Increment by 5 °C
Name Style	Display Formula	Pressure	1 atm
Unit Set	Metric, Moles	H2O	50 moles
Framework	MSE-SRK	CH4	10 moles
		C10H22	10 moles
		NaCl	10 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Temperature Survey*
3. Select the **MSE-SRK** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition of the stream given in the table above
7. Go to the **Add Calculation** button and select **Survey** calculation
8. Select **Temperature** as Type of Survey - Default
9. Change the **Survey** name to **4-Phase Partitioning** using the **<F2>** key

10. Click on the **Specs** button. This will open the **Survey Options Window**

Variable	Value
Stream Parameters	
Stream Amount (mol)	80.0000
Temperature (°C)	
Pressure (atm)	1.00000
Inflows (mol)	
H2O	50.0000
CH4	10.0000
C10H22	10.0000
NaCl	10.0000

Survey by: Temperature **Specs...**

Then by (optional): None **Specs...**

Vary: Independently Together

Calculate

11. The Temperature Range is entered in the **End Point** section. The default values for the Temperature Range are 25°C (Start) to 100°C (End). Leave the default values.

12. The **Step Size** can be given as **Increments** or **Number of Steps**. By default, in the Temperature Survey the **Step Size** by 5 increments is selected. Leave the default values. Then click **OK**.

Survey Options

Category: Var. 1 - Temperature
Calculation Type
Calculation Options

Survey Range

Temperature Range Unit: °C

Selected Range: 25.0 to 100.0 in 15 steps of 5.0

Linear Log Point List

End Points

Start: 25.0000
End: 100.0000

Step Size

Increment: 5.00000 } Select one, the other is calculated
Number Steps: 15

These are the default values

OK Cancel Apply Help

13. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

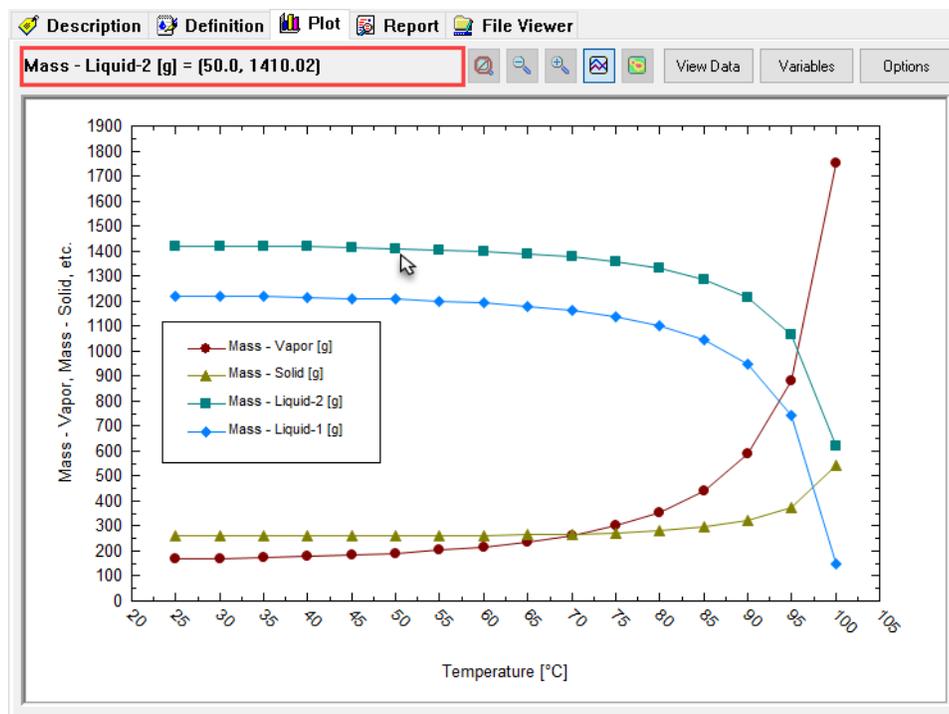
14. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( **Plot**).

The default plot is the phase amounts in grams of Liquid-1 (Aqueous Phase), Liquid-2 (Organic Phase), Solid and Vapor.

The plot below, shows that as temperature increases, the mass of Liquid-1 and Liquid-2 (organic) decreases, as they evaporate, and hence the Vapor phase increases. The solid phase mass remains constant up to 80°C, and then increases at higher temperatures.



Note: When the mouse-pointer is positioned over a point on one of the curves, the message box at the top of the plot indicates the variable and the coordinates of that point.

2.1.2. Pressure Survey

In the Survey by **Pressure**, the software computes solution properties based on a known composition and temperature at different pressures.

Example 19: Dissolution of CO₂ in water as a Function of Pressure

Many thermodynamic properties are less dependent on pressure than they are on temperature. Vapor-Liquid-Equilibrium (VLE) is affected by pressure.

In this example, the dissolution of CO₂ in water (which is a direct reflect of VLE) will be studied as a function of pressure.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Pressure Survey Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Calculated
Stream Name	Pressure Survey	Pressure Range	5-100 atm
Survey Name	CO2 dissolved in water	Step Size	Increment by 5 atm
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Moles	H2O	55.5082 moles
Framework	MSE-SRK	CO2	10 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Pressure Survey*
3. Select the **MSE-SRK** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition of the stream given in the table above
7. Go to the **Add Calculation** button and select **Survey** calculation
8. Select **Pressure** as Type of Survey
9. Change the **Survey** name to **CO₂ dissolved in water** using the **<F2>** key
10. Click on the **Specs** button. This will open the **Survey Options Window**

Variable	Value
Stream Parameters	
Stream Amount (mol)	65.5082
Temperature (°C)	25.0000
Pressure (atm)	
Inflows (mol)	
H2O	55.5082
CO2	10.0000

Survey by: Pressure [Specs...]

Then by (optional): None [Specs...]

Vary: Independently Together

- The default pressure range is from 1-10 atm with an increment of 1 atm. Change the **Pressure Range** to 5-100 atm. Set the **Step Size** to **5 atm** increments. Then click **OK**.
- We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

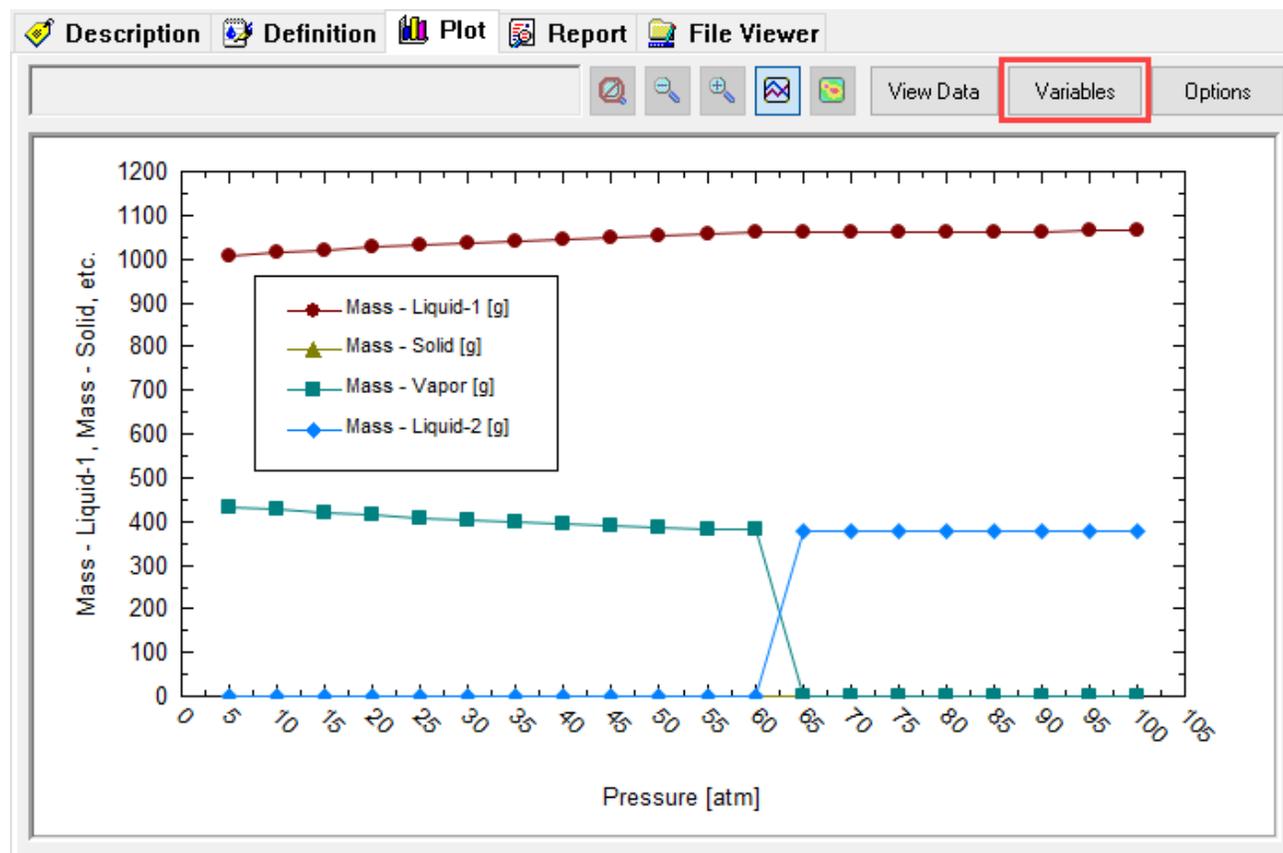
Analyzing the Results

Click on the **Plot** tab ( **Plot**). The default plot is the phase amounts in grams of Liquid-1 (Aqueous Phase), Liquid-2 (Organic Phase), Solid and Vapor.

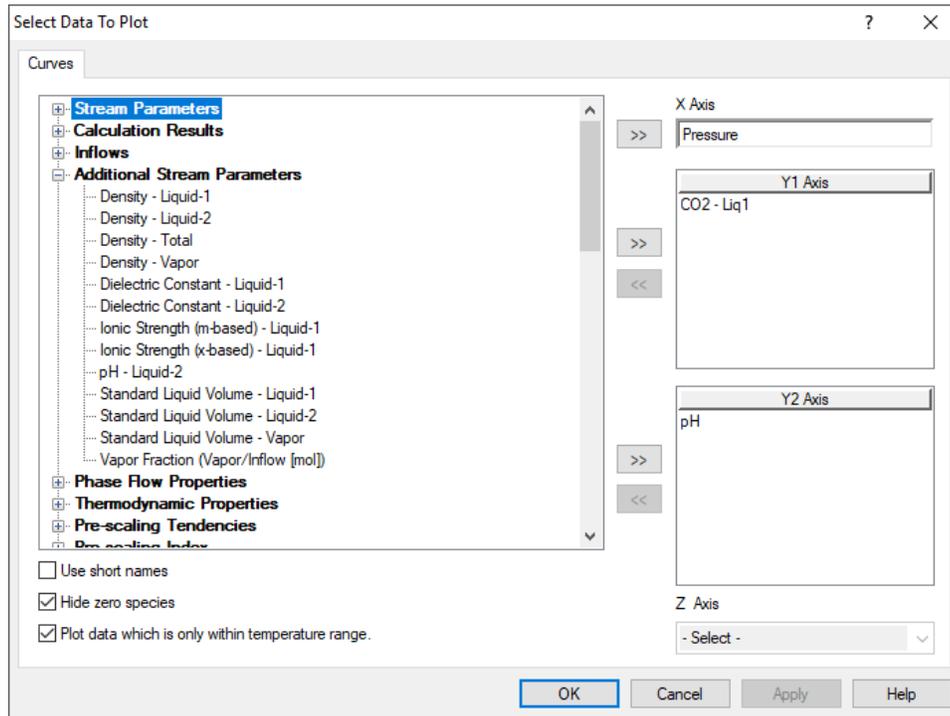
You can see that the Liquid-1 phase increases up to around 60 atm, and then it follows a constant trend as the pressure continues to increase. Regarding the Vapor phase, you can see that it shows a sudden decrease in mass from around 400 g at 60 atm to 0 g at 65 atm. The pressure of the system has increased in such a way that causes a phase change from vapor phase to Liquid-2 phase.

We are interested in the solubility of CO₂ in water, i.e. in the Liquid-1 phase. We can change the default plot to show the molecular CO₂ dissolved in water (CO₂-Liq1).

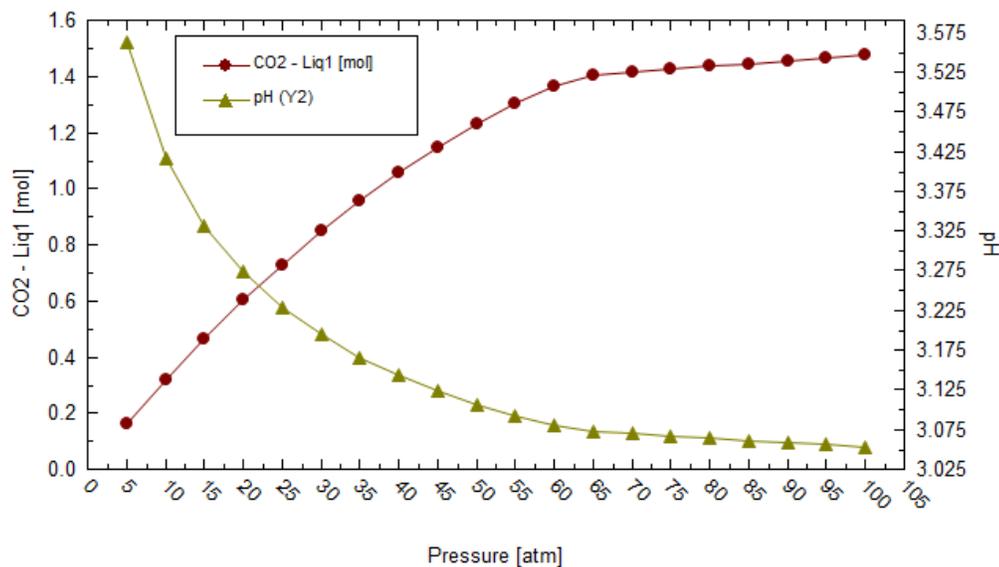
- Click on the **Variables** button. This will open the **Select Data to Plot** window.



2. **Double click** or use the << button to remove the **Phase Amount** variables.
3. Look for **Liquid-1** and click on the \oplus box to show all the available variables. **Select** CO2-Liq1 and put it in the Y1 Axis using the >> button.
4. Look for **Additional Stream Parameters** section and click on the \oplus box to show all the available variables. Select **pH** and put it in the Y2 Axis using the >> button. Then click **OK**.

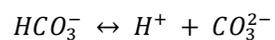
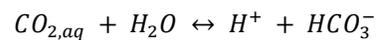
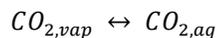


The default plot now is showing the selected variables: The dissolved CO₂ in the water (Liquid-1 Phase) in the Y1 Axis, and the pH in the Y2 Axis. Both variables are presented as function of pressure.



The dissolved CO₂ in solution increases as the pressure increases. When the pressure goes above 65 atm, the dissolved CO₂ remains nearly constant.

A similar behavior is seen in the pH. As the pressure increases, a decrease in pH is observed. This is attributed to the following equilibria dissociation reactions:



Thus, as the amount of CO₂ in the aqueous phase increases, the dissociation reactions create more hydrogen ions (H^+) available in solution, subsequently decreasing the pH. As the pressure reaches values above 65 atm, the pH value remains constant. Hence, the pH is a direct reflection of the dissolved CO₂ in solution.

2.1.3. Composition Survey

In the Survey by **Composition**, the software computes solution properties based on a given composition of species (or set of species) at a specific temperature and pressure.

Example 20: Dissolution of Calcite (CaCO₃) as a function of CO₂

Calcite is a scale that forms very easily in the production of oil. It has been found that the addition of CO₂ promotes the dissolution of Calcite scale. In this example, you are going to evaluate the effect of different CO₂ concentrations on the dissolution of Calcite.

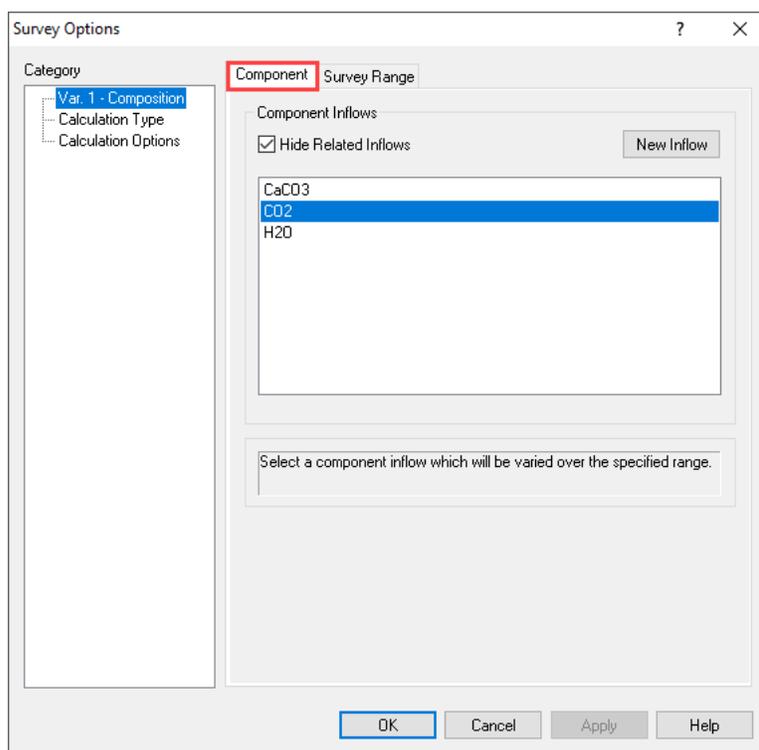
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

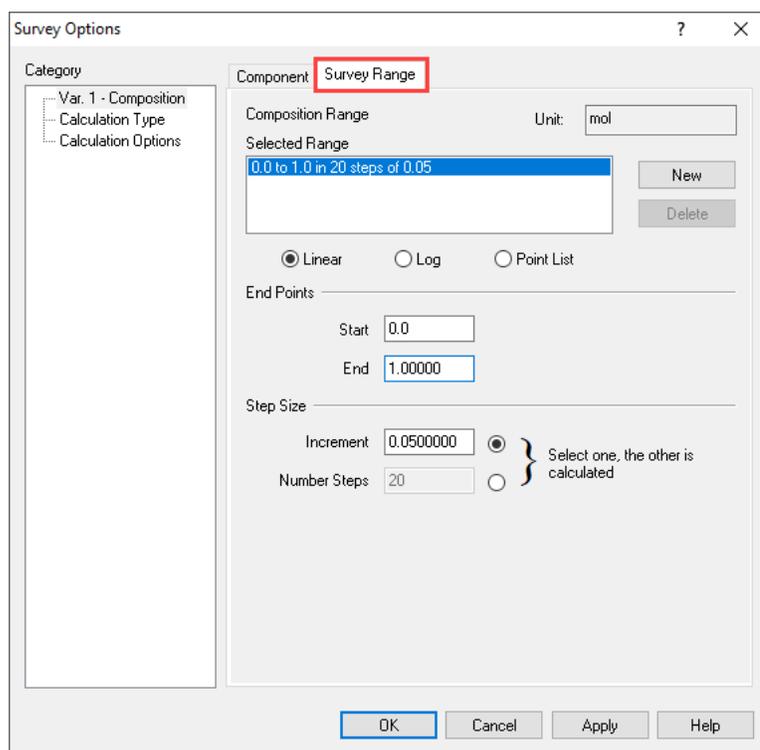
Composition Survey Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Calculated
Stream Name	Composition Survey	Temperature	25 °C
Survey Name	Calcite Dissolution	Pressure	75 atm
Name Style	Display Formula	H2O	55.5082 moles
Unit Set	Metric, Moles	CaCO3	0.05 moles
Framework	MSE	CO2 concentration range	0 - 1 moles
		Step Size	Increment by 0.05 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Composition Survey*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition of the stream given in the table above
7. Go to the **Add Calculation** button and select **Survey** calculation
8. Select **Composition** as Type of Survey.
9. Change the **Survey** name to **Calcite Dissolution** using the **<F2>** key
Note: In the summary box a message in red appears: **'Component not selected for composition survey variable'**. This means that we need to select the component that we want to vary. In this example CO₂.
10. To specify the component, click on the **Specs** button. This will open the **Survey Options Window**.

11. Under the **Component** tab, select CO2



12. Now, click on the **Survey Range** tab. Enter the CO2 composition range from 0 to 1 mol, by increments of 0.05 moles. Then click **OK**.



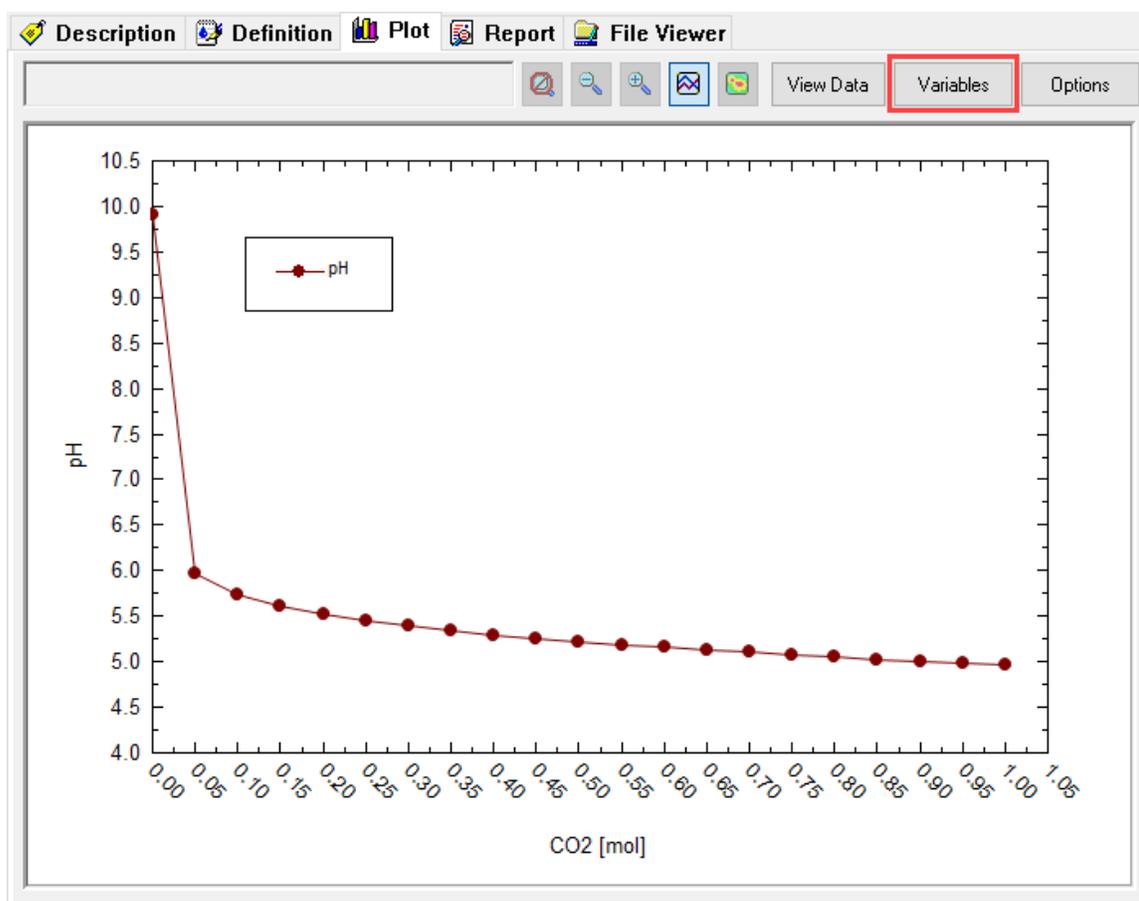
13. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
14. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( **Plot**). The default plot is the pH as a function of total CO₂ in moles. As the concentration of CO₂ increases, the pH decreases (as it was explained in the example [above](#)).

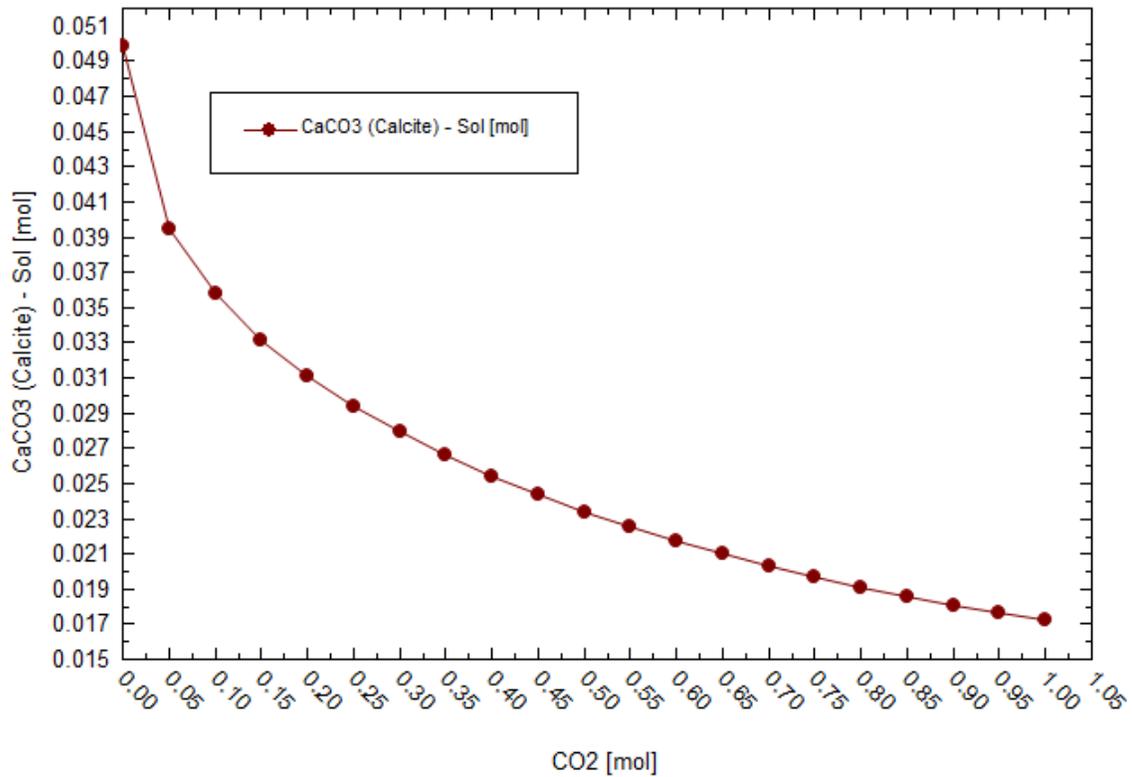
We are interested in understanding the dissolution of Calcite as a function of CO₂. To see these results, we need to study how the moles of solid calcite change as the concentration of CO₂ increases.

1. Click on the **Variables** button. This will open the **Select Data to Plot** window.



2. **Double click** or use the << button to remove the **pH** variable
3. Look for **Solid** section and click on the box to show all the available variables. **Select CaCO₃ (Calcite) – Sol** and put it in the Y1 Axis using the >> button. Click **OK**.

The default plot now is showing the selected variable: CaCO₃ (Calcite) – Sol as a function of CO₂.



As it was expected, the amount of CaCO₃ (Calcite) decreases with increasing CO₂. In an oil production setting, when there is a significant pressure drop, CO₂ will be lost. This will decrease the solubility of CaCO₃ and will increase the likelihood of scale formation.

2.1.4. pH Survey

In the Survey by **pH**, the software adjusts the flowrate of acid or basic titrants to at a predefined set of pH values and computes the solution properties of a solution based on a given composition of species (or set of species) at a specific temperature and pressure.

Example 21: A Speciation Diagram for the Carbonic Acid System as a Function of pH

In this survey calculation, a 1 molal CO₂ solution is titrated with HCl and NaOH. Instead of defining the amount of acid/base to add, the pH will be specified, and the software will compute the amounts of HCl and NaOH needed.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

pH Survey Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Calculated
Stream Name	pH Survey	Temperature	25 °C
Survey Name	Carbonic Acid System	Pressure	1 atm
Name Style	Display Formula	H2O	55.5082 moles
Unit Set	Metric, Moles	CO2	0.001 moles
Framework	AQ	pH range	4-12
		Step Size	Increment by 0.1

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *pH Survey*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. **Enter** the composition of the stream given in the table above
7. Go to the **Add Calculation** button and select **Survey** calculation
8. Select **pH** as Type of Survey
9. Change the **Survey** name to **Carbonic Acid System** using the **<F2>** key

The calculation can be run without modification. The default titrants are **HCl** and **NaOH**, and the default pH range is set from **0** to **14** with a step size of **1** increment. However, this pH range is too broad for the carbonate system, in which most of the speciation occurs between pH=4 and 12. Additionally, it is ideal to specify finer increments to see a smoother curve.

10. Click on the **Specs** button. This will open the **Survey Options Window**

11. In the **pH Titrants** tab, leave the default pH Titrants: **HCl** and **NaOH**

The screenshot shows the 'pH Titrants' tab of the 'Survey Options Window'. At the top, there is a text box with the instruction 'Select an acid and base to adjust to meet the specified pH.' Below this are two checkboxes: 'Use Single Titrant' (unchecked) and 'Hide Related Inflows' (checked), along with a 'New Inflow' button. The window is divided into two columns: 'Acid' and 'Base'. The 'Acid' column contains a list with 'CO2', 'H2O', and 'HCL' (highlighted in blue). The 'Base' column contains a list with 'CO2', 'H2O', and 'NAOH' (highlighted in blue).

12. Now, click on the **Survey Range** tab. Enter the pH range from 4 to 12, with increments of 0.1. Then click **OK**.

The screenshot shows the 'Survey Range' tab of the 'Survey Options Window'. It features a 'Target pH Range' label and a 'Unit' input field. Below is a 'Selected Range' list box containing '4.0 to 12.0 in 80 steps of 0.1', with 'New' and 'Delete' buttons to its right. Three radio buttons are present: 'Linear' (selected), 'Log', and 'Point List'. Under the 'End Points' section, there are input fields for 'Start' (4.00000) and 'End' (12.0000). Under the 'Step Size' section, there are input fields for 'Increment' (0.100000) and 'Number Steps' (80). A note indicates that either 'Increment' or 'Number Steps' can be selected, as the other is calculated.

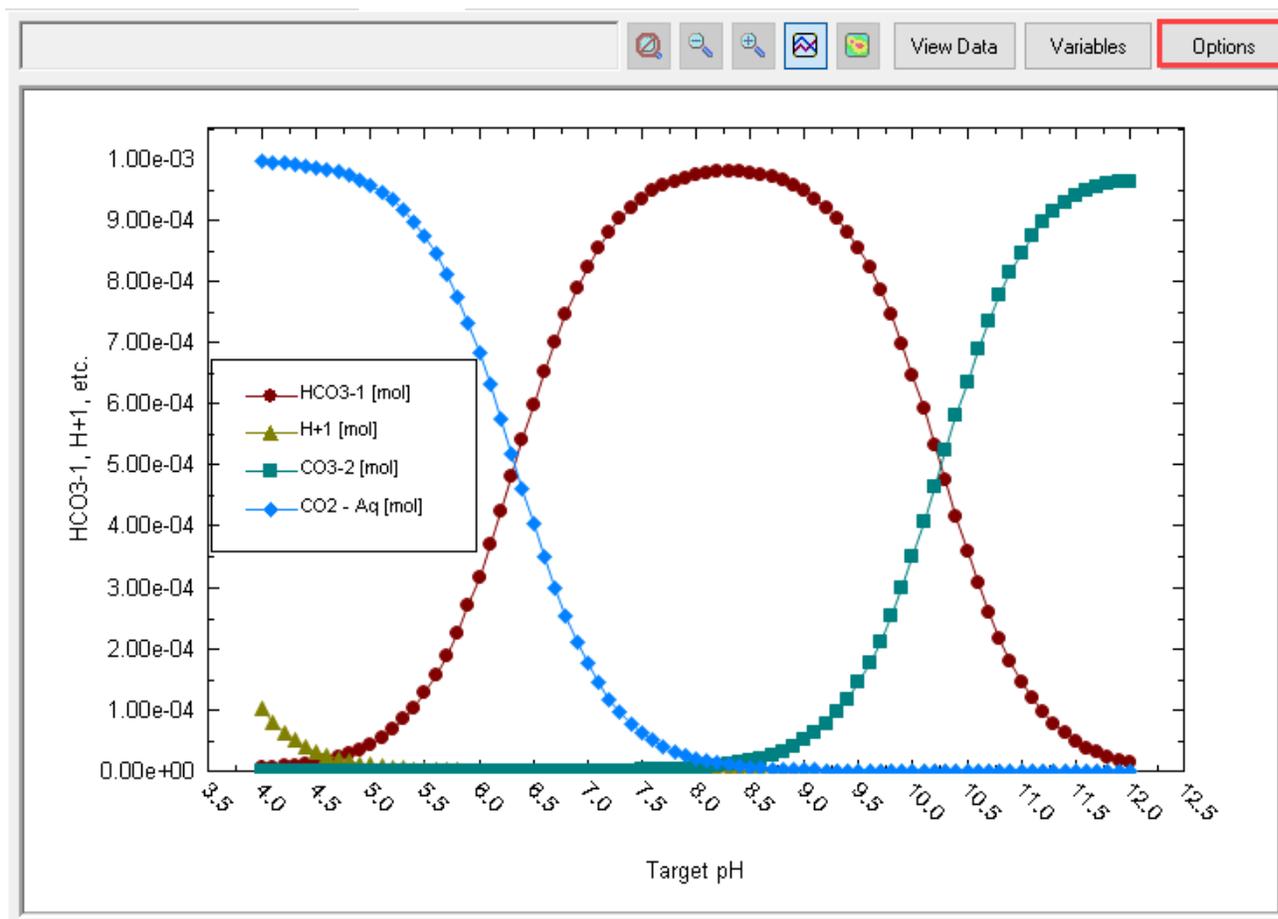
13. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

14. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

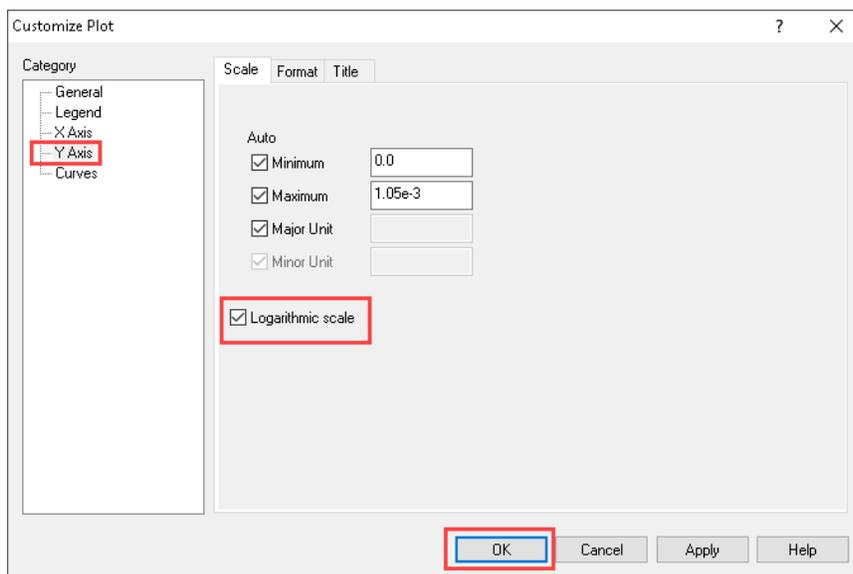
Click on the **Plot** tab ( Plot). The default plot is the moles of added HCl and NaOH vs Target pH. This is not the target variable and you will change it to display the carbonate-containing species.

1. Click on the **Variables** button
2. Remove the **NaOH** and **HCl** from the Y1 axis (double click or use the << button)
3. Look for **Aqueous** section and click on the  box to show all the available species. **Select** the following species: CO₂-Aq, HCO₃⁻¹, CO₃⁻², and H⁺ and put them in the Y1 Axis using the >> button or by double clicking. When you are done, click **OK**.



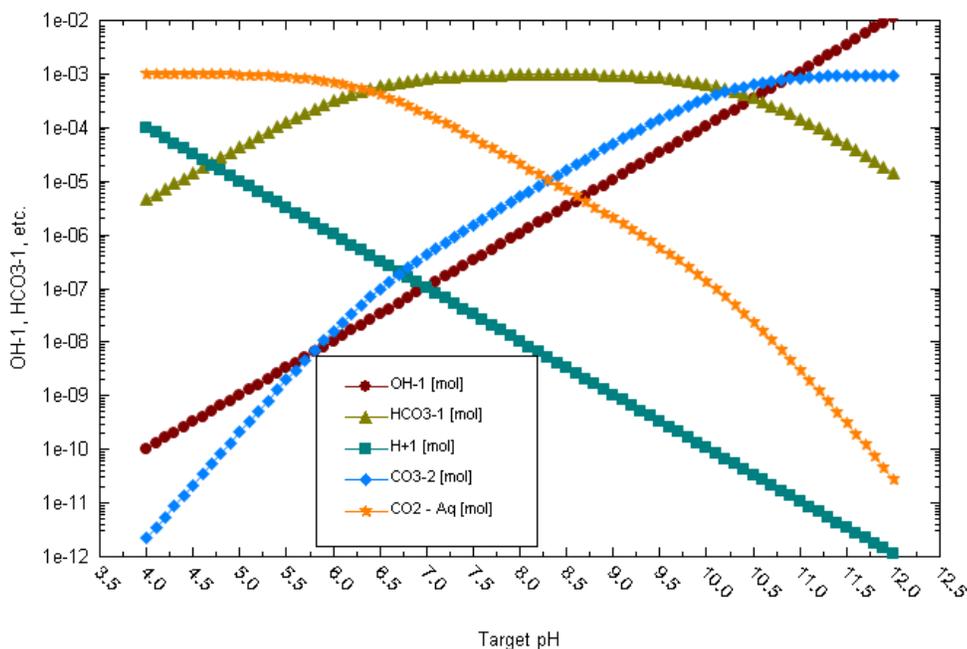
You can also present this plot on a semi-log scale.

4. Click on the **Options** button. This will bring the **Customize Plot** window
5. Select **Y Axis** in the Category window
6. **Check** the Logarithmic scale box, and then click **OK**.

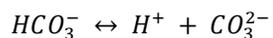
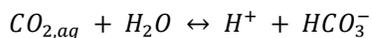


Before analyzing the plot, let's add the OH- species.

7. Click on the **Variables** button, look for OH-1 in the **Aqueous** section, add it to the Y1 Axis, and then click **OK**. Now we are ready to analyze the plot.



At lower pH, CO₂-Aq dominates the system, and notice how the HCO₃⁻ slope is 1 and the CO₃²⁻ slope is 2. Likewise, in the pH region where CO₃²⁻ dominates (high pH), the HCO₃⁻ slope is -1 and the CO₂-Aq slope is -2. These $\frac{\text{mole}}{\text{pH}}$ slopes are based on the number of H⁺ ions added or removed in the chemical reactions. See reactions below.



Note the pH where the CO₂-Aq and HCO₃⁻ lines intersect (pH~6.3), and where the HCO₃⁻ and CO₃²⁻ lines intersect (pH~10.3). These pH values are the same as the pK_a values (the equilibrium equations the specific equilibrium reactions).

As NaOH is added to convert HCO₃⁻ to CO₃²⁻, a portion of the NaOH remains as free base, OH⁻. This fraction increases at higher pH values, and its concentration is reflected in the calculated pH. A similar pattern is seen at pH below ~3 for HCl and H⁺.

2.1.5. Vapor Fraction / Vapor Amount Survey

The purpose of the **Vapor Fraction/Vapor Amount Survey** calculation is to set a specific fraction of the stream to the vapor phase, and compute the temperature or pressure required to achieve the specified Vapor Fraction/Vapor amount.

Example 22: Seawater Evaporation

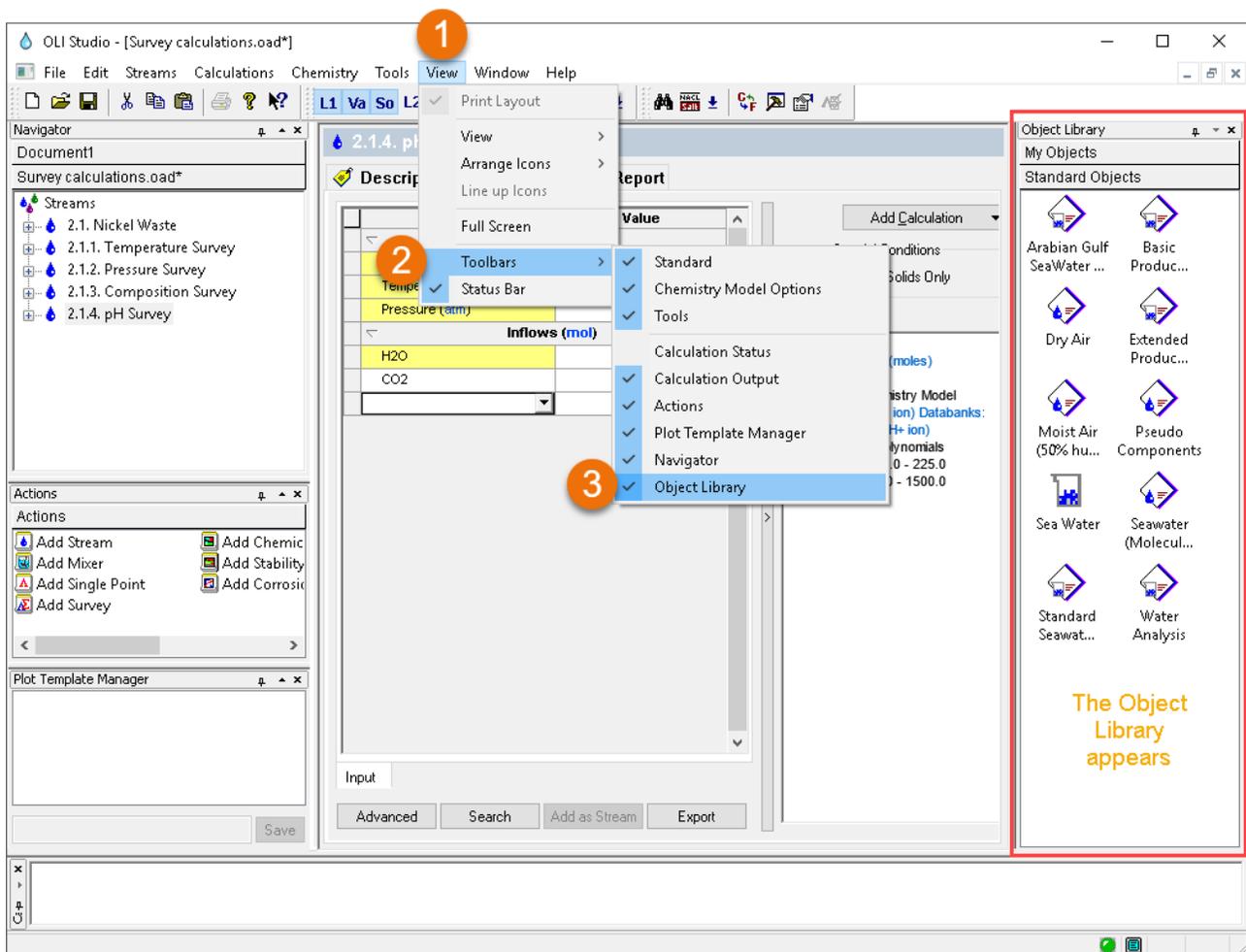
Seawater contains a variety of salts, and when seawater evaporates, these solids are left behind. The most abundant salt in seawater is sodium chloride (NaCl) which is also technically referred to as halite.

You will evaporate seawater to dryness and look at the solids that form. What is interesting is the number of phases that can be produced when seawater evaporates, giving you a sense of how certain natural systems build up sediment of a particular nature.

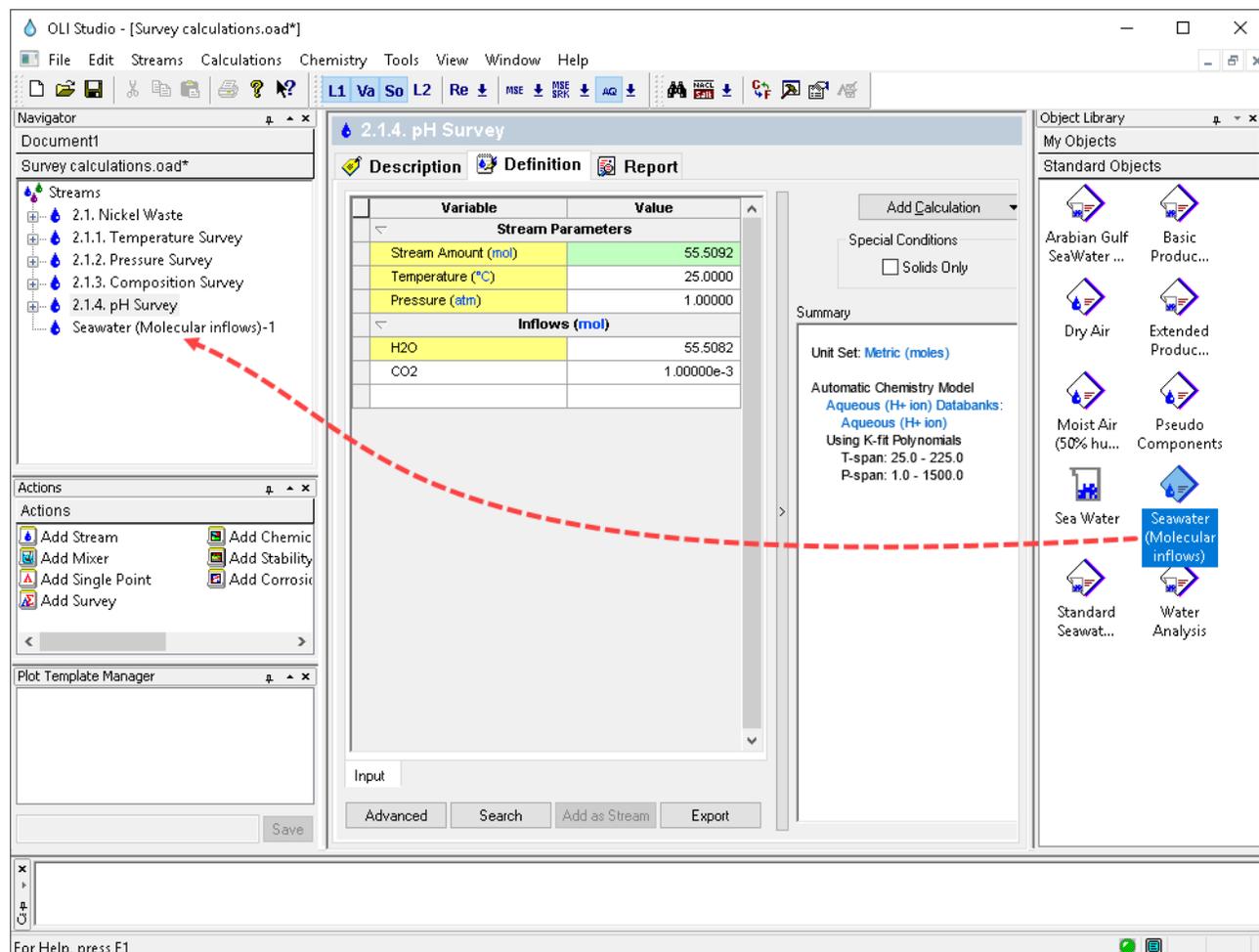
In this example we will also introduce the **Object Library** tool.

Starting the Simulation

1. Open the **Object Library** window – from the menu, View > Toolbar > Object Library. The Object Library appears in the right-hand side of the window.



2. Drag the **Seawater (Molecular inflows)** stream to the navigation panel (in the white-space below the other streams and calculation objects)

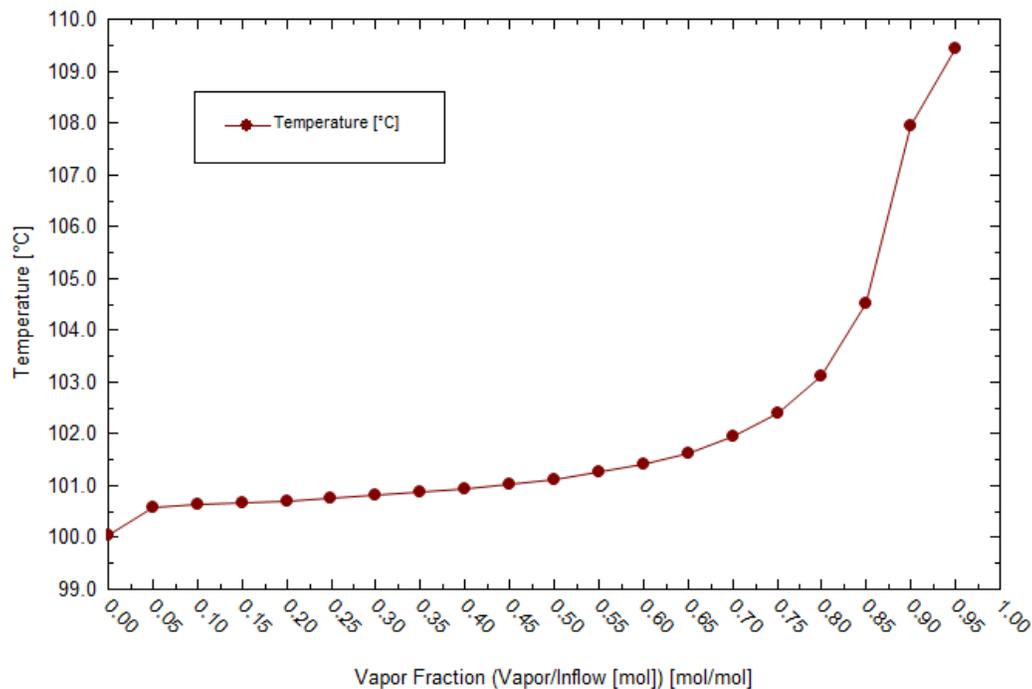


The inputs and parameters are automatically populated when selecting the Seawater (molecular inflows) from the Object Library.

3. **Click** on the new Stream and press **<F2>** to change the name to *Vapor Fraction Survey*
4. Go to the **Add Calculation** button and select **Survey** calculation
5. Select **Vapor Fraction** as Type of Survey
6. Change the **Survey** name to **Seawater Evaporation** using the **<F2>** key
7. Click on the **Specs** button. This will open the **Survey Options Window**
8. The default Vapor Fraction range is from 0-1 with an increment of 0.1. Change the **Vapor Fraction Range** to **Survey End** to 0.95. Set the **Step Size** to **0.05** increments. Then click **OK**.
9. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
10. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

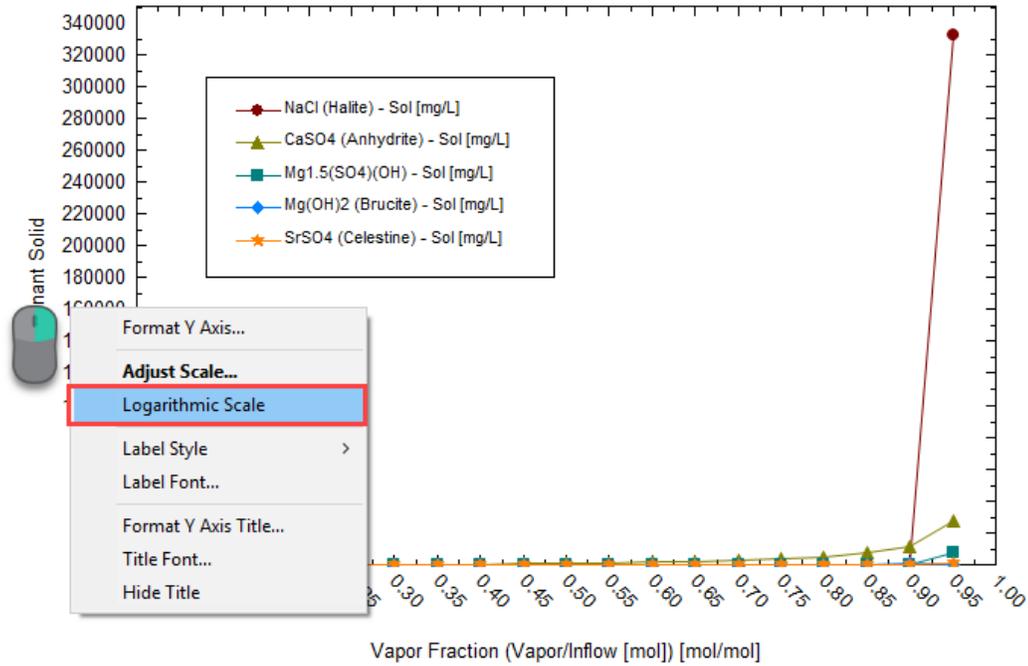
Click on the **Plot** tab ( **Plot**). The default plot is the Vapor Fraction plot (as the dependent variable) vs Temperature. It shows that seawater boils initially at 100°C, and at near complete evaporation (95%) the temperature is 109.4°C.



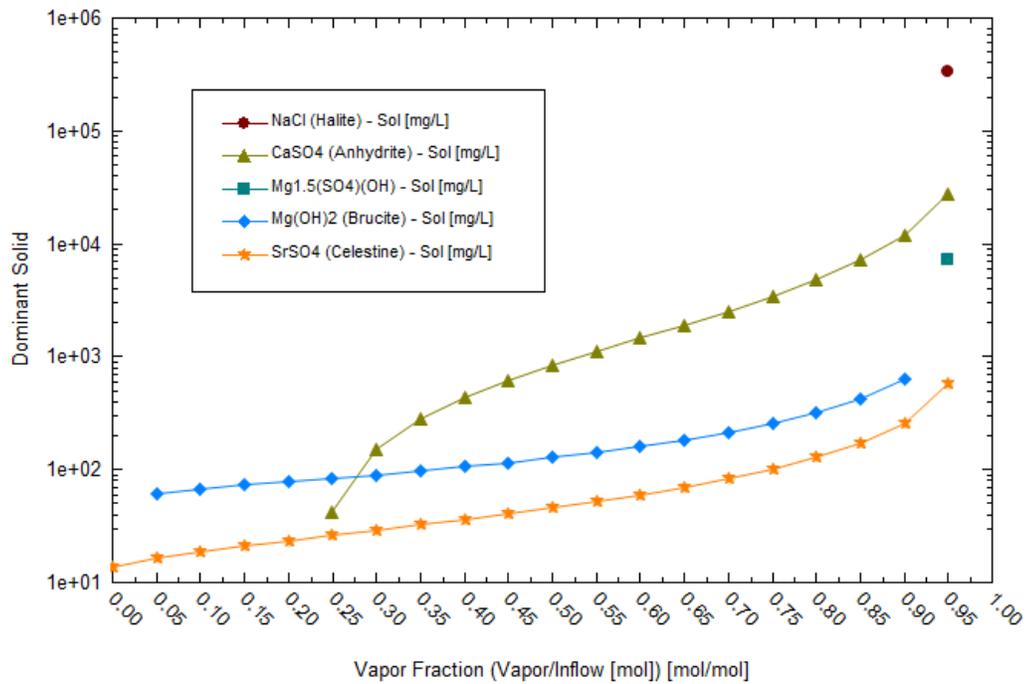
We are also interested to know which solid phases precipitate as the water evaporates.

1. Click on the **Variables** button
2. Remove **Temperature** from the Y1 axis (double click or use the << button)
3. Look for **Solid** section and click on the box to show all the available species. **Select** the option **Dominant Solids** and put it in the Y1 Axis using the >> button or by double clicking. When you are done, click **OK**.

4. The default plot is not very easy to read. To see the plot more clearly, **right click** on any number in the Y axis, and select the **Logarithmic Scale** option.



Plot in semilogarithmic scale



As the water evaporates CaSO_4 , $\text{Mg}(\text{OH})_2$ and SrSO_4 salts precipitate at all temperatures. NaCl and a Mg/SO_4 double salt start to precipitate at 95% vapor fraction.

2.2. Dual Surveys

Dual Surveys allow you to study the effect of two independent variables on your system under study.

The option for the dual survey is highlighted in red box highlighted in the image below. There are three options available, survey by Temperature, Pressure and Composition.

Additionally, you have the option of varying the selected variables independently or together. We will explore this in more detail in the upcoming examples.

The screenshot shows a software interface with a menu bar (Description, Definition, Plot, Report, File Viewer) and a main workspace. The workspace contains a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	
Pressure (atm)	
Inflows (mol)	
H2O	55.5082

Below the table is an 'Input' section with buttons for 'Advanced', 'Search', 'Add as Stream', and 'Export'. To the right is a control panel for survey settings, highlighted with a red box. It includes:

- 'Survey by' dropdown set to 'Temperature' with a 'Specs...' button.
- 'Then by (optional)' dropdown set to 'Pressure' with a 'Specs...' button.
- 'Vary' section with radio buttons for 'Independently' (selected) and 'Together'.
- 'Calculate' button with a green checkmark.

Below the control panel is a 'Summary' section with a scrollable area containing:

- Temperature survey:**
 - Range: 25.0 to 100.0 °C
 - Step size: 5.0 °C
 - No. steps: 15
- Pressure survey:**
 - Range: 1.0 to 10.0 atm
 - Step size: 1.0 atm
 - No. steps: 9
- Primary and secondary survey variables:**
 - move independently
 - Total points: 160
- Unit Set: [Metric \(moles\)](#)
- Automatic Chemistry Model: [Aqueous \(H+ ion\) Databanks:](#)

Temperature and Pressure Survey

In this type of survey two variables are adjusted simultaneously, temperature and pressure. This type of survey creates a matrix of results, which can then be interpreted using the plot function in different ways.

Example 23: Dissolution of CO₂ in water as a Function of Temperature and Pressure

In Example 19, the dissolution of CO₂ in water was studied only as a function of pressure. In this case, we are going to study the effect of both temperature and pressure on the CO₂ dissolution.

In this example the Contour Plot will be used to analyze the results.

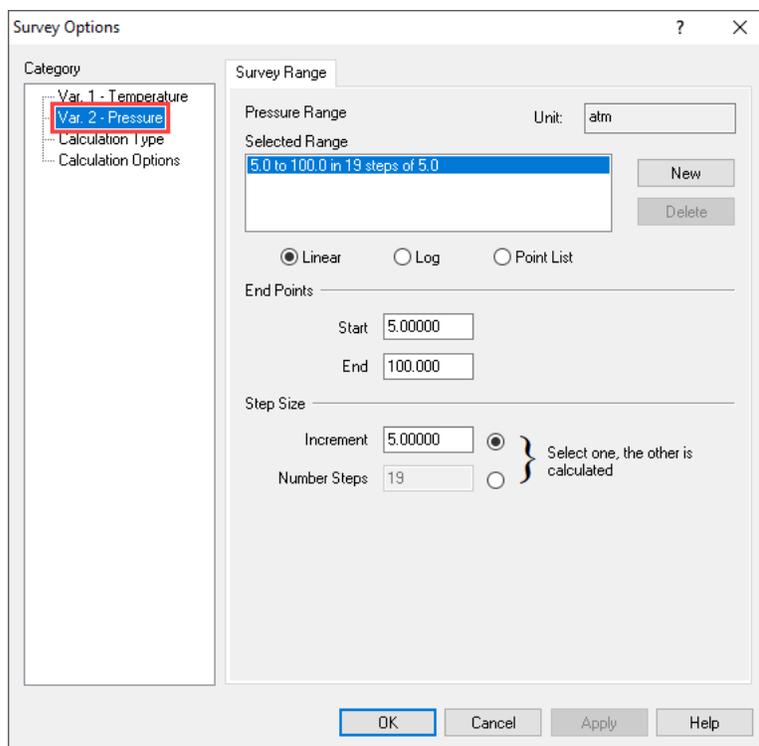
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

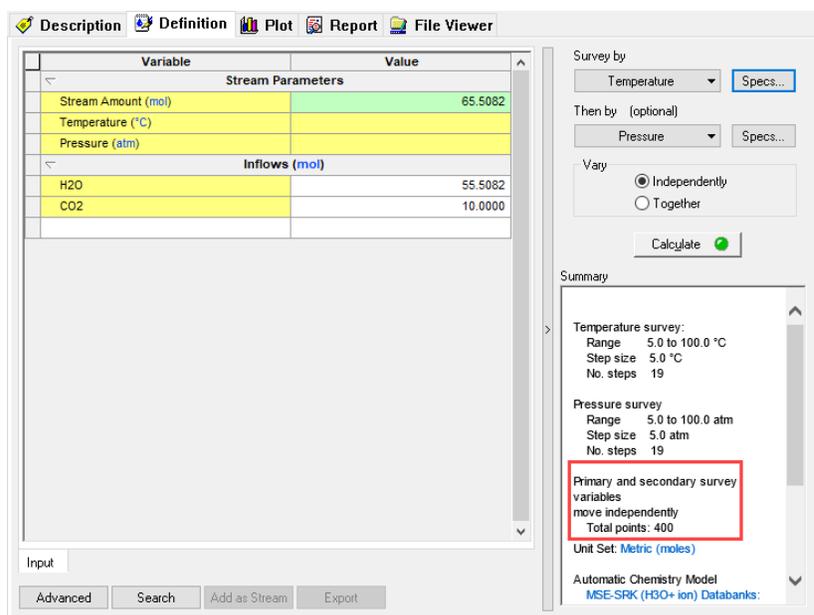
Temperature and Pressure Survey Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Calculated
Stream Name	T/P Survey	Pressure Range	5-100 atm
Survey Name	CO ₂ dissolution – T/P	Step Size	Increment by 5 atm
Name Style	Display Formula	Temperature Range	5-100 °C
Unit Set	Metric, Moles	Step Size	Increment by 5 °C
Framework	MSE-SRK	Vary	Independently
		H ₂ O	55.5082 moles
		CO ₂	10 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *T/P Survey*
3. Select the **MSE-SRK** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition of the stream given in the table above
7. Go to the **Add Calculation** button and select **Survey** calculation
8. Select **Temperature** and then by **Pressure**
9. Change the **Survey** name to **CO₂ dissolution T/P** using the **<F2>** key
10. Click on the **Temperature Specs** button. This will open the **Survey Options Window**

11. Change the **Temperature Range** to 5-100 °C. Set the **Step Size** to 5 °C increments.
12. Click on **Var. 2 – Pressure**, in the Category Window to define the Pressure Range.
13. Change the **Pressure Range** to 5-100 atm. Set the **Step Size** to 5 atm increments. Then click **OK**.



14. In the summary box, notice that a total of 400 points will be calculated. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key



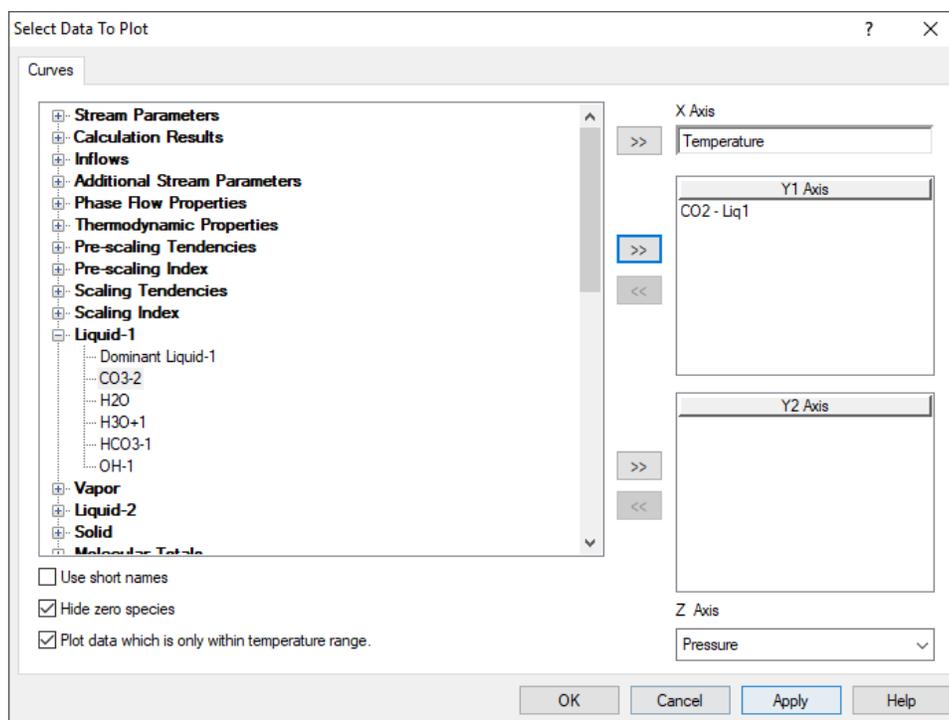
15. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( **Plot**). The default plot is the phase amounts in grams of Liquid-1 (Aqueous Phase), Liquid-2 (Organic Phase), Solid and Vapor.

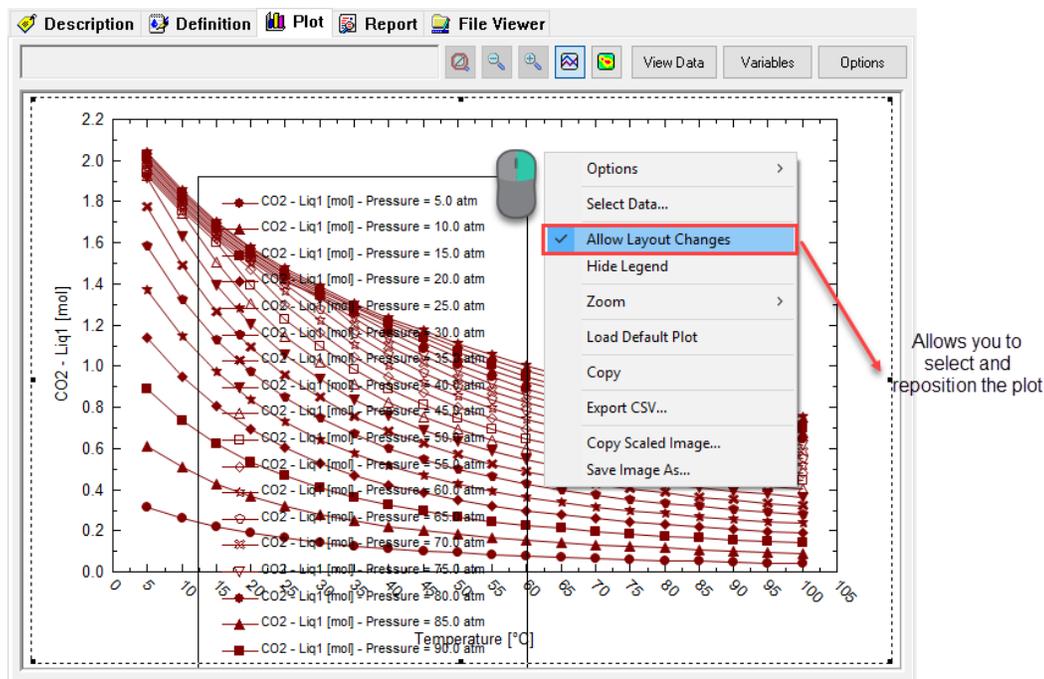
We are interested in the solubility of CO₂ in water, i.e. in the Liquid-1 phase. We can change the default plot to show the molecular CO₂ dissolved in water (CO₂-Liq1).

1. Click on the **Variables** button. This will open the **Select Data to Plot** window.
2. **Double click** or use the << button to remove the **Phase Amount** variables.
3. Look for **Liquid-1** and click on the  box to show all the available variables. **Select** CO₂-Liq1 and put it in the Y1 Axis using the >> button. Then click **OK**.

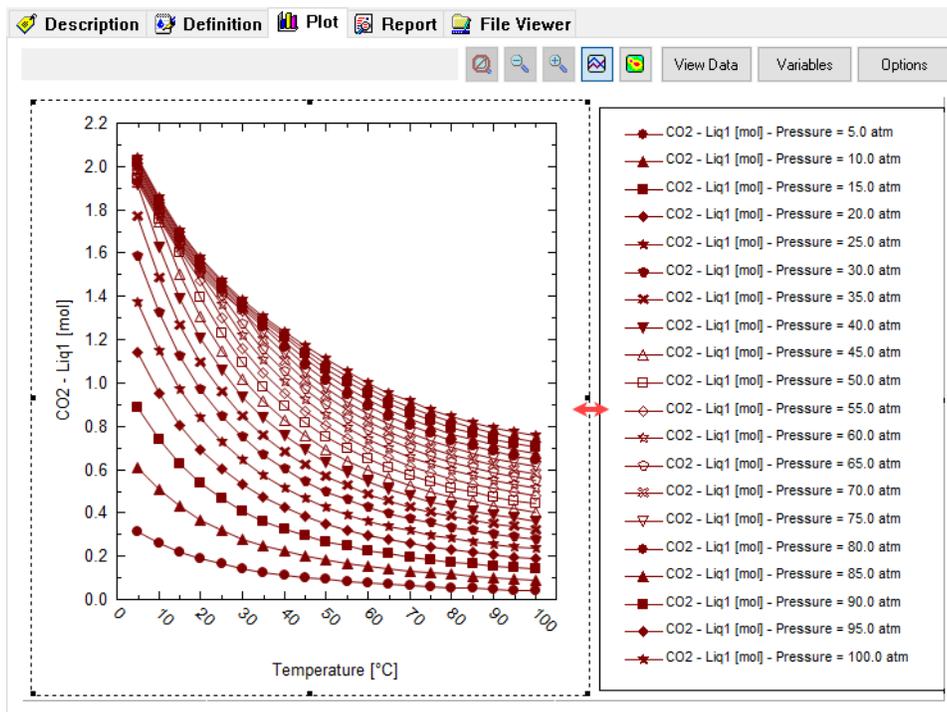


The default plot now is showing the dissolved CO₂ in the water (Liquid-1 Phase) in the Y1 Axis as function of pressure. Unfortunately, the legend is covering the plot.

4. To move the legend to the side without interfering with the results, right click on any white space within the plot and **Allow Layout Changes**. This option allows you to select and reposition the plot.



5. **Resize** the plot to make it smaller and create space for the legend. Drag the legend to the right.

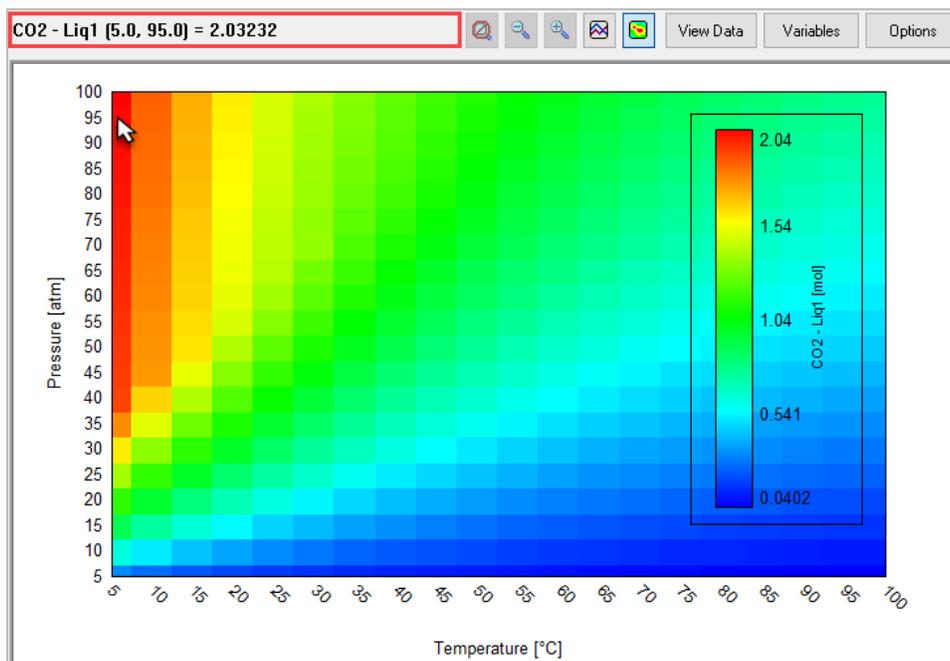


As the temperature increases (at a fixed pressure) the solubility of CO₂. This is to be expected since at higher temperatures it is easy to overcome the vapor pressure and CO₂ is released as gas. As the pressure increases (at a fixed temperature) the solubility of CO₂ in solution increases.

The plot above can be represented better using a **Contour Plot**. To convert the results into a contour plot view, simply click on the contour plot icon (📊).

The resulting plot is now a pixelated color plot showing the moles of molecular CO₂ dissolved in the Liquid-1 (Aqueous) phase, at each T and P value.

The number of moles of CO₂ is characterized by a different color that is shown in the legend (maximum value is given in red, and minimum value is given in blue). You can mouse over any location in the plot and the moles of CO₂ dissolved in the Liquid-1 phase at each T and P value will be shown in the left corner box.

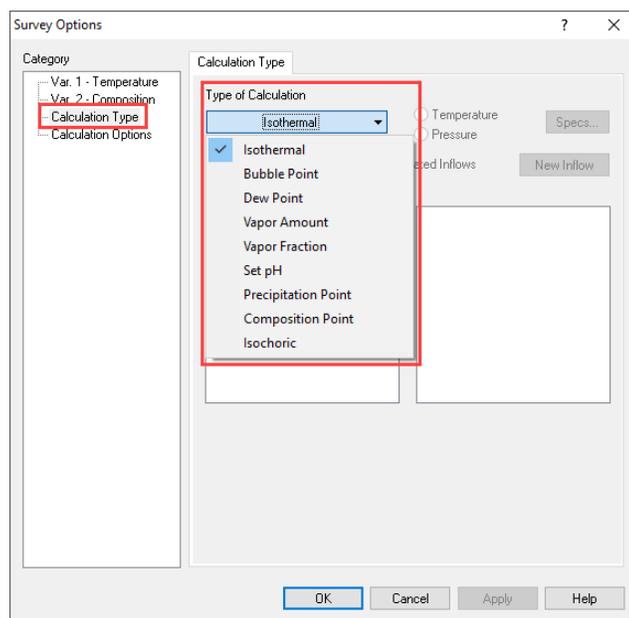


Note: The legend scale can also be optimized by either right-mouse-clicking on the Legend and selecting **Options>Plot Options>Contour** or clicking on the **Options** button in the upper right and selecting **Contour**. Both open to the Contour options window, where the color and range can be modified.

In the contour plot, you can see the effect of both Temperature (x-axis) and Pressure (y-axis) on the solubility of CO₂ in water. Higher solubilities are obtained at high pressures and low temperatures, while lower solubilities are obtained at high temperatures and low pressures.

Survey by changing the single point calculation type

Sections 2.1 and **Error! Reference source not found.** so far have presented single and dual surveys. In addition to adjusting these survey variables, you can select one of several single point calculations embedded within the survey. The embedded single point calculations include: Isothermal (default), bubble point, dew point, vapor amount, vapor fraction, set pH, precipitation point, composition point, and isochoric.



Temperature Survey with a Precipitation Point Calculation

In this **Temperature Survey**, the Calculation Type will be changed from Isothermal Calculation to **Precipitation Point**. This will allow us to model the solid solubility vs temperature.

Example 24: Solubility of Halite as a Function of Temperature

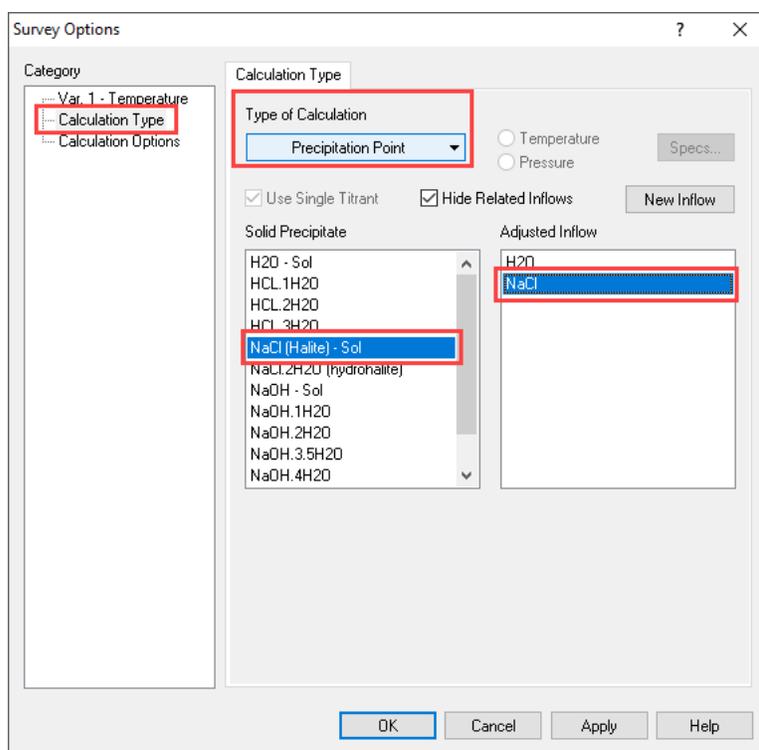
In this example, we are going to study the solubility of NaCl (halite) as a function of temperature.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Temperature Survey with a Precipitation Point Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Calculated
Stream Name	Solubility vs T	Pressure	1 atm
Survey Name	Halite Solubility vs T	Temperature Range	5-100 °C
Calculation Type	Precipitation Point	Step Size	Increment by 5 °C
Name Style	Display Formula	H2O	55.5082 moles
Unit Set	Metric, Moles	NaCl	0 moles
Framework	MSE		

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Halite Solubility vs T and P*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition of the stream given in the table above
7. Go to the **Add Calculation** button and select **Survey** calculation
8. Select **Temperature** as the type of survey
9. Change the **Survey** name to *Halite Solubility vs T* using the **<F2>** key
10. Click on the **Temperature Specs** button. This will open the **Survey Options Window**
11. Change the **Temperature Range** to 0-100 °C. Set the **Step Size** to 5 °C increments.
12. Click on **Calculation Type**, in the Category Window to define the Type of Calculation
13. Under Type of Calculation Change the Default Isothermal to **Precipitation Point** (use the drop-down arrow)
14. Select **NaCl (Halite)-Sol** as the **Solid Precipitate** and **NaCl** as the **Adjusted Inflow**. Then click **OK**.



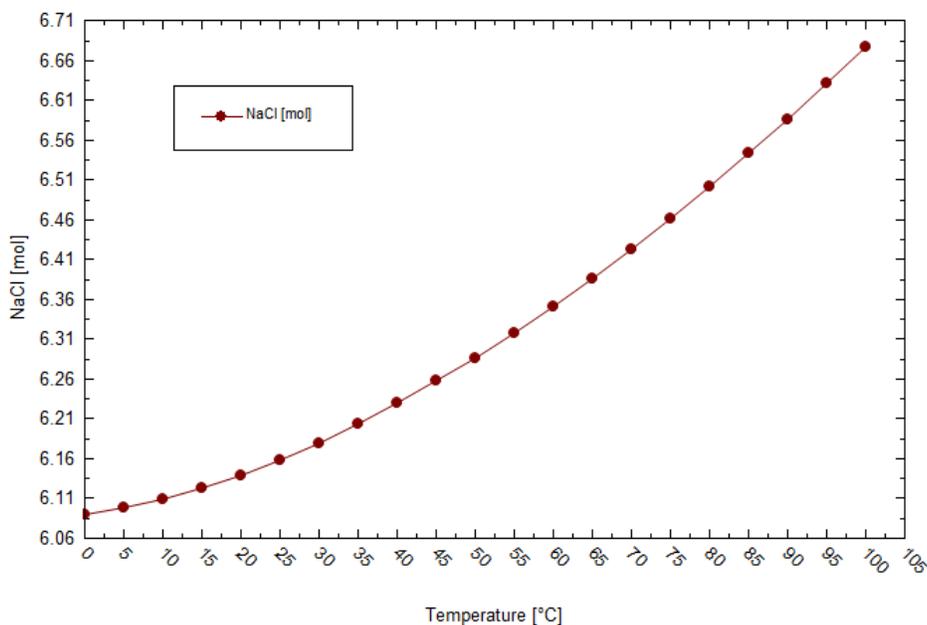
The **Calculation Parameters** section is now shown in the Definition Tab, highlighting the Precipitant (NaCl (Halite)) and the Adjusted Inflow (NaCl).

Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	
Pressure (atm)	1.00000
Calculation Parameters	
Precipitant:	NaCl (Halite)
Adjusted Inflow:	NaCl
Inflows (mol)	
H2O	55.5082
NaCl	0.0

- We are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( **Plot**). The default plot is the amount of NaCl in moles added to 1 kg of water before Halite precipitates as a function of Temperature.



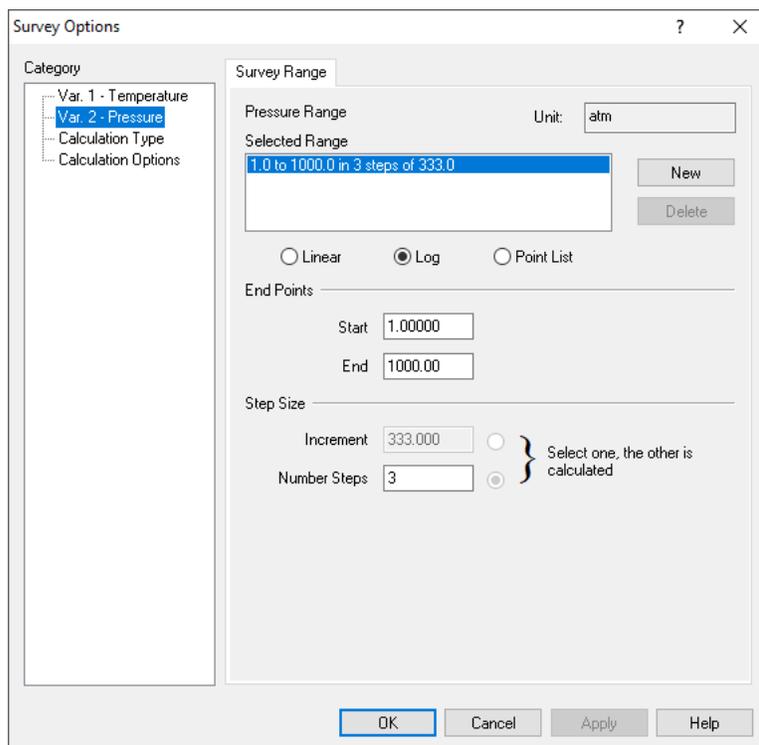
Halite solubility increases slightly with temperature, from 6.16 moles/1kg H₂O at 25°C to 6.68 moles/1kg H₂O at 100°C.

Example 25: Solubility of Halite as a Function of Temperature and Pressure

The effects of pressure on mineral solubility is generally less important than temperature. There is still an effect that can be observed. The same stream created on [Example 24](#) will be used.

Starting the Simulation

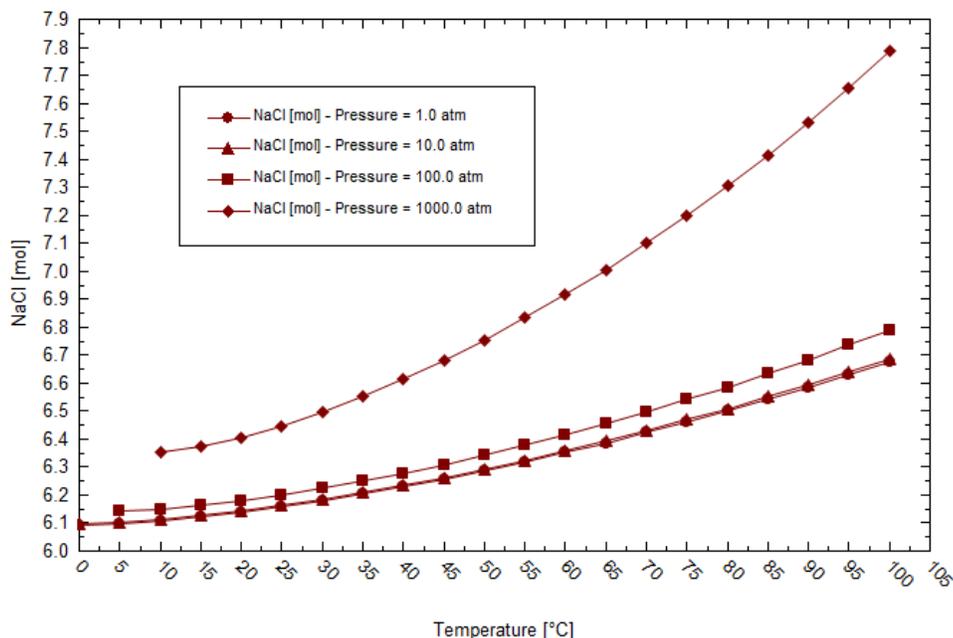
1. Under the **Solubility vs T** stream add a new Survey (see Stream information in Example 24)
2. Change the **Survey** name to **Halite Solubility vs T and P** using the <F2> key
3. Select Survey by **Temperature** and then by **Pressure** (This is a dual survey)
4. Click on the **Temperature Specs** button. This will open the **Survey Options Window**
5. Change the **Temperature Range** to 0-100 °C. Set the **Step Size** to 5 °C increments.
6. Click on **Var. 2 – Pressure**, in the Category Window to define the Pressure Range.
7. Change the Scale to **Log**, change the **Pressure Range** from 1 to 1000 atm, and set the **Number of Steps** to 3 (i.e. it will plot the following pressures: 1, 10, 100 and 1000 atm). Then click **OK**.



8. Click on **Calculation Type**, in the Category Window to define the Type of Calculation
9. Under Type of Calculation Change the Default Isothermal to **Precipitation Point** (use the drop-down arrow)
10. Select **NaCl (Halite)-Sol** as the **Solid Precipitate** and **NaCl** as the **Adjusted Inflow**. Then click **OK**.
11. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key.
12. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( **Plot**). The default plot is the amount of NaCl in moles added to 1 kg of water before Halite precipitates as a function of Temperature.



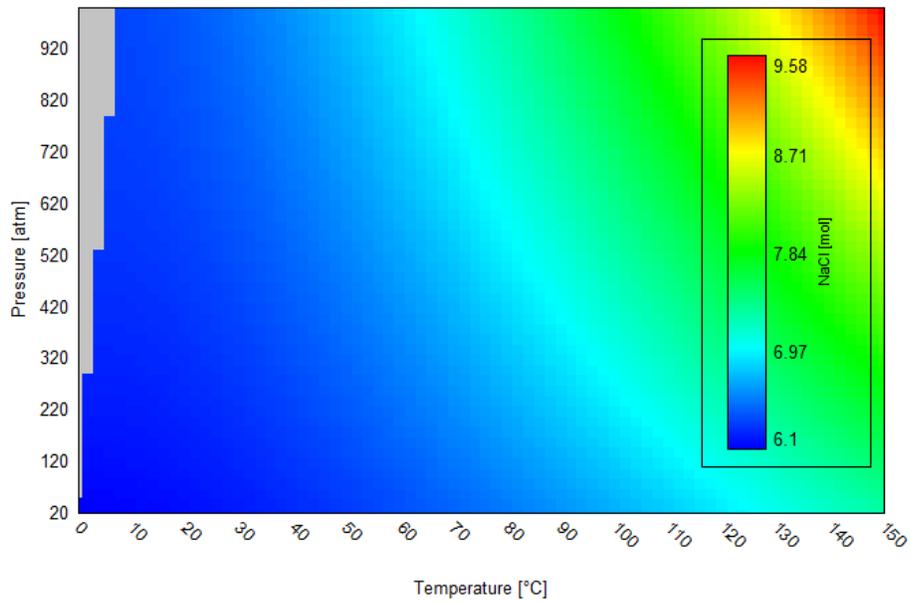
The effect of pressure is significant between 100 and 1000 atm relative to the effects between 1 and 100 atm.

We can also present the Halite Solubility using a Contour Diagram. It would be ideal to define a finer range of temperature and pressure.

1. Return to the **Definition Tab**
2. Click on the **Temperature Specs** button.
3. Change the **Temperature Range** to 0-150 °C. Set the **Step Size** to 2 °C increments.
4. Click on **Var. 2 – Pressure**, in the Category Window to define the Pressure Range.
5. Change the survey to **Linear** scale, change the **Pressure Range** from 20 to 1000 atm, and set the **Step Size** to **20 atm** increments. Then click **OK**.

Note: In the Summary box we can see that survey creates a matrix of 75 steps x 49 steps for a total of 76 temperature and 50 pressure points, or 3800 points in total.

6. Click the **Calculate** button. This calculation will take a few minutes to compute.
7. Click on the **Plot** tab and change the Plot to contour ().



The solubility is shown to increase as temperature and pressure increase. The increase is up to 50% from the low values. A few of the points failed to converge at the low temperature and high-pressure conditions (shown in gray).

Composition Survey with a Bubble and Dew Point Calculation

In this **Composition Survey**, the Calculation Type will be changed from Isothermal Calculation to **Bubble and Dew Point calculations**. This will allow us to model the vapor liquid equilibria (VLE) of mixtures.

Example 26: Ethanol-Water Azeotrope

In this example, you are going to calculate both the bubble point and dew points as a function of Ethanol-Water composition.

The two data sets will then be transferred to a spreadsheet where the curves will be plotted together to locate the azeotrope. You will need a spreadsheet/plotting software to complete this case.

Starting the Simulation

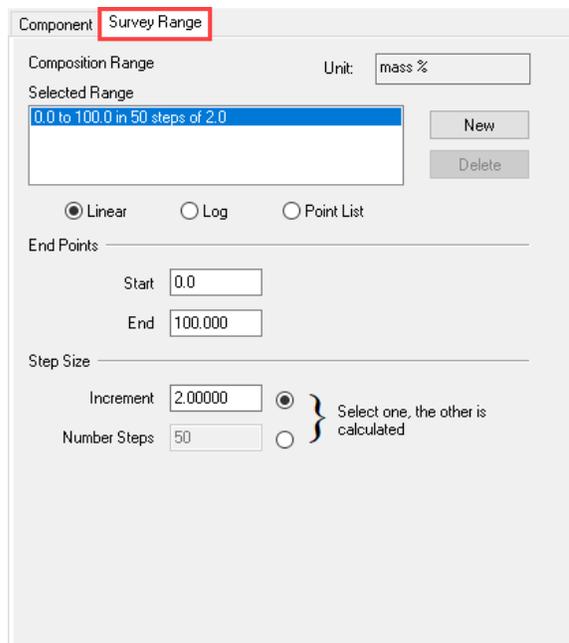
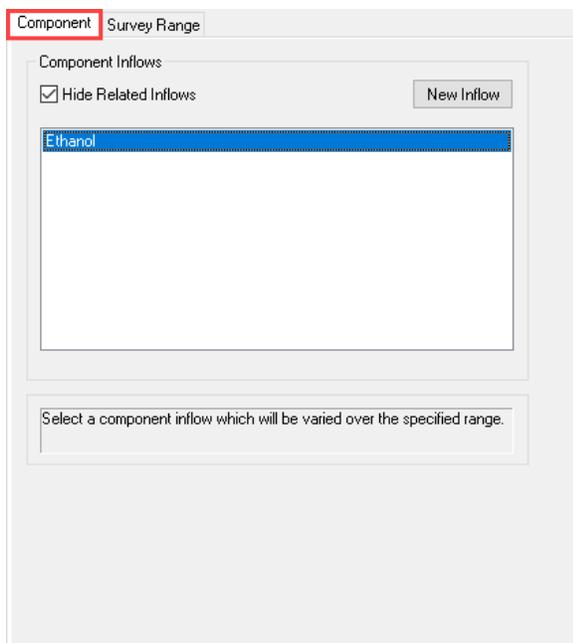
Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Composition Survey with a Bubble and Dew Point Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Default – 1kg
Stream Name	Composition survey - Azeotrope	Pressure	1 atm
Survey Name	Ethanol-Water Azeotrope	Temperature	It will be calculated
Calculation(s) Type	Bubble Point / Dew Point	H2O	100 mass % - default
Name Style	Display Name	Ethanol	0 mass%
Unit Set	Metric, Mass Frac.	Composition Range	0 -100 mass%
Framework	MSE	Step Size	Increment by 2 mass%

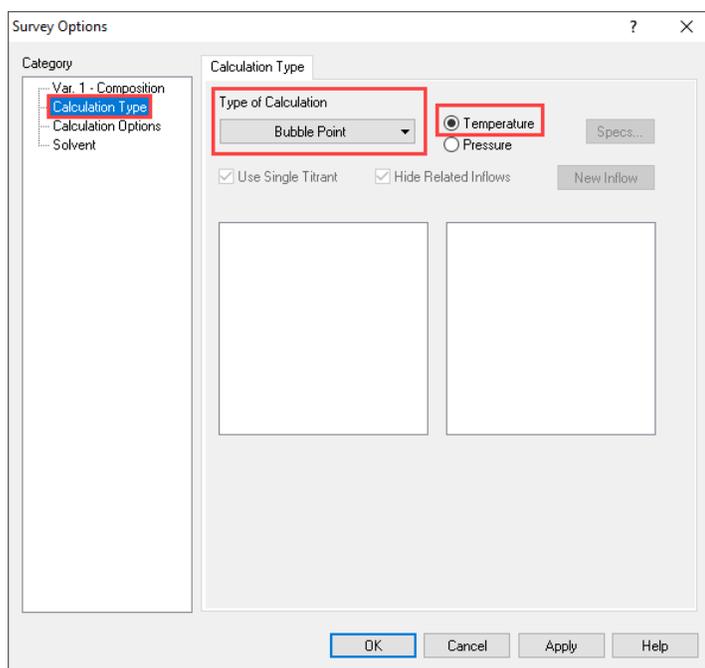
Calculating the Bubble Point

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Composition survey - Azeotrope*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Display Name** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Mass Frac.
6. Enter the composition of the stream given in the table above
7. Go to the **Add Calculation** button and select **Survey** calculation
8. Select **Composition** as the type of survey
9. Change the **Survey** name to *Ethanol-Water Azeotrope* using the **<F2>** key
10. Click on the **Composition Specs** button. This will open the **Survey Options Window**

- Under the **Component** tab, select **Ethanol**
- Click on the **Survey Range** tab. Change the **Composition Range** to 0-100 mass%. Set the **Step Size** to 2 mass% increments.



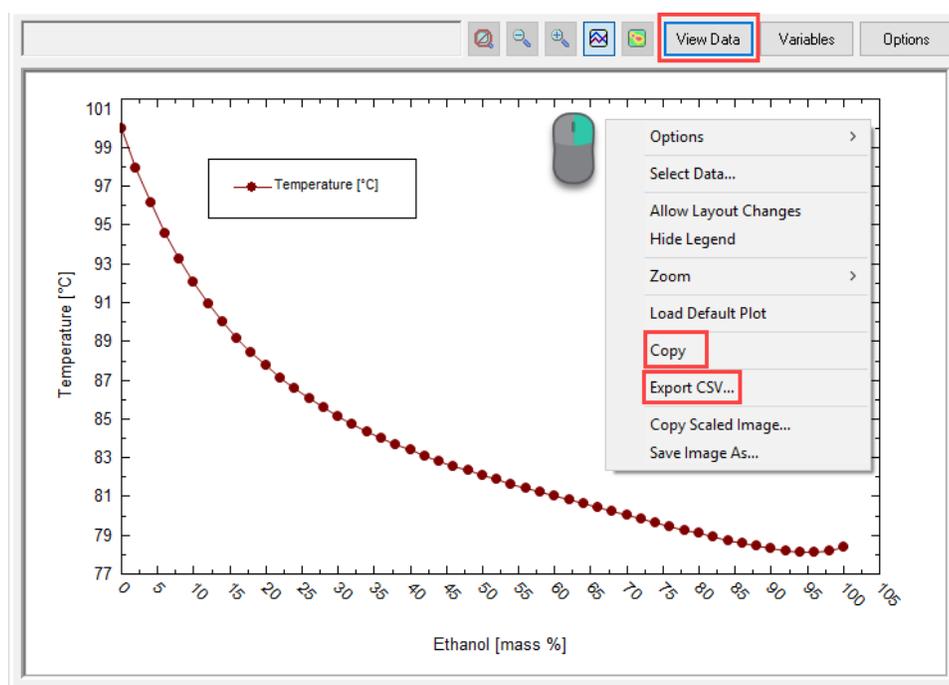
- Click on **Calculation Type**, in the Category Window to define the Type of Calculation
- Under Type of Calculation Change the Default Isothermal to **Bubble Point** (use the drop-down arrow). Then click **OK**.



15. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key.
16. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( **Plot**). The default plot is the bubble point temperature vs the mass fraction ethanol. As the mass% of ethanol increases the bubble point temperature decreases.



You have 3 different options to retrieve this data to use it in your preferred plotting software.

Option 1: **Right-click** on the white region of the plot to open the drop-down menu and select **Copy**.

Option 2: **Right-click** on the white region of the plot to open the drop-down menu and select **Export CSV**.

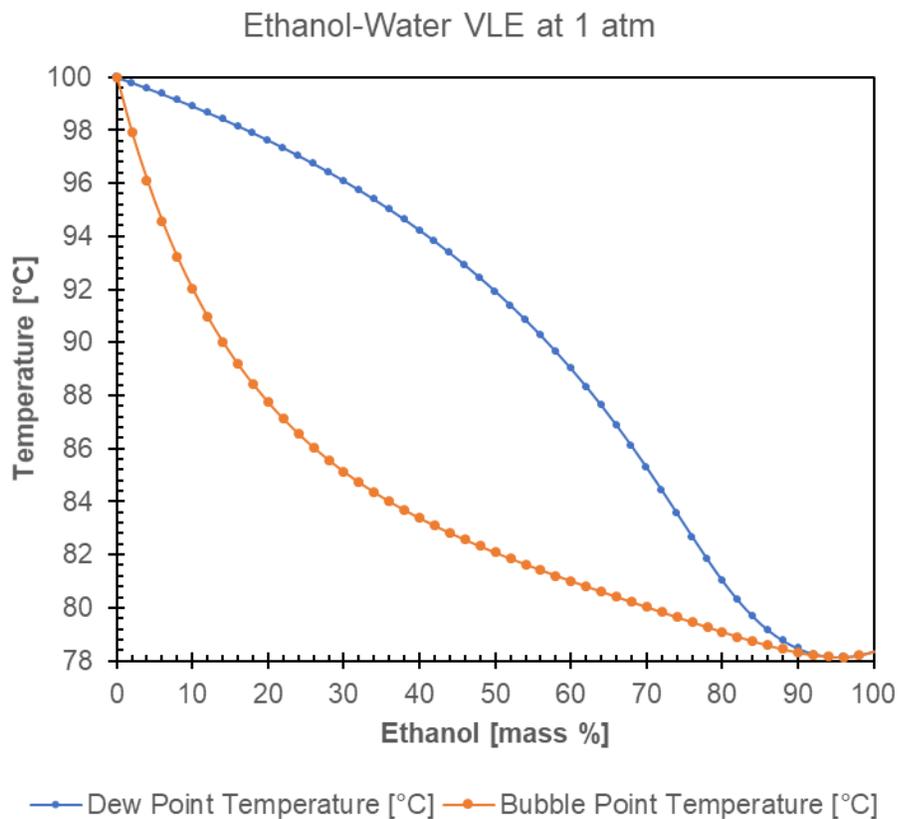
Option 3: **Click** on the **View Data** button, select all data by clicking on the upper left corner of the table, and copy the data using **Ctrl+C**.

	Ethanol	Temperature
	mass %	°C
1	0.0	99.9976
2	2.00000	97.9141
3	4.00000	96.1248
4	6.00000	94.5734
5	8.00000	93.2174
6	10.0000	92.0237
7	12.0000	90.9684
8	14.0000	90.0246
9	16.0000	89.1815

In this case let's use **Option 1**. Right click and **Copy** the data, then open your preferred plotting tool and **Paste** the data.

Calculating the Dew Point

1. Return to the **Definition tab**
2. Click on the **Composition Specs** button. This will open the **Survey Options Window**
3. Click on **Calculation Type**, in the Category Window to define the Type of Calculation
4. Change the calculation type to **Dew Point** (use the drop-down arrow). Then click **OK**.
5. **Recalculate**, and click on the **Plot tab**
6. Right click and **Copy** the data, then open your preferred plotting tool and **Paste** the data
7. **Plot** the two temperature curves vs mass% of ethanol and format as needed



The azeotrope occurs at about 95% ethanol where the two curves intersect, at 78.15 °C.

Section 3. Water Analysis (Ionic Inputs)

OLI Studio: Stream Analyzer can accept two input types: molecular inflows and ionic inflows.

Sections 2 and 3 focused on molecular inflows. In this section, we will focus on **ionic inflows**, and we will learn how to enter cations and anions using the object called **Water Analysis**. Additionally, we will show how the reconciled sample can be converted into a molecular representation.

The screenshot shows the OLI Studio interface for Water Analysis. The main window displays a table with two columns: Variable and Value. The table is organized into several sections: Analysis Parameters, Recorded Properties, Neutrals (mg/L), and Cations (mg/L). The 'Add Reconciliation' button is visible in the top right, and the 'Template Manager' shows 'Standard' selected. The 'Summary' section on the right indicates the unit set is 'Metric (mass concentration)' and lists the automatic chemistry model and databanks used.

Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Recorded Properties	
Total Dissolved Solids (mg/L)	0.0
Measured pH	0.0
Measured Alkalinity (mg HCO ₃ /L)	0.0
Density (g/ml)	0.0
Specific Electrical Conductivity (µmho/cm)	0.0
Neutrals (mg/L)	
H ₂ O	
CO ₂	0.0
H ₂ S	0.0
SiO ₂	0.0
B(OH) ₃	0.0
Cations (mg/L)	
Na+1	0.0
K+1	0.0
Ca+2	0.0
Mg+2	0.0
Sr+2	0.0
Ba+2	0.0
Fe+2	0.0

3.1. Basic Terminology

When reviewing laboratory analysis of water samples, it is quite common for the positive ions (cations) and the negatively charged ions (anions) in solution to not balance. This may be due to the precision limits of the various experimental procedures used to measure the ions - i.e. some ions may not have been analyzed. These solutions must have a neutral charge. Stream Analyzer will adjust/modify inflows in order to balance the charges and make the solution neutral. This adjusting procedure is referred to as **Reconciliation**.

The pH and the alkalinity of the solution are frequently measured. However, since the analysis is experimental and subject to errors, the pH and alkalinity values that are calculated by the Water Analysis tool may be different from what is measured experimentally. Stream Analyzer can also reconcile this difference.

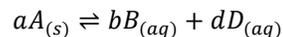
Scaling

Scaling is the deposition of a mineral salt on processing equipment. Scaling is a result of supersaturation of mineral ions in the process fluid. Through changes in temperature, or solvent evaporation or degasification, the concentration of salts may exceed the saturation, leading to a precipitation of solids (usually crystals). The saturation level of a salt in water is a good indicator of the potential for scaling.

The potential for scaling is calculated using the solubility product constant (K_{sp}) and Ion Activity Product (IAP) definitions.

Solubility Product Constant, K_{sp}

The solubility of ionic compounds of salts and minerals in water are governed by a solubility equilibrium expression and a solubility product constant known as K_{sp} . It is important to note that the solubility product, K_{sp} is a function of both temperature and pressure. Consider the general dissolution reaction below (in aqueous solutions):



With equilibrium constant K_{sp} defined as:

$$K_{sp} = (a_B)^b \cdot (a_D)^d$$

Where, a_B and a_D are the activities of the aqueous species. The activity of any species i is defined as the product of its concentration in molality by its corresponding activity coefficient:

$$a_i = m_i \gamma_i$$

Ion Activity Product, IAP

A real solution may not be in the state of equilibrium. This non-equilibrium state is described by the ion activity product (IAP). It has the same form as the equilibrium constant K_{sp} , but involves the actual activities of the species in solution.

$$IAP = (a_B)_{actual}^b \cdot (a_D)_{actual}^d$$

Scaling Tendency and Scale Index

The Scaling Tendency (ST) is defined as the ratio of the Ion Activity Product (IAP) divided by the equilibrium constant (K_{sp}).

$$ST = \frac{IAP}{K_{sp}} \quad \text{Equation (1)}$$

Scaling tendencies are essentially saturation ratios. Thus, if

- $ST < 1$ Indicates sub-saturation, and the solid is not expected to form
- $ST = 1$ Indicates saturation, and the solid is in equilibrium with water
- $ST > 1$ Indicates supersaturation, and solids will form

Note: The Scaling Tendency (ST) is reported in the software as Post-Scale.

The Scale Index (SI) (aka: Saturation Index in the literature), is given by the following relationship:

$$SI = \log_{10} \left(\frac{IAP}{K_{sp}} \right) \quad \text{Equation (2)}$$

Thus, if

- $SI < 0$ Indicates sub-saturation, and the solid is not expected to form
- $SI = 0$ Indicates saturation, and the solid is in equilibrium with water
- $SI > 0$ Indicates supersaturation, and solids will form

Note: The Scaling Index (SI) is reported in the software as SI, Index under the Post-Scale name.

Pre-scaling Tendency and Scale Index

Pre-Scaling tendency is defined as the scaling tendency before any solids are formed (this can be seen as all the species suspended in solution). The same equations (Equations 1 and 2) are used for calculating ST and SI.

The Pre-Scaling tendency is reported in the software as Pre-Scale, with its respective SI, index.

Difference between Post-scale and Pre-scale

Pre-Scale: The saturation ratio before solids precipitate.

Post-Scale: The saturation ratio **after** solids precipitate (if solids are selected).

Another way to interpret these two definitions is:

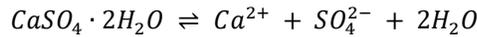
Pre-Scale represents the condition before any solids are allowed to form. This is a non-equilibrium condition and can be viewed as the condition where $time = 0$.

Post-Scale Tendency is the saturation ratio after all potential solids come to equilibrium with water. This is the true equilibrium condition ($time = \infty$).

Example 27: Calculation the Scaling Tendency and the Scale Index of $\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$

Let's calculate the Scaling Tendency and the Scale Index of 0.01 moles of gypsum ($\text{CaSO}_4 \cdot 2\text{H}_2\text{O}$) dissolved in 1 kg of water at 25°C and 1 atm.

The equilibrium expression for the dissolution reaction is:



Where, $K_{sp} = 3.2 \times 10^{-5}$

The molal concentration and the activity coefficients for each one of the species are:

$$[\text{Ca}^{+2}] = 0.0093 \text{ m} \quad \gamma_{\text{Ca}^{+2}} = 0.4663$$

$$[\text{SO}_4^{-2}] = 0.0093 \text{ m} \quad \gamma_{\text{SO}_4^{-2}} = 0.4663$$

$$a_{\text{H}_2\text{O}} = 0.9997$$

Calculating the IAP

With the information given above, we can calculate the IAP as follows:

$$IAP = a_{\text{Ca}^{+2}} \cdot a_{\text{SO}_4^{-2}} \cdot (a_{\text{H}_2\text{O}})^2$$

$$IAP = (m_{\text{Ca}^{+2}} \gamma_{\text{Ca}^{+2}}) \cdot (m_{\text{SO}_4^{-2}} \gamma_{\text{SO}_4^{-2}}) \cdot (a_{\text{H}_2\text{O}})^2$$

$$IAP = (0.0093 \times 0.4663) \cdot (0.0093 \times 0.4663) \cdot (0.9997)^2$$

$$IAP = 1.879 \times 10^{-5}$$

Calculating the Scaling Tendency

$$ST = \frac{1.879 \times 10^{-5}}{3.2 \times 10^{-5}}$$

$$ST \approx 0.587$$

This result indicates that the solution is under-saturated with respect to calcium sulfate.

Calculating the Scaling Index

$$SI = \log_{10} \frac{IAP}{K_{sp}} = \log_{10} ST$$

$$SI = \log_{10}(0.587)$$

$$SI \approx -0.231$$

3.2. Entering Data for Water Analysis

The grid for water analysis has 5 different grids where we need to enter information: Analysis Parameters, Recorded Properties, and Neutrals, Cations and Anions concentration in solution.

The **Analysis Parameters** grid is where you enter the conditions at which the sample properties were measured. The default values are 1 L, 25°C and 1 atm.

Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.00000
Pressure (atm)	1.00000

The **Recorded Properties** grid is where you enter the laboratory measured properties of the solution. These are: Total Dissolved Solids (TDS), Measured pH, Measured Alkalinity, Density, and Specific Electrical Conductivity. You can always change the units of these properties by clicking on the units highlighted in [blue](#). This action will open the Units Manager Window.

Recorded Properties	
Total Dissolved Solids (mg/L)	0.0
Measured pH	0.0
Measured Alkalinity (mg HCO ₃ /L)	0.0
Density (g/ml)	0.0
Specific Electrical Conductivity (µmho/cm)	0.0

The concentration of Neutrals, Cations and Anions is entered in the section. The Water Analysis grid comes already prepopulated with some of the most common cations, anions, and neutrals species found in laboratory water analyses. If your species is not present in the prepopulated grid, simply click on the white grid and type the ion or neutral of interest. If it is a **cation**, type the element followed by a plus (+) sign and the corresponding oxidation state, e.g. Cu+2. If it is an **anion**, type the element followed by a minus (-) sign and the corresponding oxidation state, e.g. Br-1. If it is a **neutral**, simple type the species either using the formula name or its name, as has been shown in the previous sections.

Neutrals (mg/L)	
H ₂ O	
CO ₂	0.0
H ₂ S	0.0
SiO ₂	0.0
B(OH) ₃	0.0
Cations (mg/L)	
Na+1	0.0
K+1	0.0
Ca+2	0.0
Mg+2	0.0
Sr+2	0.0
Ba+2	0.0
Fe+2	0.0
Anions (mg/L)	
Cl-1	0.0
SO ₄ -2	0.0
HCO ₃ -1	0.0
HS-1	0.0
C ₂ H ₃ O ₂ -1	0.0

The Water Analysis grid also contains search aids to find a specific cation or anion. The first search aid is the drop list located in each the cation, anion, and neutral grid sections. The list is alphabetic and is activated using the drop-down arrow within the cell, after the first few letters of the ion is typed.

Cations (mg/L)	
Na+1	0.0
K+1	0.0
Ca+2	0.0
Mg+2	0.0
Sr+2	0.0
Ba+2	0.0
Fe+2	0.0
Cu	
Display Name	OLI Name
OLI CSION	CSION
SYN Cu(+)	CUION
SYN Cu(++)	CUION
SYN Cu(+1)	CUION
SYN Cu(+2)	CUION

If a name is misspelled or if the text is unrecognized, then a red 'X' appears to the left of the name. This name needs to be corrected or the row deleted before proceeding. To delete the row, simply select the wrong entry (which will turn black) and hit the key <Delete>.

Variable	Value
Density (g/ml)	0.0
Specific Electrical Conductivity (µmho/cm)	0.0
Neutrals (mg/L)	
H2O	
CO2	0.0
H2S	0.0
SiO2	0.0
B(OH)3	0.0
X OLI	0.0

3.3. Water Analyses - Reported Elements

Water analysis data obtained from ICP measurements will contain concentrations for B, P, S, and Si. These elements do not exist in the water, rather they exist as dissolved ions. If they are part of your analysis, then you should convert them to the following before entering them into the Water Analyses object.

Table 1. Converting element concentration to species for Brine or Water Analysis

ICP data	Aqueous Species	Formula to enter	Formula weight multiplier
B, boron	Boric Acid	H3BO3	B (mg/l) × 5.72 = H3BO3 (mg/l)
Si, Silicon	Silica	SiO2	Si (mg/l) × 2.14 = SiO2 (mg/l)
P, Phosphorus	Dihydrogen Phosphate	H2PO4-1	P (mg/l) × 3.13 = H2PO4 (mg/l)
S, Sulfur	Sulfate or Sulfide	HS-1 or SO4-2	S (mg/l) × 1.03 for HS-1 (mg/l)
		(cannot tell from total S only)	or S (mg/l) × 3.0 for SO4-2 (mg/l)

3.4. A Basic Water Analysis

A brief introduction to the water analysis tool will be shown in the example below. As we go through the example, the basic definitions, functionalities and reporting for the *Water Analysis tool* will be introduced.

Example 28: Ground Water Analysis

Will calculate the **pH** and **density** of a Ground Water sample based upon its measured composition at 1 atm and 25 °C. Then we will create a molecular stream based on the ionic inflows.

Starting the Simulation

Use the inputs and parameters from the table below to create the water analysis. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Ground Water Analysis					
Analysis Parameters/Settings			Recorded Properties		
Stream Amount	1 L (Default)		Total Dissolved Solids	Not recorded	
Temperature	25 °C		Measured pH	6.7	
Pressure	1 atm		Measured Alkalinity	Not recorded	
Name Style	Display Formula		Density	Not recorded	
Unit Set	Metric, Batch, Concentration		Specific Electrical Conductivity	Not recorded	
Framework	MSE				
Calculation Type	Water Analysis				
Stream Name	Basic Water Analysis				
Composition					
Neutrals (mg/L)		Cations (mg/L)		Anions (mg/L)	
CO2	150	Na+1	1060	Cl-1	3896
H2S	15	K+1	50	SO4-2	54
NH3	5	Ca+2	773		
		Mg+2	177		
		Sr+2	0.18		
		Ba+2	0.46		
		Fe+2	62.1		
		Mn+2	2.80		
		Al+3	0.74		

Setting the Water Analysis

1. Add a **Water Analysis**
2. **Click** on the new WaterAnalysis and press **<F2>** to change the name to *Basic Water Analysis*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Concentration (it may be defined by default)

- Under the **Analysis** Tab, enter the Analysis Parameters, Recorded properties, and composition of the water given in the table above.
- Go to the **Add Reconciliation** button of the top right corner or select **Add Reconciliation** from the Actions Panel.

OLI Studio - [Water Analysis.oad*]

File Edit Streams Calculations Chemistry Tools View Window Help

Navigator: Document1, Water Analysis.oad*, Streams, Basic Water Analysis

Basic Water Analysis

Description Analysis Report

Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Recorded Properties	
Total Dissolved Solids (mg/L)	0.0
Measured pH	6.70000
Measured Alkalinity (mg HCO ₃ /L)	0.0
Density (g/ml)	0.0
Specific Electrical Conductivity (µmho/cm)	0.0
Neutrals (mg/L)	
H ₂ O	
CO ₂	150.000
H ₂ S	15.0000
SiO ₂	0.0
B(OH) ₃	0.0
NH ₃	5.00000
Cations (mg/L)	
Na+1	1060.00
K+1	50.0000
Ca+2	773.000
Mg+2	177.000
Sr+2	0.180000
Ba+2	0.460000
Fe+2	62.1000
Mn+2	2.80000
Al+3	0.740000
Anions (mg/L)	
Cl-1	3896.00
SO ₄ -2	54.0000
HCO ₃ -1	0.0
HS-1	0.0
C ₂ H ₃ O ₂ -1	0.0

Measured | Advanced

Actions: Add Reconciliation, Add Water Analysis

Plot Template Manager

Summary: Unit Set: Metric (mass concentration), Automatic Chemistry Model, MSE (H₃O+ ion) Databanks, MSE (H₃O+ ion), Using Helgeson Direct

For Help, press F1

Note: You may notice that after selecting **Add Reconciliation** option, the navigator panel displays a sub-stream called **Reconcile**, and this **Reconcile** sub-stream opens a new tab named **Reconciliation**. The Reconcile sub-stream copies the original inputs entered in the *Water Analysis*. Any changes made in the sub-stream will not change the original Water Analysis.

Additionally, three different types of reconciliation are enabled in the upper right corner of the window: (1) No Reconcile, (2) Reconcile pH and (3) Reconcile pH/Alkalinity. These types of reconciliation will be described in more detail later in the next section.

The selected default calculation is **No Reconcile**. This option means that the software will compute the water properties based on the current concentration of neutral, cations, and anions species. The calculation will not use the measured pH, or the measured alkalinity entered (if any).

The Calculate Alkalinity box (Calculate Alkalinity) allows you to compute the alkalinity, also based on the concentration entered.

8. Select the **No Reconcile** option

The screenshot shows the OLI Studio interface with the 'Reconciliation' tab selected. The 'Reconciliation' panel on the right contains the following options:

- No Reconcile
- Reconcile pH
- Reconcile pH/Alkalinity
- Calculate Alkalinity

The main table displays the following data:

Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Recorded Properties	
Total Dissolved Solids (mg/L)	0.0
Measured pH	6.70000
Measured Alkalinity (mg HCO ₃ /L)	0.0
Density (g/ml)	0.0
Specific Electrical Conductivity (µmho/cm)	0.0
Neutrals (mg/L)	
H ₂ O	
CO ₂	150.000
H ₂ S	15.0000
SiO ₂	0.0
B(OH) ₃	0.0
NH ₃	5.00000
Cations (mg/L)	
Na+1	1060.00
K+1	50.0000
Ca+2	773.000
Mg+2	177.000
Sr+2	0.180000
Ba+2	0.460000
Fe+2	62.1000
Mn+2	2.80000
Al+3	0.740000
Anions (mg/L)	
Cl-1	3896.00
SO ₄ -2	54.0000
HCO ₃ -1	0.0
HS-1	0.0
C ₂ H ₃ O ₂ -1	0.0

- Now, we are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key
- It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. Create a new file and name it: *Water Analysis Calculations*.

Analyzing the Results

Viewing the Summary Box

Review the Summary Box. Let's analyze it in detail since it contains several pieces of important information, as shown in the image below.

Specific Electrical Conductivity (µmho/cm)		0.0
Neutrals (mg/L)		
H2O		
CO2		150.000
H2S		15.0000
SiO2		0.0
B(OH)3		0.0
NH3		5.00000
Cations (mg/L)		
Na+1		1060.00
K+1		50.0000
Ca+2		773.000
Mg+2		177.000
Sr+2		0.180000
Ba+2		0.460000
Fe+2		62.1000
Mn+2		2.80000
Al+3		0.740000
Anions (mg/L)		
Cl-1		3896.00
SO4-2		54.0000
HCO3-1		0.0
HS-1		0.0
C2H3O2-1		0.0

Summary	
Unit Set: Metric (mass concentration)	
Automatic Chemistry Model	
MSE (H3O+ ion) Databanks:	
MSE (H3O+ ion)	
Using Helgeson Direct	
Dominant Ion Charge Balance (eq/L):	
Cation Charge: 0.102945 eq/L	
Anion Charge: -0.111016 eq/L	
Imbalance: -8.07170e-3 eq/L	
185.568 mg/L of Na+1 is needed to balance.	
Isothermal Calculation	
25.0000 °C 1.00000 atm	
Phase Amounts	
Aqueous 1001.98 g	
Vapor 0.0 g	
Solid 0.0115758 g	
Aqueous Phase Properties	
pH 4.47595	
Ionic Strength 2.49905e-3 mol/mol	
Density 1.00198 g/ml	
Calc. elapsed time: 30.438 sec	
Calculation complete	

The top section contains the **charge balance information** showing the total equivalent charge (positive and negative), and the charge imbalance. This example has a negative imbalance of -8.072×10^{-3} eq/L, indicating that more cations are needed in solution in order to reach electroneutrality. The software calculates that 185.568 mg/L of Na⁺ are needed to balance the solution. The software adds this amount of Na⁺ to the solution. This information can be further confirmed in the **Report Tab** in the Charge Balance table.

The **calculation type information** shows the calculation type the software used. In this example, the software performed a default isothermal calculation at 25 °C and 1 atm. If we selected other calculation specifications, they would appear here.

The **phase amounts information** shows the distribution of species in the different phases. This analysis contains two phases: aqueous and solid.

The **aqueous properties information** shows the computed pH, ionic strength, and density of the solution. It is important to note here that the measured pH is 6.70 and the computed pH is 4.47. The density of this solution is 1.00198 g/ml. Remember, for this example the software used only the concentration of neutrals, cations and anions in solution to do a reconciliation.

Viewing the Molecular Basis Tab

Let's review the **Molecular Basis** Tab. The Molecular Basis tab is one of several tabs of the Reconciliation object. The information contained in this tab is the molecular composition of the solution after it has been reconciled. In other words, the software has converted the **ionic inflows** into a **molecular stream**.

Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Volume - Liquid-1 (L)	1.00000
Volume - Solid (cm ³)	2.40298e-3
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Molecular Totals (mg/L)	
AlCl ₃	3.61208
Al(OH) ₃	0.0262829
BaCl ₂	0.631654
BaSO ₄	0.0738067
CaCl ₂	2092.78
CaO	24.1565
CO ₂	150.000
FeCl ₂	124.399
FeS	11.4757
H ₂ O	9.95556e5
H ₂ S	10.5511
KCl	95.3381
MgCl ₂	693.368
MnCl ₂	6.41382
NaCl	3166.36
NH ₃	4.99999
SO ₃	44.9809
SrCl ₂	0.325663

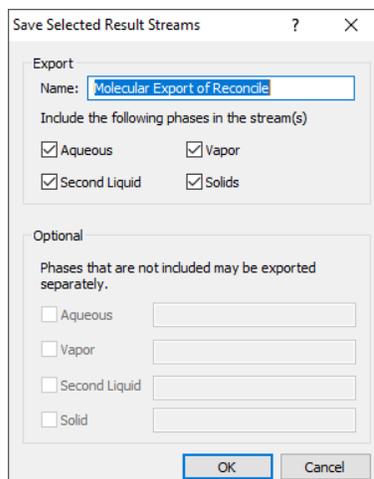
Note: The software generates molecular concentrations based on two priorities. The first priority is to create the least number of molecular inflows. This example contains eighteen inflows (plus H₂O not shown). The second priority is to create the least number of total moles. Moles are not shown here, since the units are mg/l. The moles are shown in the Report tab.

You can use this molecular form as a new Stream in OLI Studio, by using the **Add as Stream** button, or it can be exported to a separate software like Flowsheet: ESP, Aspen Plus, UniSim Design, or other simulators.

Converting the Ionic Inflows into a Molecular Stream

For practice, let's add this Molecular Basis as a Stream into the Navigator Panel.

1. Click on the **Add as Stream** button. This will open a new window



Note: By default, the name of the stream is **Molecular Export of Reconcile**. You can change the name if you prefer. Additionally, you can include or exclude the phases that you want to export into your stream by checking or unchecking the corresponding boxes.

2. Leave the defaults and click **OK**. The program automatically adds a new stream in the navigation panel.

OLI Studio - [Water Analysis Calculations.oad]

File Edit Streams Calculations Chemistry Tools View Window Help

Navigator
Document1
Water Analysis Calculations.oad
Streams
Basic Water Analysis
Reconcile
Molecular Export of Reconcile

Actions
Add Stream Add Stabl
Add Mixer Add Corn
Add Single Point
Add Survey
Add Chemical Diagram

Plot Template Manager

Molecular Export of Reconcile

Description Definition Report

Variable	Value
Stream Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mg/L)	
H2O	
CO2	150.000
H2S	10.5511
NH3	4.99999
AlCl3	3.61208
BaCl2	0.631654
CaCl2	2092.78
CaO	24.1565
FeCl2	124.399
KCl	95.3381
MgCl2	693.368
MnCl2	6.41382
NaCl	3166.36
SO3	44.9809
SrCl2	0.325663
BaSO4	0.0738067
FeS	11.4757
Al(OH)3	0.0282829

Input

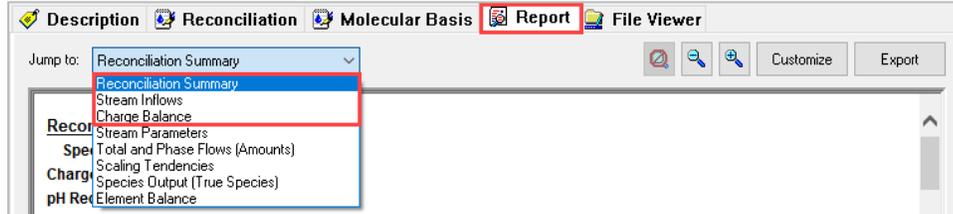
Advanced Search Add as Stream Export

For Help, press F1

NUM

Viewing the Report Tab

The **Report** tab is slightly different from the Single Point report described in Section 1. This Report contains three additional tables, all of which are located at the top. These tables are the Reconciliation Summary, Stream Inflows, and Charge Balance.



The **Reconciliation Summary** table confirms the specifications for the reconciliation such as the charge balance method and the reconciliation type (these concepts will be discussed in more detail later in the manual). Additionally, shows the conditions at which the calculation was run, in this case 25°C and 1 atm. And finally, shows a comparison between the measured and calculated properties, in this case it shows the measured vs calculated pH.

Reconciliation Summary

Specification

Charge Balance Method Dominant Ion

pH Reconciliation Type No reconciliation

	Measured	Calculated
Temperature, °C	25.0000	
Pressure, atm	1.00000	
pH	6.70000	4.47595
Density, g/ml		1.00198
Water, mg/L		9.95554e5

The **Stream Inflows** table summarizes all the species that were entered in the water analysis grid.

Stream Inflows

Row Filter Applied: Only Non Zero Values

Species	Input mg/L	Output mg/L
H2O	1.00000e6	9.95554e5
Na+1	1060.00	
K+1	50.0000	
Ca+2	773.000	
Mg+2	177.000	
Sr+2	0.180000	
Ba+2	0.460000	
Fe+2	62.1000	
Mn+2	2.80000	
Al+3	0.740000	
CO2	150.000	150.000
H2S	15.0000	15.0000
Cl-1	3896.00	
SO4-2	54.0000	
NH3	5.00000	4.99999

The **Charge Balance** table contains the concentrations entered and the final balanced values. In this case only the sodium (Na+1) concentration was changed.

Charge Balance

Cation Charge: 0.102945 eq/L
 Anion Charge: -0.111016 eq/L
 Imbalance: -8.07170e-3 eq/L
 Adjusted Species: Na+1

Charged Species	Input	Balanced	Difference
	mg/L	mg/L	%
Na+1	1060.00	1245.57	17.51
K+1	50.0000	50.0000	
Ca+2	773.000	773.000	
Mg+2	177.000	177.000	
Sr+2	0.180000	0.180000	
Ba+2	0.460000	0.460000	
Fe+2	62.1000	62.1000	
Mn+2	2.80000	2.80000	
Al+3	0.740000	0.740000	
Cl-1	3896.00	3896.00	
SO4-2	54.0000	54.0000	
HCO3-1	0.0	0.0	
HS-1	0.0	0.0	
C2H3O2-1	0.0	0.0	

3.5. Exploring Reconciliation Options

When reconciling a Water Analysis, there are three options for reconciliation:

- 1. No Reconcile:** The software will run an electroneutrality reconciliation only, and then compute the water properties such as pH, density, etc., based on the entered concentration of neutral, cations, and anions species. In the **No Reconcile** option you may allow the program to pick the species to adjust for electroneutrality or you may manually choose the species to perform the adjustment. ([See electroneutrality options](#)).
- 2. Reconcile pH:** The software will run both an electroneutrality and pH reconciliation. This type of reconciliation will match your recorded pH. Additionally, the software will compute the water properties such as, density, electrical conductivity, etc. The pH of the solution is automatically adjusted by the software by adding either HCl or NaOH, or you may select your preferred acids and bases to adjust the pH.
- 3. Measured pH and Alkalinity:** The purpose of the Measured pH and Alkalinity reconciliations is to match the computed pH and alkalinity values with those you measured (TIC is unknown). The software will run an electroneutrality, pH and alkalinity reconciliation. Additionally, the software will compute the water properties such as density, electrical conductivity, etc. The pH of the solution is automatically adjusted by the software by adding either HCl or NaOH or you may select your preferred acids and bases to adjust the pH. The Alkalinity is automatically calculated by the software, using CO₂ as the alkalinity titrant, H₂SO₄ as the alkalinity pH titrant and 4.5 as the alkalinity end point pH. You can also change a different alkalinity pH titrant if you prefer. However, you cannot change the CO₂ as the alkalinity titrant for the alkalinity adjustment.
- 4. Measured pH, Alkalinity, TIC:** The purpose of this reconciliation is to match the measured pH, alkalinity and Total Inorganic Carbon (TIC). The pH of the solution is automatically adjusted by the software by adding either HCl or NaOH or you may select your preferred acids and bases to adjust the pH. The TIC is automatically calculated by the software, using CO₂ as the alkalinity titrant, H₂SO₄ as the alkalinity pH titrant and 4.5 as the alkalinity end point pH. The (total) Alkalinity is adjusted by the software by adjusting the acetate concentration (organic acids) to match the target Alkalinity. The Alkalinity is adjusted by adding or removing acetic acid. In this calculation, you cannot change the CO₂ or Acetic Acid for the alkalinity adjustment, these are fixed by the software.

Additionally, there is the option to Calculate Alkalinity: Calculate Alkalinity . It is important to note, that this is only an alkalinity calculation based on the concentration entered, it is not an alkalinity reconciliation.

We will explore the different types of reconciliation and introduce the different specification options according to the reconciliation type.

In this section we will create a new file. We will run a basic water analysis, from which the various reconciliation options will be explored.

Example 29: Water Analysis – No Reconcile Option

In this example we will calculate the **pH** and different properties of a Produced Water sample based upon its measured composition at 1 atm and 25 °C.

Starting the Simulation

Use the inputs and parameters from the table below to create the water analysis. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Water Analysis – Reconcile Options					
Analysis Parameters/Settings			Recorded Properties		
Stream Amount	1 L (Default)		Total Dissolved Solids	36500 mg/L	
Temperature	25 °C		Measured pH	7.8	
Pressure	1 atm		Measured Alkalinity	160 mg HCO ₃ /L	
Name Style	Display Formula		Density	1.013	
Unit Set	Metric, Batch, Concentration		Specific Electrical Conductivity	Not recorded	
Framework	MSE				
Calculation Type	Water Analysis				
Stream Name	Water Analysis – Reconcile Options				
Composition					
Neutrals (mg/L)		Cations (mg/L)		Anions (mg/L)	
SiO ₂	16	Na ⁺¹	10000	Cl ⁻¹	19000
		Ca ⁺²	500	SO ₄ ⁻²	2700
		Mg ⁺²	1200	HCO ₃ ⁻¹	142
		Sr ⁺²	200	AsO ₄ ⁻³	12
		Ba ⁺²	5	CHO ₂ ⁻¹	20
		Fe ⁺²	5	C ₂ H ₃ O ₂ ⁻¹	50

Calculating the pH

Setting the Water Analysis

1. Add a **Water Analysis**
2. **Click** on the new WaterAnalysis and press <F2> to change the name to *Water Analysis – Reconcile Options*
3. Select the **MSE** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Concentration (it may be defined by default)
6. Under the **Analysis** Tab, enter the Analysis Parameters, Recorded properties, and Composition of the water given in the table above.

- Go to the **Add Reconciliation** button of the top right corner or select **Add Reconciliation** from the Actions Panel, and name it **No Reconcile**.
- Select the **No Reconcile** option (selected by default)

The screenshot shows the software interface with the **Reconciliation** panel active. The main table displays the following data:

Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Recorded Properties	
Total Dissolved Solids (mg/L)	36500.0
Measured pH	7.80000
Measured Alkalinity (mg HCO ₃ /L)	160.000
Density (g/ml)	1.01300
Specific Electrical Conductivity (µmho/cm)	0.0
Neutrals (mg/L)	
H ₂ O	
CO ₂	0.0
H ₂ S	0.0
SiO ₂	16.0000
B(OH) ₃	0.0
Cations (mg/L)	
Na ⁺¹	10000.0
Ca ⁺²	500.000
Mg ⁺²	1200.00
Sr ⁺²	200.000
Ba ⁺²	5.00000
Fe ⁺²	5.00000
Anions (mg/L)	
Cl ⁻¹	19000.0
SO ₄ ⁻²	2700.00
HCO ₃ ⁻¹	142.0000
AsO ₄ ⁻³	12.0000
HCOO ⁻¹	20.0000
C ₂ H ₃ O ₂ ⁻¹	50.0000

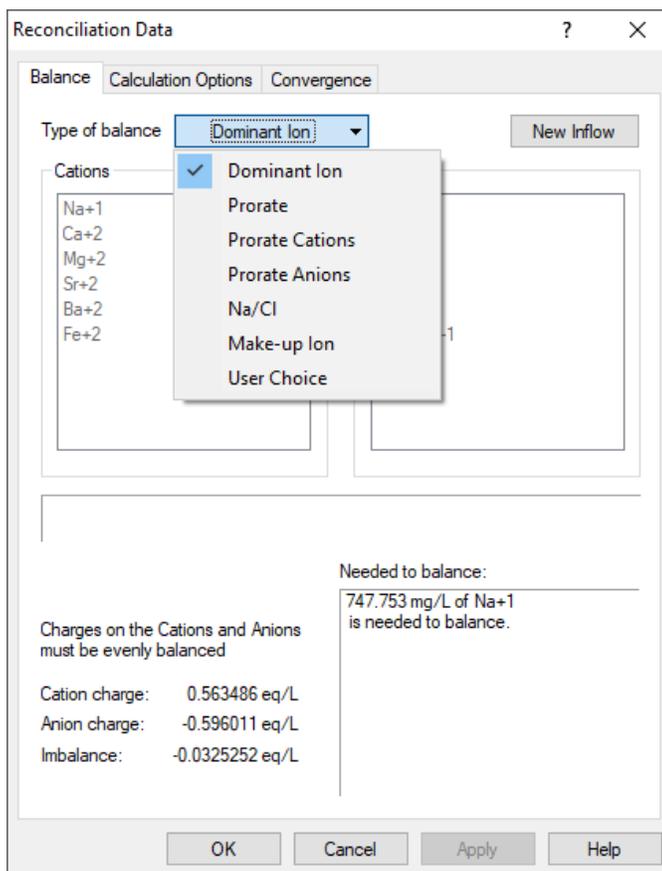
In the **Reconciliation** panel, the **No Reconcile** option is selected. The **Calculate** button is active. The **Summary** panel shows the following information:

- Unit Set: Metric (mass concentration)
- Automatic Chemistry Model
- MSE (H₃O⁺ ion) Databanks: MSE (H₃O⁺ ion)
- Using Helgeson Direct
- Dominant Ion Charge Balance (eq/L): Isothermal Calculation 25.0000 °C 1.00000 atm
- Calculation not done

Note: In the **No reconcile** option, the software runs an electroneutrality reconciliation. The **type of balance** for reconciling electroneutrality is the **Dominant Ion** method. You can select different types of balance for electroneutrality by clicking on the **Specs** button.

Types of Balance for Electroneutrality

9. Click on the **Specs** button. This will open a new window.



There are 7 different Types of Balance:

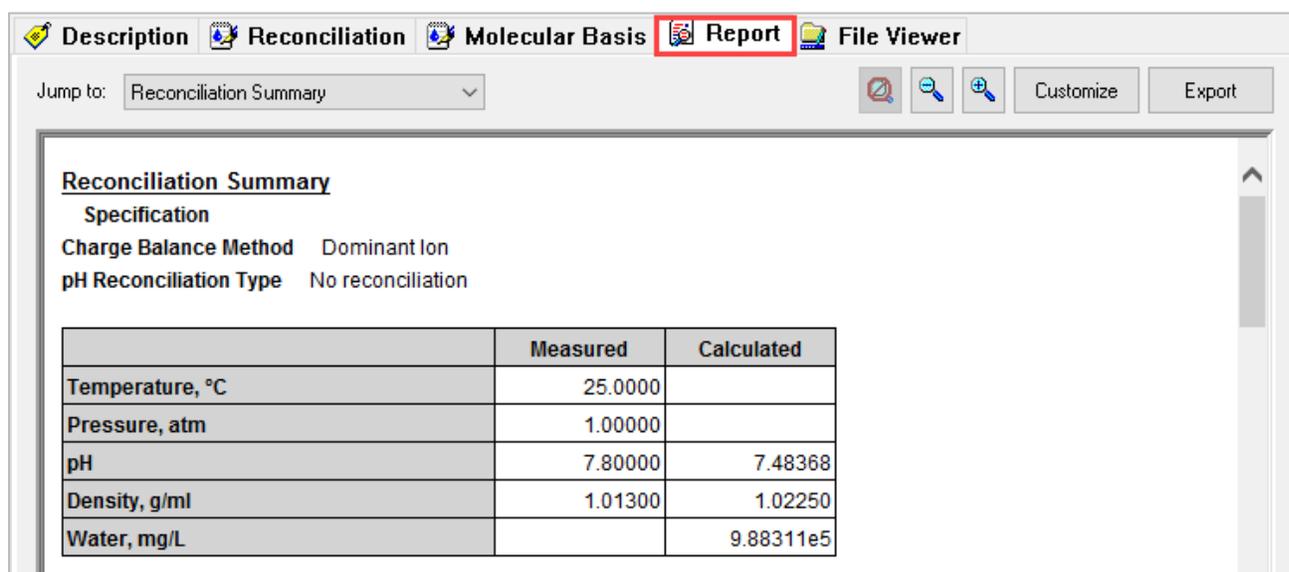
1. **Dominant Ion:** This is the default method. The largest counter ion is used to adjust the electroneutrality. In our example, 747.753 mg/L of Na+1 are added since there is an excess of negative charge (see the above image).
2. **Prorate:** This option keeps the relative amount of the counter ions (for this example, the cations) the same and are adjusted up or down equally until reaching electroneutrality.
3. **Prorate Cations:** All cations are adjusted up or down equally
4. **Prorate Anions:** All anions are adjusted up or down equally
5. **Na+/Cl-:** Sodium is added when there is an excess of negative charge. Chloride is added when there is an excess of positive charge.
6. **Make-up Ion:** This option allows for a single ion species to be adjusted. User selects an ion to increase or decrease.
7. **User Choice:** The software determines if an anion or cation is needed to balance the solution and the user chooses the specific ion.

10. Keep the default option, **Dominant Ion**, as the balance type then press **OK**
11. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
12. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named *Water Analysis Calculations*.

Analyzing the Results

Once you run the simulation there are two options to analyze the results: The summary box and the Report

1. Go to the **Report** Tab and look at the **Reconciliation Summary** Table.



The screenshot shows a software window with a toolbar at the top containing icons for Description, Reconciliation, Molecular Basis, Report (highlighted with a red box), and File Viewer. Below the toolbar is a 'Jump to:' dropdown menu set to 'Reconciliation Summary'. The main content area displays the 'Reconciliation Summary' section, which includes a 'Specification' area with 'Charge Balance Method' set to 'Dominant Ion' and 'pH Reconciliation Type' set to 'No reconciliation'. Below this is a table with three columns: 'Property', 'Measured', and 'Calculated'.

	Measured	Calculated
Temperature, °C	25.0000	
Pressure, atm	1.00000	
pH	7.80000	7.48368
Density, g/ml	1.01300	1.02250
Water, mg/L		9.88311e5

The calculated pH and density are different to the measured values. The software only used the concentration data to calculate these properties.

Example 30: Water Analysis – pH Reconcile Option

In this example we will reconcile the sample by **pH** and also calculate the **alkalinity** of the same Produced Water sample used in the previous Example 29: Water Analysis – No Reconcile Option.

Starting the Simulation

1. Under the *Water Analysis – Reconcile Options* Stream go to the **Add Reconciliation** button
2. **Click** on the new Reconcile-1 icon and press **<F2>** to change the name to *Reconcile pH*
3. The default units, names and framework have been previously defined
4. Select the **Reconcile pH** option

The screenshot displays the 'Reconciliation' tab of a software interface. The main table lists various variables and their values, categorized into Analysis Parameters, Recorded Properties, Calculation Parameters, Neutrals, Cations, and Anions. The 'Measured pH' row is highlighted in red. The 'Calculation Parameters' section is also highlighted in red, showing 'Use Single pH Titrant' set to 'No', 'pH Acid Titrant' as 'HCL', and 'pH Base Titrant' as 'NAOH'. On the right side, the 'Reconciliation' panel shows the 'Reconcile' section with 'Reconcile pH' selected. Below it, the 'Calculate' button is visible. The 'Summary' panel shows the 'Set pH Calculation' section with 'Measured pH: 7.80000' and 'Calculation not done'.

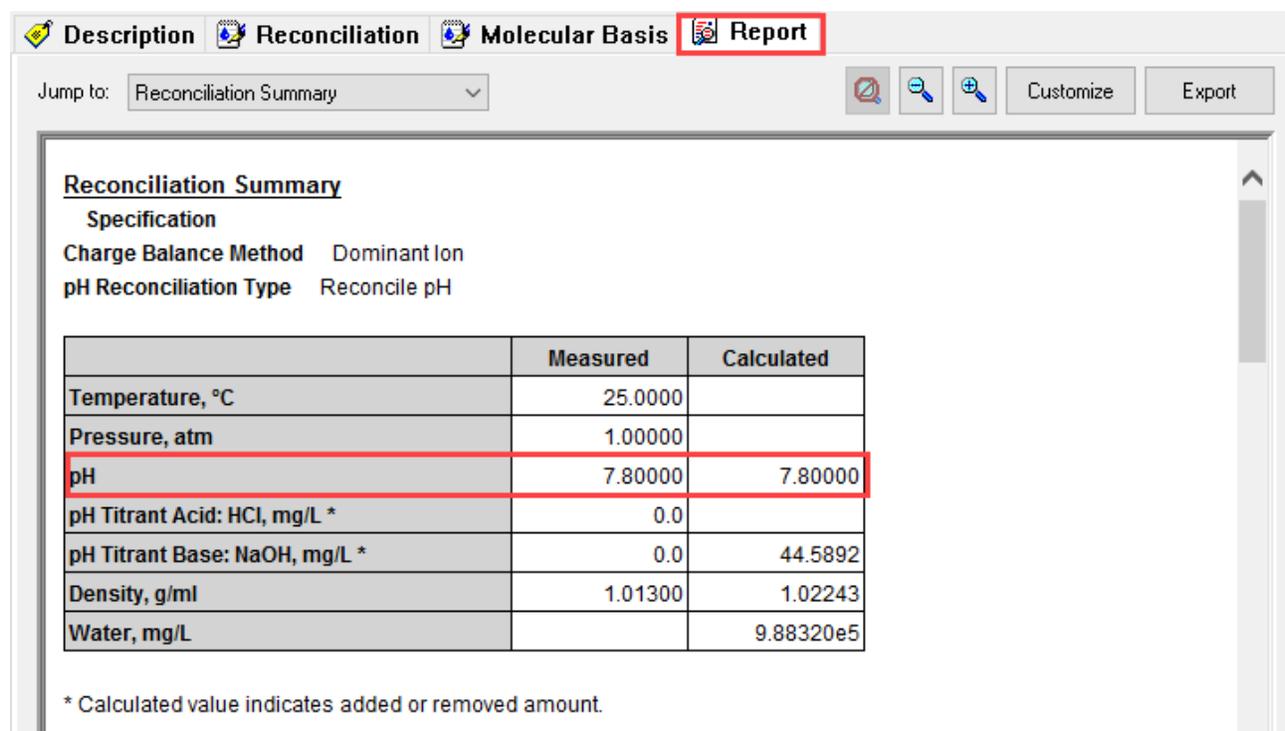
Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.00000
Pressure (atm)	1.00000
Recorded Properties	
Total Dissolved Solids (mg/L)	36500.0
Measured pH	7.80000
Measured Alkalinity (mg HCO ₃ /L)	160.000
Density (g/ml)	1.01300
Specific Electrical Conductivity (µmho/cm)	0.0
Calculation Parameters	
Use Single pH Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Neutrals (mg/L)	
H ₂ O	
CO ₂	0.0
H ₂ S	0.0
SiO ₂	16.0000
B(OH) ₃	0.0
Cations (mg/L)	
Na ⁺¹	10000.0
Ca ⁺²	500.000
Mg ⁺²	1200.00
Sr ⁺²	200.000
Ba ⁺²	5.00000
Fe ⁺²	5.00000
Anions (mg/L)	
Cl ⁻¹	19000.0
SO ₄ ⁻²	2700.00
HCO ₃ ⁻¹	142.000
AsO ₄ ⁻³	12.0000
HCOO ⁻¹	20.0000
C ₂ H ₃ O ₂ ⁻¹	50.0000

Note that by selecting the *Reconcile pH* option, now the measured pH is a fixed value (and brown dot appears in front of this cell). To match the measured pH, the software added a Calculation Parameters section which indicates the acid and basic pH titrants to adjust the pH. By default, HCl and NaOH are selected by the software. This is similar to the set pH single point calculation.

5. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
6. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named *Water Analysis Calculations*.

Analyzing the Results

1. Go to the **Report** Tab and look at the **Reconciliation Summary** Table.



The screenshot shows the software interface with the 'Report' tab selected. The 'Reconciliation Summary' table is displayed, showing measured and calculated values for various parameters. The 'pH' row is highlighted with a red border, indicating that the measured and calculated values are identical (7.80000). The 'pH Titrant Base: NaOH, mg/L *' row shows a calculated value of 44.5892 mg/L, which is the amount of NaOH added to match the measured pH.

	Measured	Calculated
Temperature, °C	25.0000	
Pressure, atm	1.00000	
pH	7.80000	7.80000
pH Titrant Acid: HCl, mg/L *	0.0	
pH Titrant Base: NaOH, mg/L *	0.0	44.5892
Density, g/ml	1.01300	1.02243
Water, mg/L		9.88320e5

* Calculated value indicates added or removed amount.

The measured and calculated pH are the same. The software added 44.5892 mg/L of NaOH to match the experimentally measured pH.

Calculating Alkalinity

Now we will instruct the software to calculate Alkalinity.

1. Go back to the **Reconciliation Tab** and check the **Calculate Alkalinity** box.

Alkalinity titrants
pH titrants

The screenshot displays the 'Reconciliation' tab of a software interface. The main table lists various variables and their values, categorized into Analysis Parameters, Recorded Properties, Calculation Parameters, Neutrals, Cations, and Anions. The 'Calculation Parameters' section is highlighted with a red box, showing 'Alkalinity pH Titrant' set to H2SO4 and 'Alkalinity End Point pH' set to 4.50000. The 'Reconciliation' panel on the right has the 'Calculate Alkalinity' checkbox checked. The 'Summary' panel on the right shows the measured pH is 7.80000 and the calculation is not done.

Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Recorded Properties	
Total Dissolved Solids (mg/L)	36500.0
Measured pH	7.80000
Measured Alkalinity (mg HCO3/L)	160.000
Density (g/ml)	1.01300
Specific Electrical Conductivity (µmho/cm)	0.0
Calculation Parameters	
Alkalinity pH Titrant	H2SO4
Alkalinity End Point pH	4.50000
Use Single pH Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Neutrals (mg/L)	
H2O	
CO2	0.0
H2S	0.0
SiO2	16.0000
B(OH)3	0.0
Cations (mg/L)	
Na+1	10000.0
Ca+2	500.000
Mg+2	1200.00
Sr+2	200.000
Ba+2	5.00000
Fe+2	5.00000
Anions (mg/L)	
Cl-1	19000.0
SO4-2	2700.00
HCO3-1	142.000
AsO4-3	12.0000
HCOO-1	20.0000
C2H3O2-1	50.0000

Reconciliation

Reconcile

No Reconcile

Reconcile pH

Reconcile pH/Alkalinity

Calculate Alkalinity

Calculate

Summary

Unit Set: Metric (mass concentration)

Automatic Chemistry Model

MSE (H3O+ ion) Databanks:

MSE (H3O+ ion)

Using Helgeson Direct

Dominant Ion Charge Balance (eq/L):

Cation Charge: 0.563486 eq/L

Anion Charge: -0.596011 eq/L

Imbalance: -0.0325252 eq/L

747.753 mg/L of Na+1 is needed to balance.

Set pH Calculation

Measured pH: 7.80000

pH Titrants:

Acid: HCL

Base: NaOH

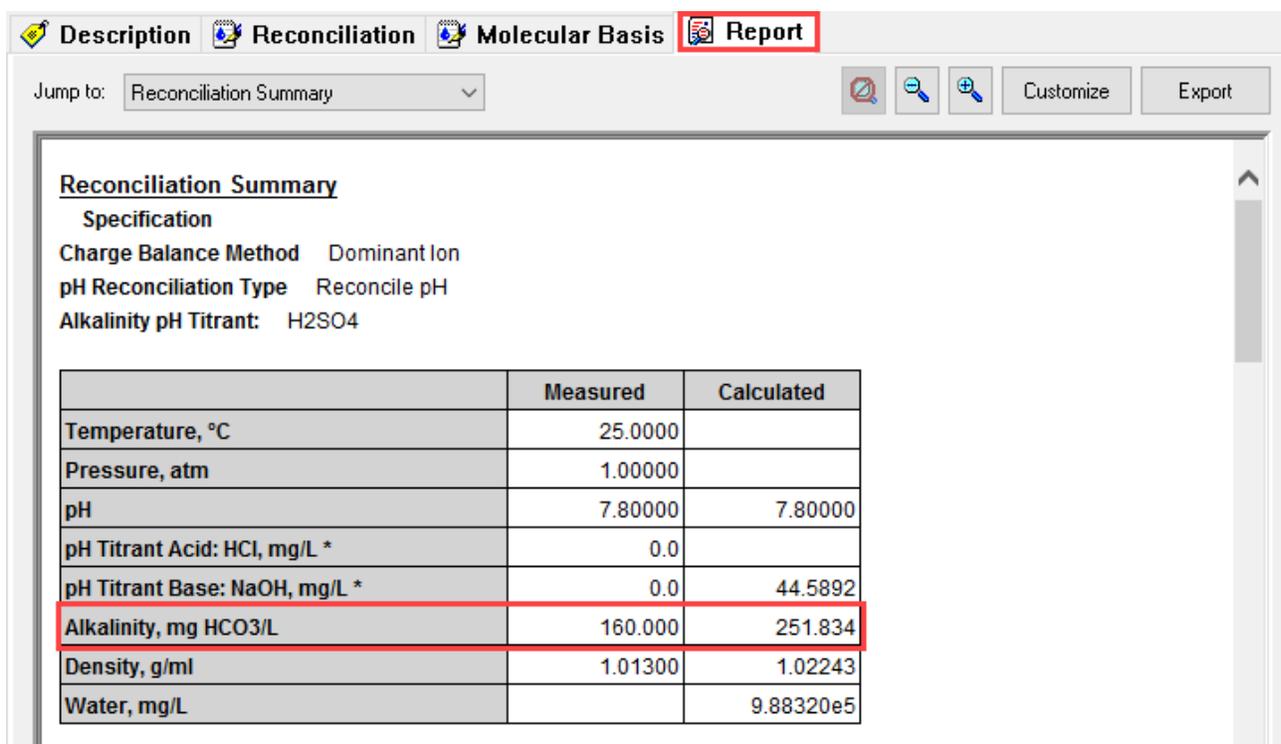
Calculation not done

Notice that by selecting the Calculate Alkalinity box two more rows were added to the Calculation Parameters section: Alkalinity pH Titrant and Alkalinity End Point pH, besides the pH titrants rows. These two new rows indicate that the software will add H₂SO₄ (selected by default) until the pH reduces to 4.5. The software then converts the amount of additional H₂SO₄ into the alkalinity value.

2. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key.
3. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

1. Go to the **Report** Tab and look at the **Reconciliation Summary** Table.



The screenshot shows the software interface with the 'Report' tab selected. The 'Reconciliation Summary' table is displayed, showing measured and calculated values for various parameters. The 'Alkalinity, mg HCO₃/L' row is highlighted in red, indicating a discrepancy between the measured and calculated values.

	Measured	Calculated
Temperature, °C	25.0000	
Pressure, atm	1.00000	
pH	7.80000	7.80000
pH Titrant Acid: HCl, mg/L *	0.0	
pH Titrant Base: NaOH, mg/L *	0.0	44.5892
Alkalinity, mg HCO ₃ /L	160.000	251.834
Density, g/ml	1.01300	1.02243
Water, mg/L		9.88320e5

The calculated alkalinity value is different to the measured value. This is because the software is not doing an alkalinity reconciliation, rather the software is using only the concentration data to calculate alkalinity. You can see this as single point alkalinity calculation.

Note that in this example, the alkalinity being reported because we checked the **Calculate Alkalinity** box; if the box wasn't checked we would not see the calculated value in the Reconciliation Summary table.

Example 31: Water Analysis – Reconcile pH/Alkalinity Option

In this example we will reconcile the sample by **pH and alkalinity** and also calculate the **pre-scaling tendencies** of the same Produced Water sample used in the previous Example 29: Water Analysis – No Reconcile Option.

Starting the Simulation

1. Under the *Water Analysis – Reconcile Options* Stream go to the **Add Reconciliation** button
2. **Click** on the new Reconcile-1 icon and press **<F2>** to change the name to *Reconcile pH*
3. The default units, names and framework have been previously defined
4. Select the **Reconcile pH/Alkalinity** option

Alkalinity titrants

pH titrants

Variable	Value
Analysis Parameters	
Stream Amount (L)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Recorded Properties	
Total Dissolved Solids (mg/L)	36500.0
Measured pH	7.80000
Measured Alkalinity (mg HCO ₃ /L)	160.000
Density (g/ml)	1.01300
Specific Electrical Conductivity (µmho/cm)	0.0
Calculation Parameters	
Alkalinity Titrant	CO ₂
Alkalinity pH Titrant	H ₂ SO ₄
Alkalinity End Point pH	4.50000
Use Single pH Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Neutrals (mg/L)	
H ₂ O	
CO ₂	0.0
H ₂ S	0.0
SiO ₂	16.0000
B(OH) ₃	0.0
Cations (mg/L)	
Na+1	10000.0
Ca+2	500.000
Mg+2	1200.00
Sr+2	200.000
Ba+2	5.00000
Fe+2	5.00000
Anions (mg/L)	
Cl-1	19000.0
SO ₄ -2	2700.00
HCO ₃ -1	142.000
AsO ₄ -3	12.0000
HCOO-1	20.0000
C ₂ H ₃ O ₂ -1	50.0000

Reconciliation

Reconcile

No Reconcile

Reconcile pH

Reconcile pH/Alkalinity

Calculate Alkalinity

Calculate

Summary

Unit Set: Metric (mass concentration)

Automatic Chemistry Model

MSE (H₃O⁺ ion) Databanks:

MSE (H₃O⁺ ion)

Using Helgeson Direct

Dominant Ion Charge Balance (eq/L):

Reconcile pH Alkalinity Calculation

Alkalinity: 160.000 mg HCO₃/L

Titration End Pt: 4.50000

Alkalinity Titrant: CO₂

Alkalinity pH Titrant: H₂SO₄

pH Reconciliation:

Measured pH: 7.80000

pH Titrants:

Acid: HCL

Base: NAOH

Calculation not done

Note that by selecting the *Reconcile pH/Alkalinity* option, now both the measured pH and alkalinity values are fixed values (and brown dot appears in front of this cell).

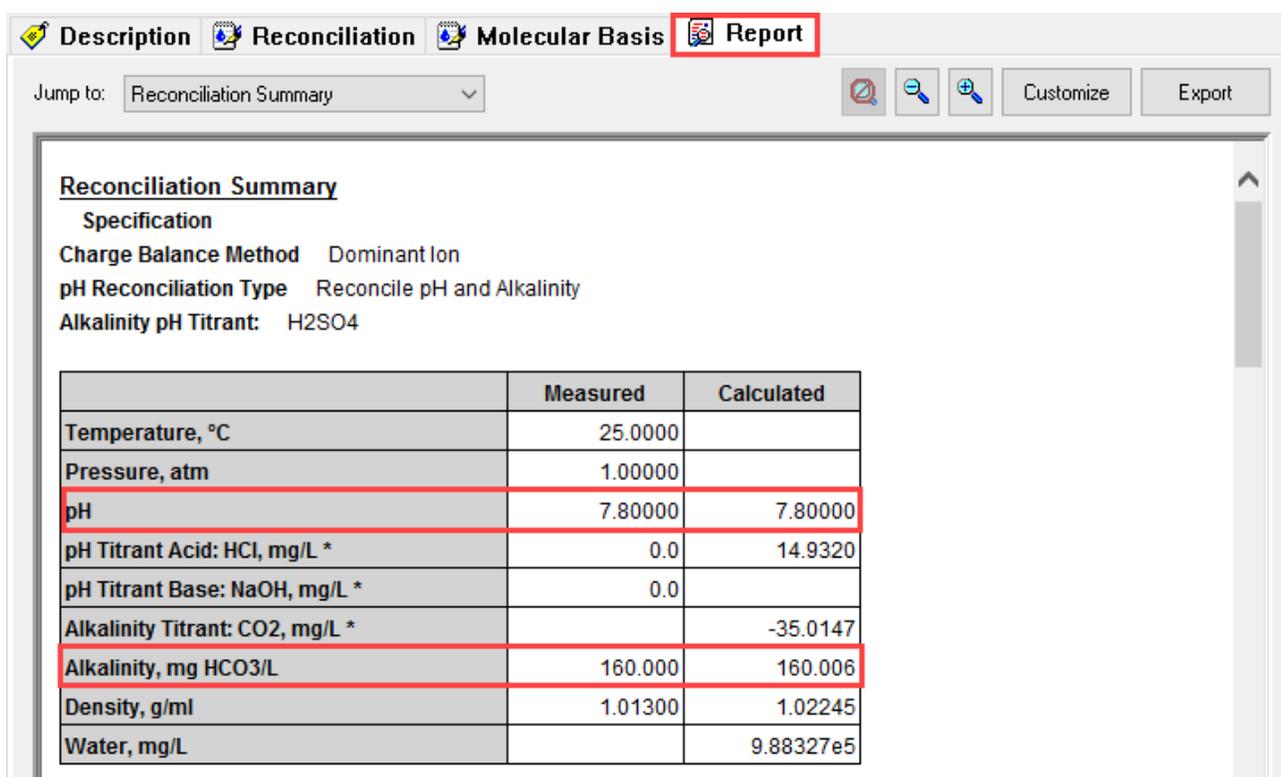
To match the measured alkalinity value, the software added a **Calculation Parameters** section which indicates the alkalinity titrant and the pH titrant used to adjust the alkalinity. CO₂ is used by default as the alkalinity titrant. This is similar to an *alkalinity* single point calculation.

To match the measured pH, the software also added a **Calculation Parameters** section which indicates the acid and basic pH titrants to adjust the pH. By default, HCl and NaOH are selected by the software. This is similar to the *set pH* single point calculation. Also notice that the alkalinity box is grayed out. This is because we have asked the software to match the measured alkalinity value. This means that calculated alkalinity value is no longer needed.

7. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
8. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named *Water Analysis Calculations*.

Analyzing the Results

1. Go to the **Report** Tab and look at the **Reconciliation Summary** Table.



The screenshot shows the software interface with the **Report** tab selected. The **Reconciliation Summary** table is displayed, showing measured and calculated values for various parameters. The **pH** and **Alkalinity** rows are highlighted with red boxes, indicating that the measured and calculated values are identical.

	Measured	Calculated
Temperature, °C	25.0000	
Pressure, atm	1.00000	
pH	7.80000	7.80000
pH Titrant Acid: HCl, mg/L *	0.0	14.9320
pH Titrant Base: NaOH, mg/L *	0.0	
Alkalinity Titrant: CO ₂ , mg/L *		-35.0147
Alkalinity, mg HCO₃/L	160.000	160.006
Density, g/ml	1.01300	1.02245
Water, mg/L		9.88327e5

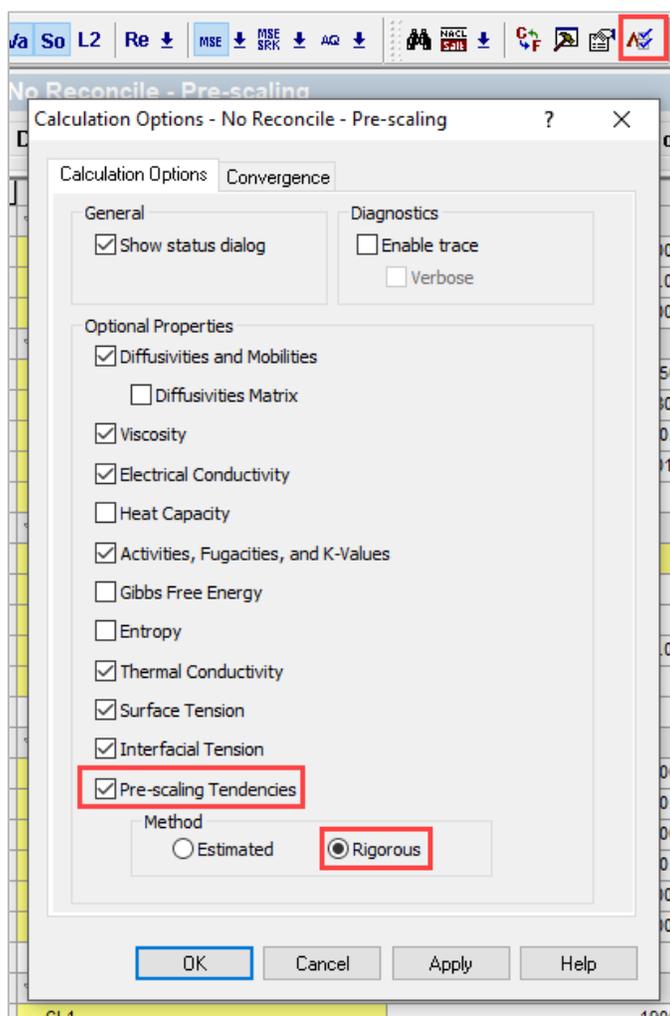
The measured and calculated pH and alkalinity values are the same. The software added 14.9320 mg/L of HCl to match the experimentally measured pH and removed 35.0147 mg/L of CO₂ to match the experimentally measured alkalinity value.

Calculating Pre-scaling Tendencies

Now we will instruct the software to calculate Pre-scaling tendencies. In OLI Studio: Stream Analyzer, Pre-scaling tendencies are turned OFF by default. We need to enable this option.

Setting the Water Analysis

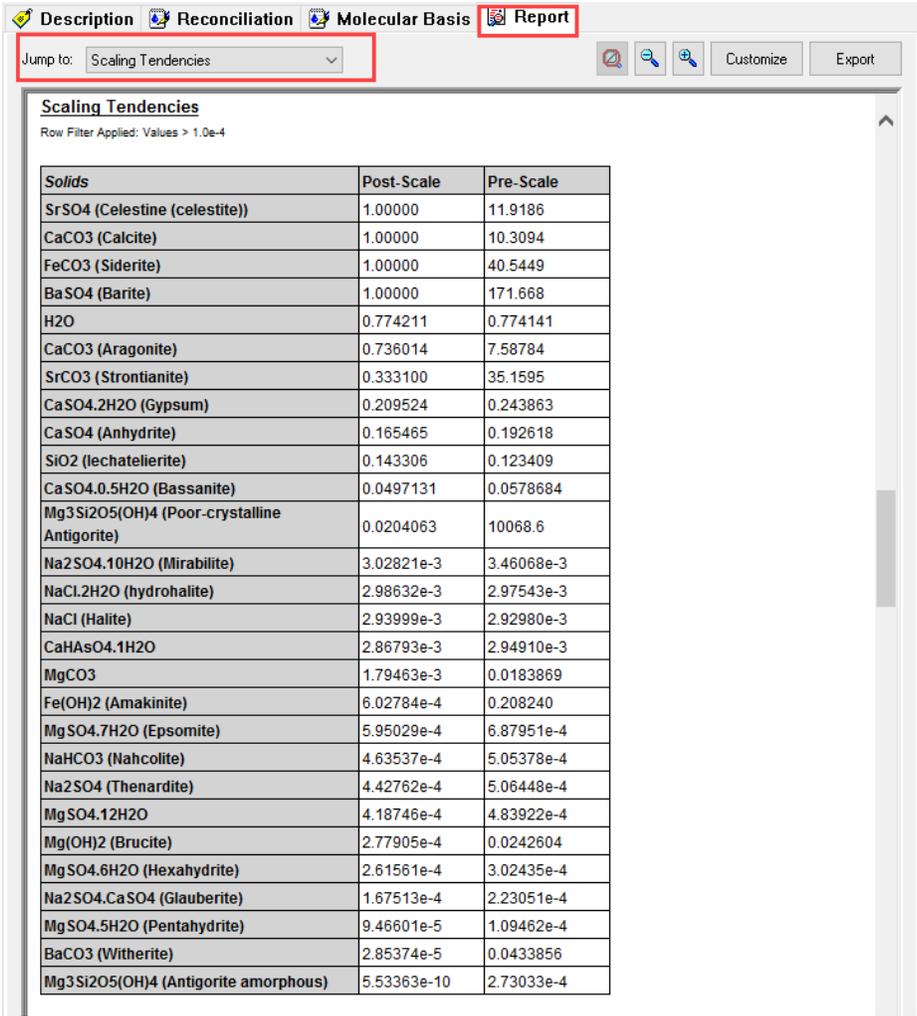
1. Go back to the **Reconciliation** tab of the *Reconcile pH/Alkalinity* water analysis
2. Click on the **Calculation Options** icon . This will open the Calculation Options window.
3. Check the **Pre-scaling Tendencies** box and select the **Rigorous method**. Then click **OK**.



4. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
5. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

1. Go to the **Report** Tab and search for the **Scaling Tendencies** Table.



Jump to: Scaling Tendencies

Scaling Tendencies
Row Filter Applied: Values > 1.0e-4

Solids	Post-Scale	Pre-Scale
SrSO4 (Celestine (celestite))	1.00000	11.9186
CaCO3 (Calcite)	1.00000	10.3094
FeCO3 (Siderite)	1.00000	40.5449
BaSO4 (Barite)	1.00000	171.668
H2O	0.774211	0.774141
CaCO3 (Aragonite)	0.736014	7.58784
SrCO3 (Strontianite)	0.333100	35.1595
CaSO4.2H2O (Gypsum)	0.209524	0.243863
CaSO4 (Anhydrite)	0.165465	0.192618
SiO2 (lechatelierite)	0.143306	0.123409
CaSO4.0.5H2O (Bassanite)	0.0497131	0.0578684
Mg3Si2O5(OH)4 (Poor-crystalline Antigorite)	0.0204063	10068.6
Na2SO4.10H2O (Mirabilite)	3.02821e-3	3.46068e-3
NaCl.2H2O (hydrohalite)	2.98632e-3	2.97543e-3
NaCl (Halite)	2.93999e-3	2.92980e-3
CaHAsO4.1H2O	2.86793e-3	2.94910e-3
MgCO3	1.79463e-3	0.0183869
Fe(OH)2 (Amakinite)	6.02784e-4	0.208240
MgSO4.7H2O (Epsomite)	5.95029e-4	6.87951e-4
NaHCO3 (Nahcolite)	4.63537e-4	5.05378e-4
Na2SO4 (Thenardite)	4.42762e-4	5.06448e-4
MgSO4.12H2O	4.18746e-4	4.83922e-4
Mg(OH)2 (Brucite)	2.77905e-4	0.0242604
MgSO4.6H2O (Hexahydrite)	2.61561e-4	3.02435e-4
Na2SO4.CaSO4 (Glauberite)	1.67513e-4	2.23051e-4
MgSO4.5H2O (Pentahydrite)	9.46601e-5	1.09462e-4
BaCO3 (Witherite)	2.85374e-5	0.0433856
Mg3Si2O5(OH)4 (Antigorite amorphous)	5.53363e-10	2.73033e-4

This table reports both the Post-Scale and Pre-scale Tendencies. See the section 3.1 Basic Terminology to see a more detailed explanation.

The Scaling Tendencies (reported in the software as **Post-Scale**), are essentially saturation ratios. When the scaling tendency for a given mineral is equal to 1.0 (saturation conditions) it indicates that the mineral is in equilibrium with water, a solid phase has formed. A scaling tendency below 1.0 indicates sub-saturation and that the solid phase will not form. A solid is at risk of forming when the scale tendency value is greater than 1.0 (supersaturation conditions).

The Pre-Scaling Tendencies (reported in the software as **Pre-Scale**), is defined as the scaling tendency before any solids are formed (this can be seen as all the species suspended in solution).

Note: The Post-Scale and the Pre-Scale tendencies are equivalent if the solid phase is turned OFF.

Section 4. Hydrocarbons and Pseudocomponents

So far, we have learned how to enter molecular and ionic inflows in Stream Analyzer. Stream Analyzer also allows you to enter assays or pseudocomponents in order to crude oils as streams.

Crude oils are complex groups of organic molecules containing hundreds, perhaps thousands of pure components in a single oil. Modeling crude oils using pure components is impractical, because analyzing for each pure component is cost prohibitive and the number of species would make calculations overwhelming. A convenient solution to this problem and to modeling the properties of a crude oil is to create pseudo components.

Crude Oil properties may be defined through a distillation curve, where each boiling point range is a progression of molecular weights, densities, solubilities, viscosities and other properties associated with that section. It is reasonable for low boiling point molecules to be low molecular weight, low density, low viscosity, and more soluble in water. We can dice boiling point curves using well accepted methods standard to create pseudocomponents that in combination reflect the property of the whole oil.

There are two ways to create a crude oil stream on Stream Analyzer:

1. The first is to start with a PVT curve and create pseudocomponents using one of the three thermodynamic methods coded into the software.
2. The second is to enter the pseudocomponent data directly and using the same thermodynamic methods to predict the component properties.

The three thermodynamic methods are: API, Lee Kesler, and Cavett. More details about this method can be found in Section 11. .

A brief introduction of how to enter PVT curves and/or pseudocomponents will be shown in the examples below.

4.1. Entering a PVT Analysis

Example 32: Creating an Assay

In this example, we are going to learn how to enter a simple PVT analysis in order to create a *Crude Oil* Stream.

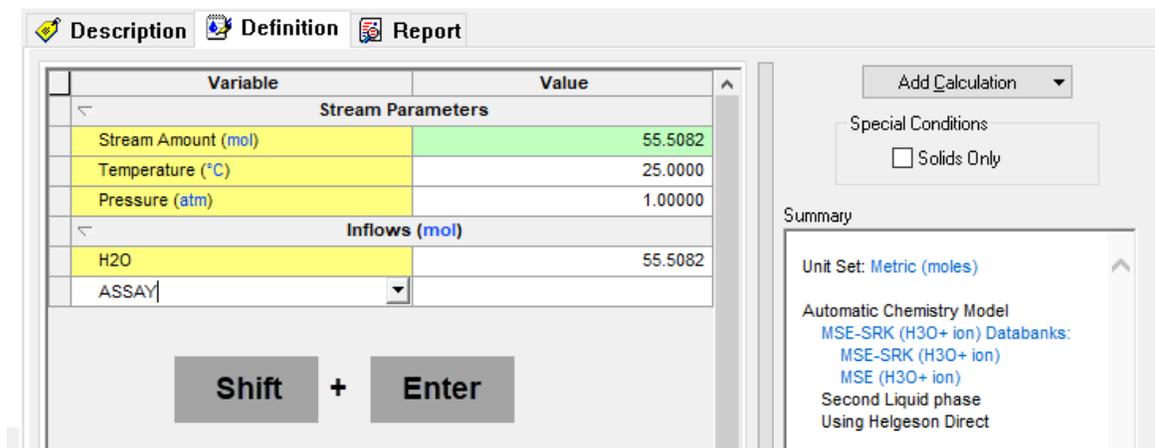
Starting the Simulation

1. Add a new **Stream**
2. **Click** on the new Stream and press <F2> to change the name to *Crude Oil*
3. Select the **MSE-SRK** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. **Enter** the conditions of the Stream T= 25 °C and 1 atm

Crude Oil Stream			
Calculation Settings		Conditions	
Stream Name	Crude Oil	Stream Amount	Default
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Moles	Pressure	1 atm
Framework	MSE-SRK		

7. In the inflows grid, in the white cell below H2O, type ASSAY and then press **<Shift + Enter>**. You can assign other name to your Assay; however, you are limited to 5 characters for the name of the Assay.

Note: The <Shift + Enter> action instructs the software to create an Assay rather than look for a species or pure component from the database.

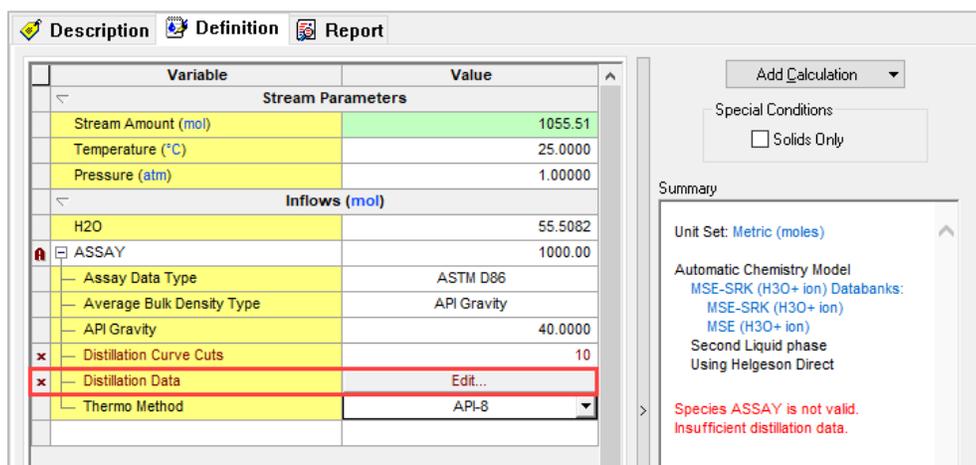


Note: After typing the name of your Assay, immediately press Shift + Enter command keys together.

8. Use the information provided in the table below to complete the grid.

Assay Information			
Calculation Settings		Distillation Data	
Assay amount	1000 moles	Percent Distilled	Temperature, °C
Assay Data Type	ASTM D86	1	20
Average Bulk Density Type	API Gravity	5	30
API Gravity	40	10	50
Distillation Curve Cuts	10	20	60
Distillation Data	See next two columns	40	80
Thermo Method	API-8	60	120
		80	150
		90	180
		95	200
		99	220
		100	240

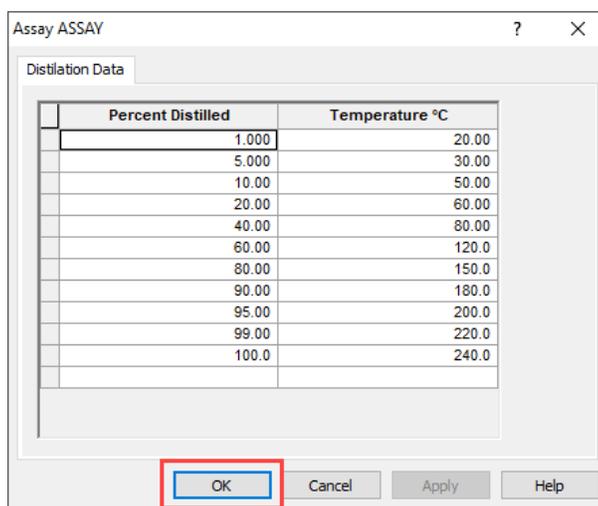
Your screen should look like the image below:



Note: You can change the Assay Data Type, the Average Bulk Density Type and the Thermo Method options by clicking on the white cells. This will enable a drop-down arrow that will show you the different options.

- Click on the **Edit** button next to the Distillation Data. This will open a new window. Complete the Distillation Data using the information given in the table above. Then click **OK**.

Note: Ctrl+C and then Ctrl+V can be used to copy and paste the data in the Distillation Data table.



The Distillation Curve Cuts will eventually become individual pseudocomponents, each with its own critical parameters and thermodynamic reference data.

- At this point we are ready to perform a calculation. Add a **Single Point** calculation, and then select an **Isothermal** calculation.
- Change the **SinglePoint** name to **Assay** using the <F2> key
- Click on the **Calculate** button or press the <F9> key to run the simulation
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. Save the calculations of this section under the name *Hydrocarbons and Pseudocomponents*.

Analyzing the Results

We will review the results first in the Output Tab and then in the Report Tab.

1. Click on the **Output Tab**

The Output Tab shows a grid with 10 different pseudocomponents, identified with the letter P, corresponding to each distillation cut of the crude. Notice that the name of each cut is the combination of the oil name (ASSAY for this example) plus its boiling point in K.

The '+' sign adjacent to each Assay expands a sub-table that contains the critical properties of each cut. These properties are: Normal boiling point, density and molecular weight.

Variable	Value
Stream Parameters	
Stream Amount (mol)	1055.51
Moles (True) - Liquid-1 (mol)	55.0810
Moles (True) - Liquid-2 (mol)	1000.43
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	55.5082
P ASSAY_243K	87.6615
Thermo Method	API-8
Normal Boiling Point (°C)	-30.2796
Specific Gravity	0.717259
Molecular Weight	47.1866
P + ASSAY_278K	82.2275
P + ASSAY_307K	200.849
P + ASSAY_337K	173.140
P + ASSAY_370K	109.658
P + ASSAY_403K	131.728
P + ASSAY_431K	110.846
P + ASSAY_464K	57.0493
P + ASSAY_496K	35.2169
P + ASSAY_524K	11.6247

Input **Output**

Advanced Search Add as Stream Export

Type of calculation: Isothermal Specs... Calculate

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model
MSE-SRK (H3O+ ion) Databanks:
MSE-SRK (H3O+ ion)
MSE (H3O+ ion)
Second Liquid phase
Using Helgeson Direct

Isothermal Calculation
25.0000 °C 1.00000 atm

Phase Amounts
Aqueous 55.0810 mol
Vapor 0.0 mol
Solid 0.0 mol
2nd Liquid 1000.43 mol

Aqueous Phase Properties
pH 6.99753
Ionic Strength 1.81246e-9 mol/mol
Density 0.997043 g/ml

Calc. elapsed time: 1.137 sec
Calculation complete

2. Click on the **Report Tab** and scroll down to the **Species Output** table.

This table shows how the pseudocomponents are distributed between the Liquid-1 and Liquid-2 phases. Notice how the Liquid-1 (or aqueous) solubility decreases with each increasing boiling point.

Jump to: Species Output (True Species)

Species Output (True Species)
Row Filter Applied: Only Non Zero Values
column Filter Applied: Only Non Zero Values

	Total	Liquid-1	Liquid-2
	mol	mol	mol
ASSAY_307K	200.849	8.35967e-5	200.849
ASSAY_337K	173.14	2.54502e-5	173.14
ASSAY_403K	131.728	1.3826e-6	131.728
ASSAY_431K	110.846	3.8351e-7	110.846
ASSAY_370K	109.657	4.50941e-6	109.657
ASSAY_243K	87.6615	2.74791e-4	87.6612
ASSAY_278K	82.2275	8.8662e-5	82.2274
ASSAY_464K	57.0493	4.39268e-8	57.0493
H2O	55.5082	55.0806	0.427678
ASSAY_496K	35.2169	4.91447e-9	35.2169
ASSAY_524K	11.6246	2.99999e-10	11.6246
OH-1	9.98321e-8	9.98321e-8	
H3O+1	9.98321e-8	9.98321e-8	
Total (by phase)	1055.51	55.081	1000.43

4.2. Entering Pseudocomponents to a Stream

There are times when the user does not have (or does not want to use) distillation data. Rather the user had the individual properties for a single pseudocomponent. OLI allows the user to enter the individual pseudocomponents. In the following example we will illustrate how.

Example 33: Creating Pseudocomponents

In this example, we will enter two properties - boiling point and density. The software will use one of four thermodynamic models – API-8, API-5, Cavett or Kessler-Lee – to calculate critical properties of pseudocomponents.

Starting the Simulation

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Crude Oil - Pseudocomponents*
3. Select the **MSE-SRK** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. **Enter** the conditions of the Stream T= 15 °C and 1 atm
7. **Change** H2O from the default value to 20 moles

Crude Oil Stream			
Calculation Settings		Conditions	
Stream Name	Crude Oil - Pseudocomponents	Stream Amount	Calculated
Name Style	Display Formula	Temperature	15 °C
Unit Set	Metric, Moles	Pressure	1 atm
Framework	MSE-SRK	H2O	20 moles

8. In the inflows grid, in the white cell below H2O, type PC1 and then press **<Ctrl + Enter>**

Note: The <Ctrl + Enter> action instructs the software to create an pseudocomponent rather than look for a species or pure component from the database.

The screenshot shows the 'Definition' tab of the software. The 'Inflows (mol)' table is visible, with 'H2O' and 'PC1' listed. A 'Ctrl + Enter' button is overlaid on the interface. The right sidebar shows 'Special Conditions' and a 'Summary' section with 'Unit Set: Metric (moles)' and 'Automatic Chemistry Model' details.

Note: After typing the name of your pseudocomponent, immediately press Ctrl + Enter command keys together.

9. Repeat step 8 four more time with the following names: PC2, PC3, PC4 and PC5. Use the information provided in the table below to complete the grid. The molecular weight will be calculated by the software. In general, only two of the three parameters need be entered.

Pseudocomponents Information					
Pseudocomponent name	PC1	PC2	PC3	PC4	PC5
Inflow (moles)	100	200	250	250	180
Thermo Method	API-8	API-8	API-8	API-8	API-8
Boiling Point (°C)	33	60	100	140	190
Specific Gravity	0.72	0.76	0.8	0.85	0.9

Your screen should look like the image below:

The screenshot displays the 'Definition' tab of a software interface. The main table lists variables and their values for various pseudocomponents. The table is structured as follows:

Variable	Value
Stream Parameters	
Stream Amount (mol)	1000.00
Temperature (°C)	15.0000
Pressure (atm)	1.00000
Inflows (mol)	
H2O	20.0000
PC1	100.000
Thermo Method	API-8
Normal Boiling Point (°C)	33.0000
Specific Gravity	0.720000
Molecular Weight	
Calculated Properties	
PC2	200.000
Thermo Method	API-8
Normal Boiling Point (°C)	60.0000
Specific Gravity	0.760000
Molecular Weight	
Calculated Properties	
PC3	250.000
Thermo Method	API-8
Normal Boiling Point (°C)	100.000
Specific Gravity	0.800000
Molecular Weight	
Calculated Properties	
PC4	250.000
Thermo Method	API-8
Normal Boiling Point (°C)	140.000
Specific Gravity	0.850000
Molecular Weight	
Calculated Properties	
PC5	180.000
Thermo Method	API-8
Normal Boiling Point (°C)	190.000
Specific Gravity	0.900000
Molecular Weight	
Calculated Properties	

The right sidebar contains the following information:

- Unit Set: Metric (moles)
- Automatic Chemistry Model
- MSE-SRK (H3O+ ion) Databanks:
 - MSE-SRK (H3O+ ion)
 - MSE (H3O+ ion)
- Second Liquid phase
- Using Helgeson Direct

Notice that at the bottom of each pseudocomponent there is a “+” and a field called calculated properties. Stream Analyzer immediately predicts all the calculated properties for each pseudocomponent. Click the “+” sign next to PC1 to expand and see these properties.

Description			Definition			Report		
		Variable			Value			
Stream Parameters								
		Stream Amount (mol)			1000.00			
		Temperature (°C)			15.0000			
		Pressure (atm)			1.00000			
Inflows (mol)								
		H2O			20.0000			
		PC1			100.000			
		Thermo Method			API-8			
		Normal Boiling Point (°C)			33.0000			
		Specific Gravity			0.720000			
		Molecular Weight						
		Calculated Properties						
		Calc:Molecular Weight			70.3287			
		Calc:Specific Gravity			0.720000			
		Calc:Boiling Point (°C)			33.0000			
		Calc:Critical Temperature (°C)			213.813			
		Calc:Critical Pressure (atm)			42.1427			
		Calc:Critical Volume (L/mol)			0.271026			
		Calc:Acentric Factor			0.197144			
		Calc:HREF Vapor			-1.28412e5			
		Calc:GREF Vapor			-9686.26			
		Calc:SREF Vapor			343.881			
		Calc:CPREF Vapor			103.303			
		Calc:VREF			24.4483			
		Calc:HREF Aqueous			-1.39845e5			
		Calc:GREF Aqueous			9148.86			
		Calc:SREF Aqueous			242.360			
		Calc:CPREF Aqueous			244.429			
		Calc:Rackett			0.277609			
		PC2			200.000			
		Thermo Method			API-8			
		Normal Boiling Point (°C)			60.0000			
		Specific Gravity			0.760000			
		Molecular Weight						
		Calculated Properties						
		PC3			250.000			
		Thermo Method			API-8			
		Normal Boiling Point (°C)			100.000			

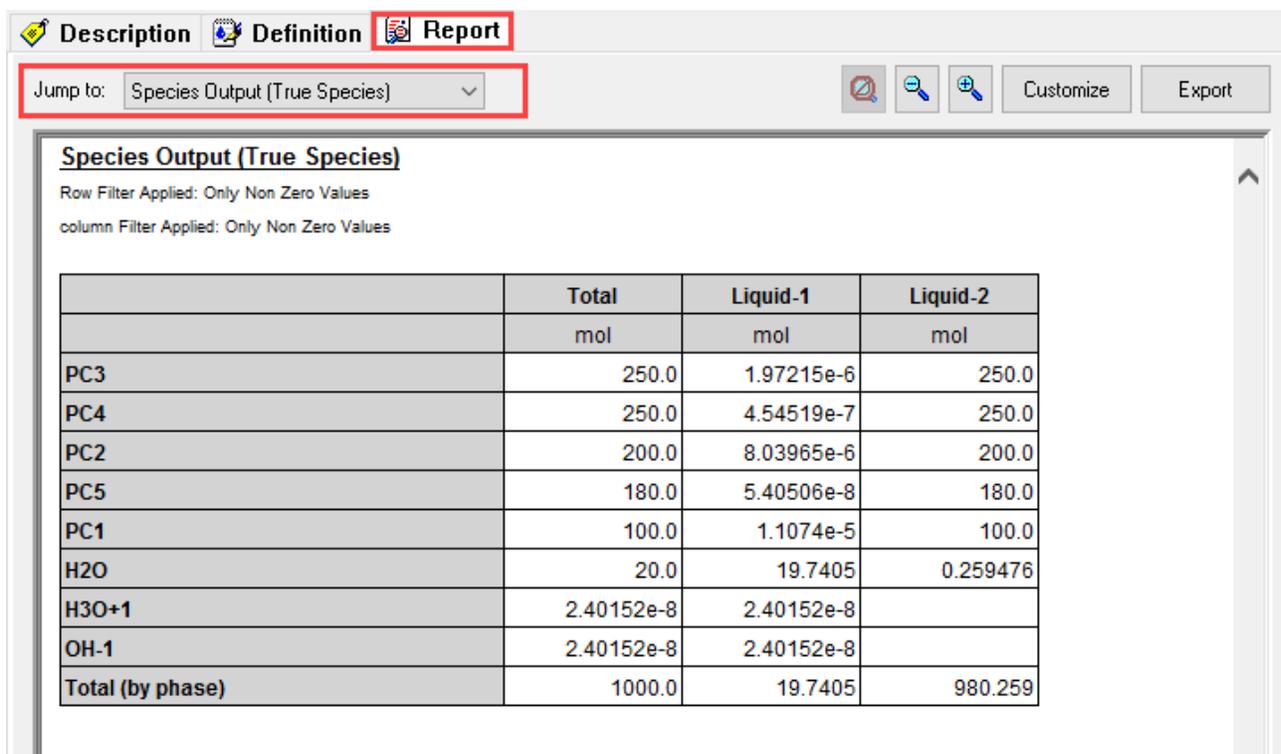
The values in the green boxes can be changed to match data from other programs.

- At this point we are ready to perform a calculation. Add a **Single Point** calculation, and then select an **Isothermal** calculation.
- Change the **SinglePoint** name to **Pseudocomponents** using the <F2> key
- Click on the **Calculate** button or press the <F9> key to run the simulation
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. Save the calculations of this section under the name *Hydrocarbons and Pseudocomponents*.

Analyzing the Results

1. Click on the **Report Tab** and scroll down to the **Species Output** table.

This table shows how the pseudocomponents are distributed between the Liquid-1 and Liquid-2 phases.



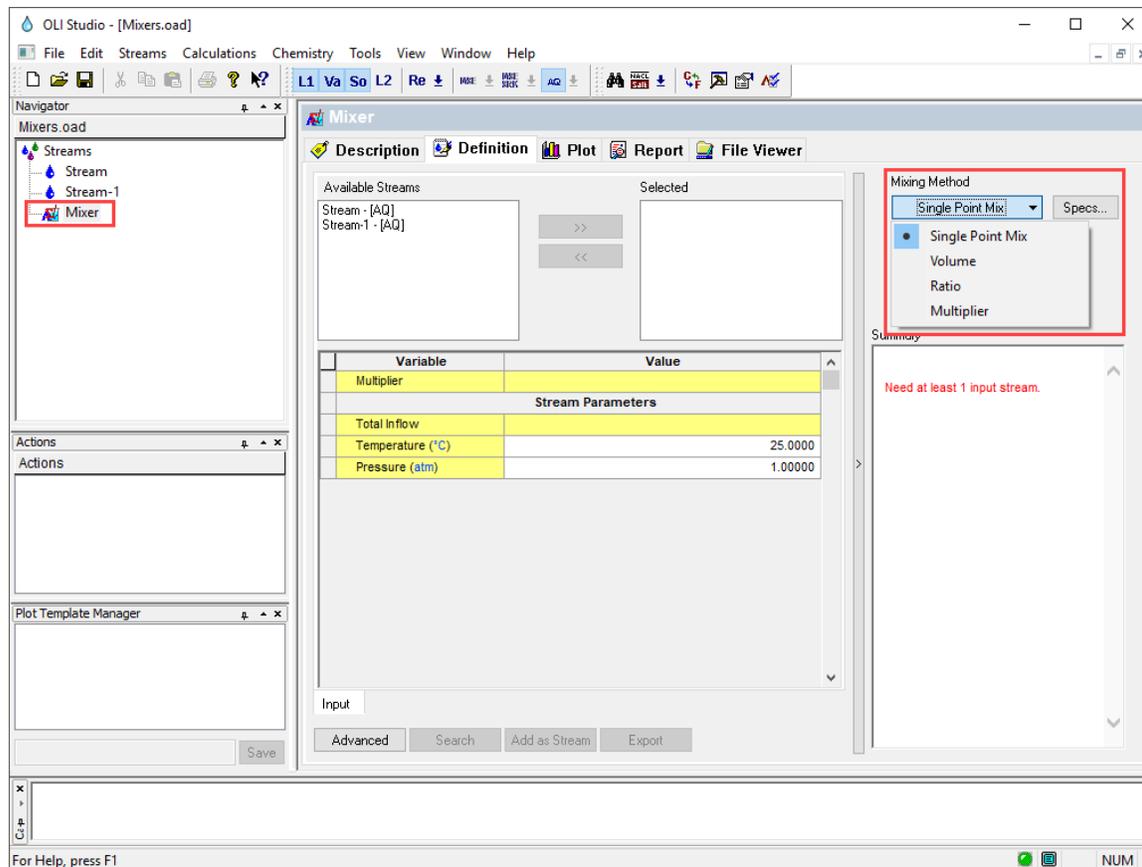
The screenshot shows a software interface with three tabs: 'Description', 'Definition', and 'Report'. The 'Report' tab is selected and highlighted with a red box. Below the tabs, there is a 'Jump to:' dropdown menu with 'Species Output (True Species)' selected, also highlighted with a red box. To the right of the dropdown are icons for zooming and buttons for 'Customize' and 'Export'. Below this is a table titled 'Species Output (True Species)'. The table has a row filter 'Only Non Zero Values' and a column filter 'Only Non Zero Values'. The table has four columns: 'Total', 'Liquid-1', and 'Liquid-2', all with units in 'mol'. The rows are: PC3, PC4, PC2, PC5, PC1, H2O, H3O+1, OH-1, and Total (by phase).

	Total	Liquid-1	Liquid-2
	mol	mol	mol
PC3	250.0	1.97215e-6	250.0
PC4	250.0	4.54519e-7	250.0
PC2	200.0	8.03965e-6	200.0
PC5	180.0	5.40506e-8	180.0
PC1	100.0	1.1074e-5	100.0
H2O	20.0	19.7405	0.259476
H3O+1	2.40152e-8	2.40152e-8	
OH-1	2.40152e-8	2.40152e-8	
Total (by phase)	1000.0	19.7405	980.259

You can download a worked copy of this example from here: [Chapter 13 – Petroleum Fractions.](#)

Section 5. Mixers

Mixers are a useful tool to mix one or more streams. This tool allows you to mix Molecular Streams or Reconciled Streams.



In this section, you will learn how to set up a **Mixer** and differentiate the different mixing options to get the most out of your simulation results.

5.1. Mixing Options (Definitions)

The Mixer Object has four different mixing options: Single point mix, Volume, Ratio, and Multiplier. A quick summary of what each mixing options allows you to do is summarized here.

Single Point Mix

This option allows you to multiply up or down a stream inflow. When selecting the streams to mix, this option will enable the multiplier option for both streams. You can leave the default values that are set by default to 1.0 or change the multiplier values to any other number.

Volume

In this option, one stream stays at a constant volume, while the other stream's volume changes within a range specified by the user, as is illustrated in the table below:

Stream 1	Stream 2
1 L	1 L
1 L	2 L
...	...
1 L	n L

Ratio

In the ratio mixing type, both streams change at the same time. For example, stream will be 100% and Stream will be 0%, then Stream 1 will be 90% and Stream 2 will be 10%, and so on, until it reaches Stream 1 0% and Stream 2 100%.

Stream 1	Stream 2
100 %	0 %
90 %	10%
...	...
0 %	100 %

Multiplier

In this mixing option, one stream stays constant, while the other stream changes using a multiplier. The range of the multiplier values is given by the user.

Stream 1	Stream 2
1	Stream 2 \times 0
1	Stream 2 \times 1
...	...
1	Stream 2 \times n

5.2. A Basic Mixer Calculation

A brief introduction to the Mixer tool will be shown in the example below. As we go through the example, basic definitions, functionalities and reporting for the *Mixer tool* will be introduced.

Example 34: Calculating the Heat of Mixing

You will mix 1 L of a 10 wt% Ca(OH)₂ solution with 1 L of a 10% HCl solution, and then you will ask the software to calculate the **heat of mixing** and the **final temperature** of the mixture.

Starting the Simulation

In this example we need to create two different streams: a 10 wt% Ca(OH)₂ solution and a 10% HCl solution.

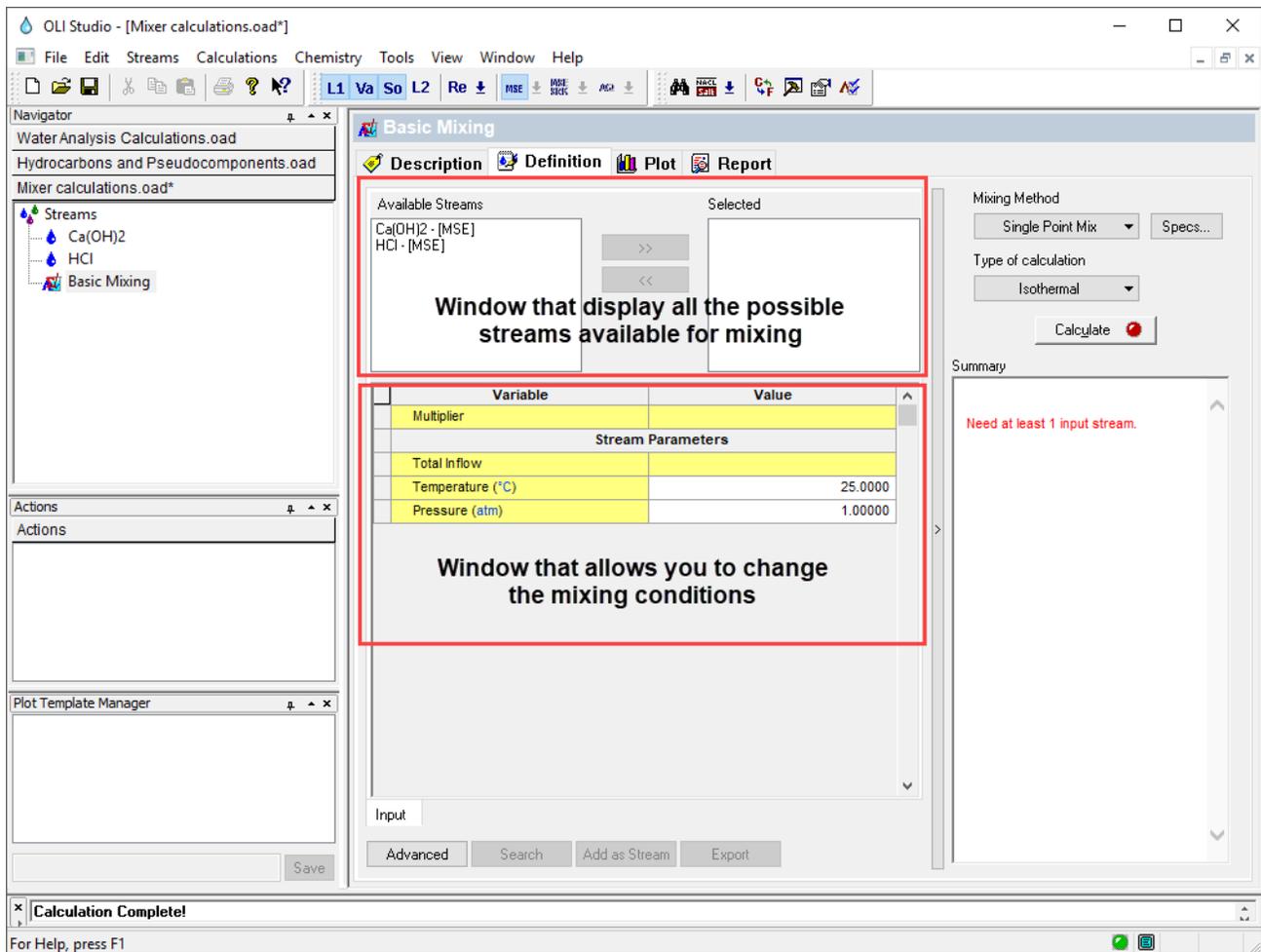
Use the inputs and parameters from the table below to create each stream. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Basic Mixing Calculation			
1 st Stream		2 nd Stream	
Stream Name	Ca(OH) ₂	Stream Name	HCl
Name Style	Display Formula	Name Style	Display Formula
Unit Set	Metric, Batch, Mass Frac.	Unit Set	Metric, Batch, Mass Frac.
Framework	MSE	Framework	MSE
Stream Amount	1 kg	Stream Amount	1 kg
Temperature	25 °C	Temperature	25 °C
Pressure	1 atm	Pressure	1 atm
H ₂ O	Calculated	H ₂ O	Calculated
Ca(OH) ₂	10 mass%	HCl	10 mass%

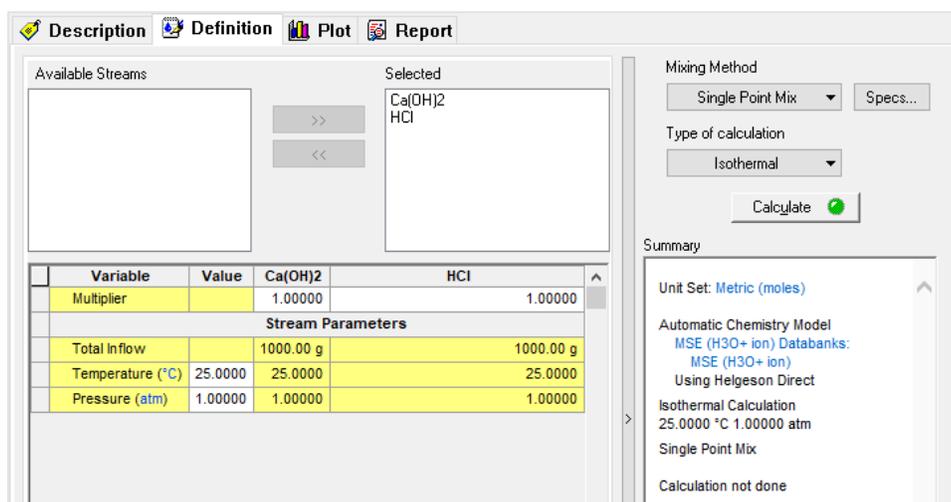
1. After creating the streams, **Add a Mixer**. The Mixer object can be accessed from the Menu Bar by selecting Calculations > **Add Mixer** or by selecting the **Add Mixer** in the Actions Pane.
2. Press <F2> to rename the mixer to *Basic Mixing*

Notice that the display layout for the Mixer tool is slightly different. There are two different windows (see image below).

- The first window displays all possible streams available for the mix calculation. There is no limit to the number of streams to be mixed.
- The second window allows you to change the mixing conditions, e.g. temperature, and pressure of the mixing.



3. **Select** the Ca(OH)₂ stream from the available streams and use the >> button to put it under the **Selected** window
4. **Select** the HCl stream from the available streams and use the >> button to put it under the **Selected** window



Also notice that the default calculation is the **Single Point Mix** Method at **Isothermal** conditions. In this example, we want to calculate the heat of mixing and the final temperature of the mixture. Thus, an adiabatic calculation is required to see this effect.

- Click on the **Type of Calculation** button and select the **Adiabatic** calculation option

Note: Once the streams for the mixing have been selected, notice that the multipliers of both streams: Ca(OH)₂ and HCl can be edited. This specific calculation will be carried out at a constant pressure of 1 atm, and the final temperature of the mixture will be calculated.

The screenshot shows the software interface with the following details:

- Available Streams:** (Empty)
- Selected:** Ca(OH)₂, HCl
- Mixing Method:** Single Point Mix
- Type of calculation:** Adiabatic
- Calculate:** (Green checkmark icon)
- Summary:**
 - Unit Set: Metric (moles)
 - Automatic Chemistry Model
 - MSE (H3O+ ion) Databanks: MSE (H3O+ ion)
 - Using Helgeson Direct
 - Isoenthalpic Calculation
 - 0.0 cal
 - 1.00000 atm
 - Single Point Mix
 - Calculation not done

Variable	Value	Ca(OH) ₂	HCl
Multiplier		1.00000	1.00000
Stream Parameters			
Total Inflow		1000.00 g	1000.00 g
Temperature (°C)	25.0000	25.0000	25.0000
Pressure (atm)	1.00000	1.00000	1.00000

- Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
- It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it and name it as *Mixer Calculations*.

Analyzing the Results

Review the Summary Box. After mixing these two streams, the temperature increased from 25 °C to approximately 48.65 °C at a constant pressure of 1 atm. This indicates that the enthalpy (or heat) of mixing is exothermic, and the software calculated this value to be approximately -7.25×10^6 calories.

5.3. A Titration Experiment

In this example, you will explore the volume mixing option to recreate a titration experiment. As we go through the example, different functionalities, reporting and plotting for the *Mixer tool* will be introduced.

Example 35: HF Titration with CaCl₂

In this example, first, we will create two new streams, a 0.1 m HF solution and a 0.1 m CaCl₂ solution. What is the pH of these individual streams?

Second, we will mix these two streams in equal amounts. What is the final pH of the mixture?

And finally, the 0.1 m HF solution will be titrated with a 0.1 m CaCl₂ solution. What will the titration curve look like?

Starting the Simulation

For this example, we need to create two different streams: a 0.1 m HF solution and a 0.1 m CaCl₂ solution.

Use the inputs and parameters from the table below to create each stream. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Titration Calculation			
1 st Stream		2 nd Stream	
Stream Name	0.1 m HF	Stream Name	0.1 m CaCl ₂
Name Style	Display Formula	Name Style	Display Formula
Unit Set	Metric, Batch, Moles	Unit Set	Metric, Batch, Moles
Framework	AQ	Framework	AQ
Stream Amount	Calculated	Stream Amount	Calculated
Temperature	30 °C	Temperature	30 °C
Pressure	1 atm	Pressure	1 atm
H ₂ O	55.5082 moles	H ₂ O	55.5082 moles
HF	0.1 moles	CaCl ₂	0.1 moles

Calculating the pH of the individual streams

1. Add a **Single Point – Isothermal** calculation for each stream
2. **Change** the name to **pH 0.1 m HF** and **pH 0.1 m CaCl₂** respectively using the <F2> key
3. **Calculate** the isothermal calculation for each stream
4. **Check** the pH values of the individual streams in the **Summary Box**

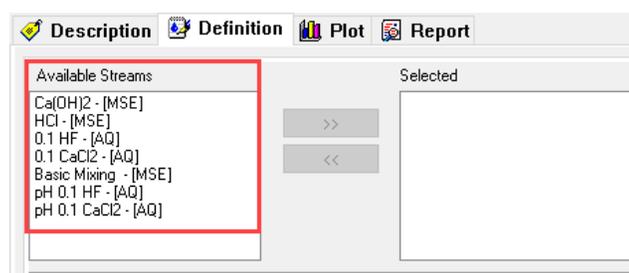
Results – pH of the individual streams

pH 0.1 m HF	pH 0.1 m CaCl ₂
2.13	6.82

Calculating the pH of the Mixture

- After creating the streams, **Add a Mixer**. The Mixer object can be accessed from the Menu Bar by selecting Calculations > **Add Mixer** or by selecting the **Add Mixer** in the Actions Pane.
- Press <F2> to rename the mixer to *Titration*

Note: Notice that the Available Streams window is showing all the available streams for the mixing calculation. Also notice that this window is showing both: *Streams* and *Single Point calculations*. Additionally, in front of the name of the available streams, the thermodynamic framework appears within brackets, e.g. AQ, MSE or MSE-SRK. This is important because in order to carry out mixing calculations, the selected streams need to use the same thermodynamic framework.



- Select** the 0.1 HF – [AQ] stream. Use the >> button to move it to the **Selected** window
- Select** the 0.1 CaCl2 stream. Use the >> button to move it to the **Selected** window
- Select **Single Point Mix** as the Mixing Method and **Isothermal** as the Type of Calculation
- Leave** the default values for the multipliers (1.0) and **change** the temperature at which the mixture takes place to 30 °C.

Variable	Value	0.1 HF	0.1 CaCl2
Multiplier		1.00000	1.00000
Stream Parameters			
Total Inflow		55.6082 mol	55.6082 mol
Temperature (°C)	30.0000	30.0000	30.0000
Pressure (atm)	1.00000	1.00000	1.00000

- Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
- At this point is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Mixer Calculations*.
- Check** the pH values of the individual streams in the **Summary Box**

Results – pH of the individual streams

The resultant pH is 1.44. How can this be? An acid stream (the HF stream had a pH of approximately 2.13) and a nominally basic stream (the CaCl₂ stream had a pH of 6.82) are mixed and the pH is outside the value of either stream.

We will continue using Stream Analyzer to further examine the chemistry in more detail. We will titrate the HF stream with CaCl₂.

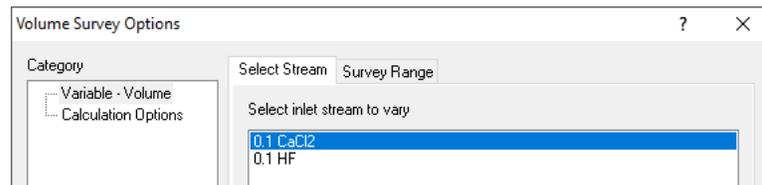
Titrating HF with CaCl₂

14. Change the **Single Point Mix** as the Mixing Method to the **Volume** option.

Note: You will receive a warning message: **Need 1 stream selected as the variable stream (Specs...)**

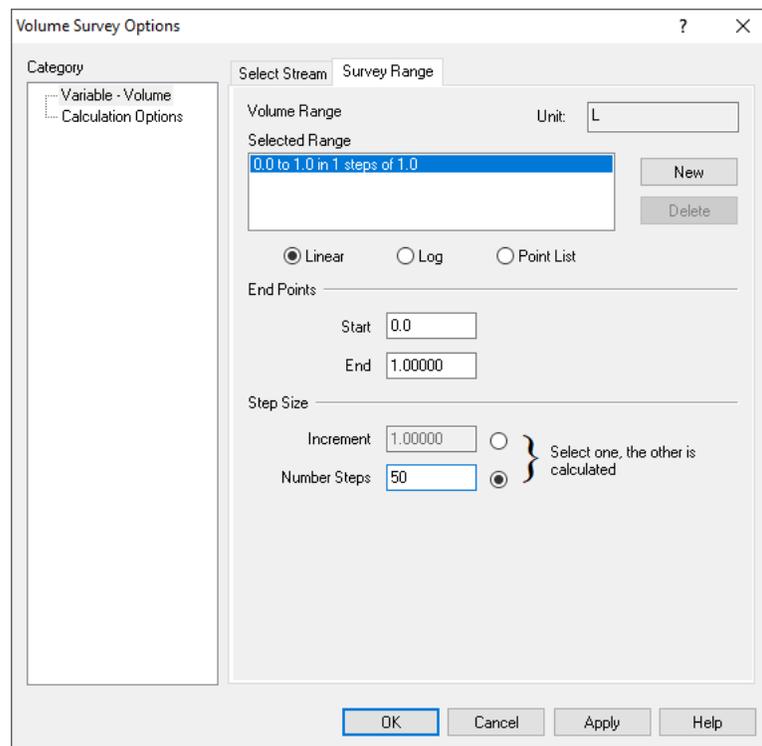
15. **Click** on the **Specs** button. This will open a new window indicating you to select the Stream to vary

16. In the **Select Stream** tab **Select** the 0.1m CaCl₂ stream



17. **Select** the **Survey Range** tab. Change the Volume Range from 0 L to 1 L.

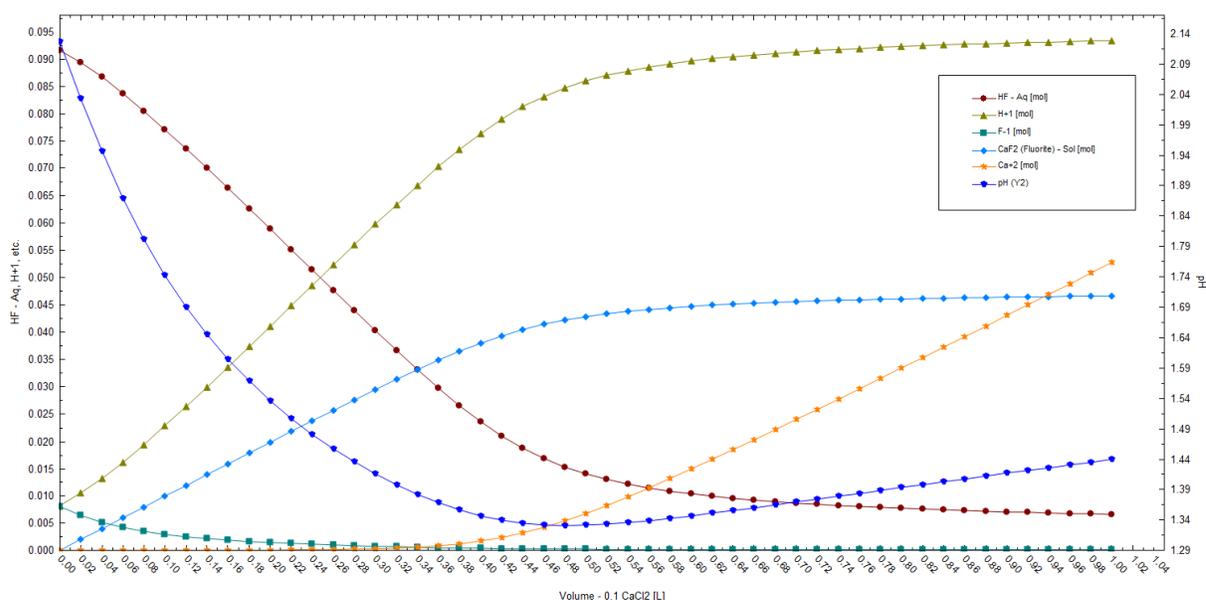
18. Change the **Number of Steps** to 50. Then click **OK**.



- Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
- It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Mixer Calculations*.

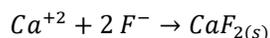
Titration Results and Plotting

- Click** on the **Plot** tab. **Note:** You will see an empty plot, since we need to define the variables that we want to report.
- Click** on the **Variables** button and expand the **Aqueous** section. **Select** and put the following species in the **Y1 axis** using the **>>** button: HF-Aq, H+1, F-1, Ca+2. Expand the **Solid** section and **select** CaF₂(s).
- Next, expand the **Additional Parameters** Section and **Select** **pH**. Put it in the **Y2 Axis** using the **>>** button. Then click **OK**.

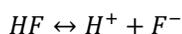


As you can see, adding CaCl₂ to this solution lowers the pH to values as low as 1.33. The pH does begin to slowly increase after 0.48 L of CaCl₂ have been added.

Why the unusual pH behavior? You can see that a small amount of Ca⁺² in solution, causes the formation of the solid CaF₂. This effectively removes F⁻ from solution according to the following equation:



As we add more CaCl₂ in solution, more CaF₂ is formed. As a result, the molecular HF decreases, because it dissociates in order to maintain the equilibrium, by producing more F⁻ ions. This shifts the following equilibrium to the right:



This causes an increase of H⁺ in solution, and as a result a decrease in the pH. At some point, at around 0.48 L of 0.1 m CaCl₂, the solid reaches a steady value, indicating that the solid has reached its saturation value.

5.4. Cascading Mixers **NEED TO FINISH THIS SECTION**

Example 36: Cascading Mixers

In this example, we will mix two streams, one basic and one acidic, and mix them together under adiabatic conditions. The output of this mixer will then be used as the input to a second mixer where a new caustic stream is added. The schematic in Figure 0-1 below illustrates the layout.

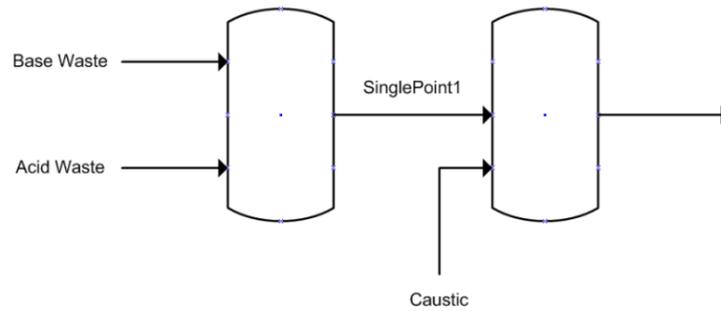


Figure 0-1 Schematic of cascading mixers

For this example, we need to create three streams. You have already done this in other examples, so we will only give you the input data (for all streams, we will use the AQ – default – thermodynamic framework)

Table 2 Cascading Mixer Stream Data

Parameter	Value	Units
Stream Name	Base Waste	
Temperature	25.0	°C
Pressure	1.0	Atmospheres
Stream Amount	55.5082 (Default)	Mole
H ₂ O	55.5082	Mole

CO2	0.1	Mole
NH3	0.01	Mole
SO2	0.01	Mole
Stream Name	Acid Waste	
Temperature	25.0	°C
Pressure	1.0	Atmospheres
H ₂ O	55.5082	Mole
HCl	0.1	Mole
H ₂ SO ₄	1.0	Mole
Stream Name	Acid Waste	
Temperature	25.0	°C
Pressure	1.0	Atmospheres
H ₂ O	55.5082	Mole
NaOH	1.0	Mole

To test that our streams are representing their respective names, perform a single point isothermal flash on each stream. When you are done you should have a window that looks like Figure 0-2 below:

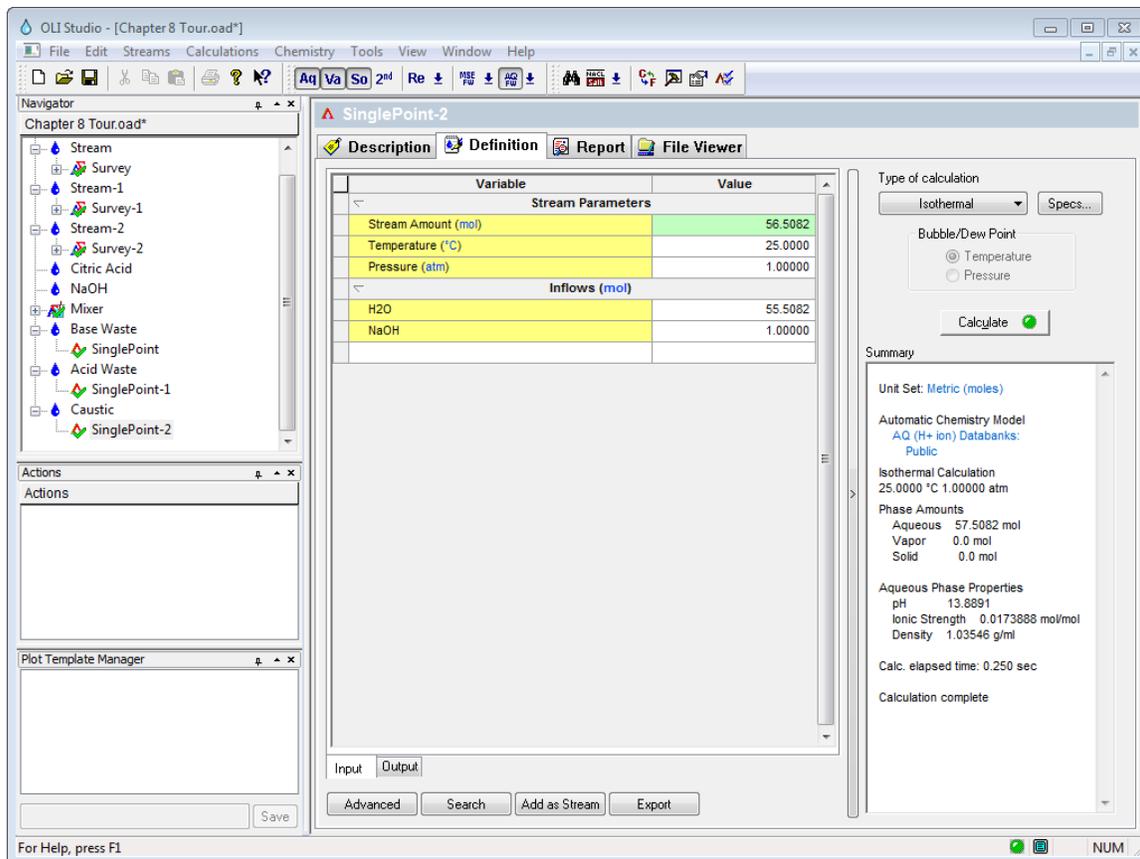


Figure 0-2 completed inputs for cascading mixer

Now we are ready to begin. Click on the “Streams” at the top of the tree-view in the left-hand window and then select Add Mixer from the actions panel.

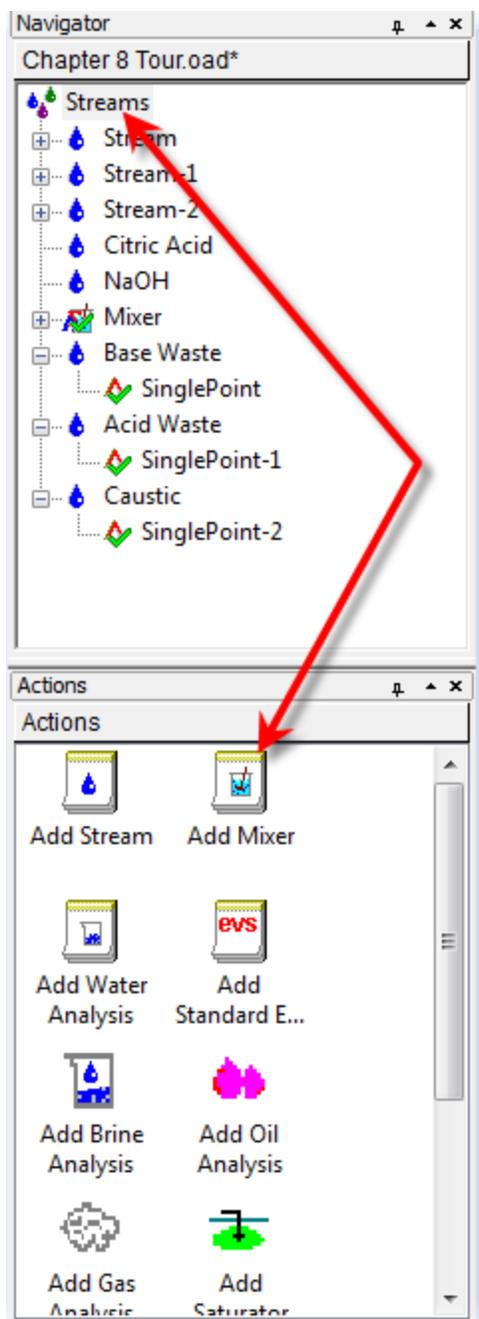


Figure 0-3 Adding a mixer

We can now add the “Base Waste” and “Acid Waste” stream as we have done in previous examples. The only difference here is that we are selecting an **Adiabatic** calculation instead of the default isothermal calculation.

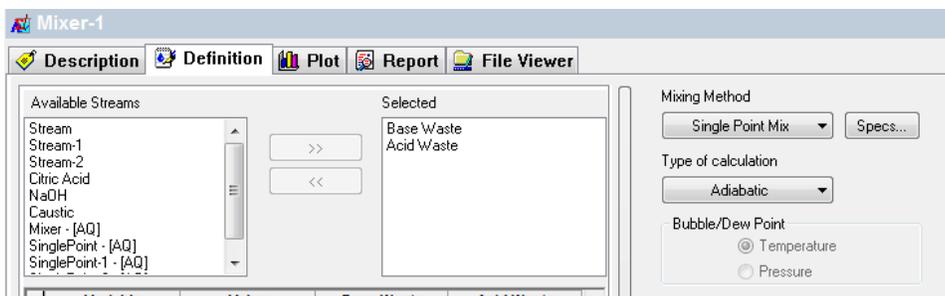


Figure 0-4 Selecting the Base and Acid waste stream

Let's calculate this mixer. Click the Calculate button. If everything is set up correctly the resultant mixed pH should be approximately 0.37

In the stream tree-view panel, locate your mixer and click the "+" sign.

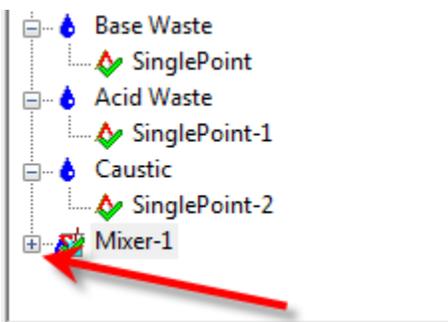


Figure 0-5 Click the "+" sign to expand the tree

Click the "+" sign to expand the tree.

⁷ You can use the Report Tab to find the pH value.

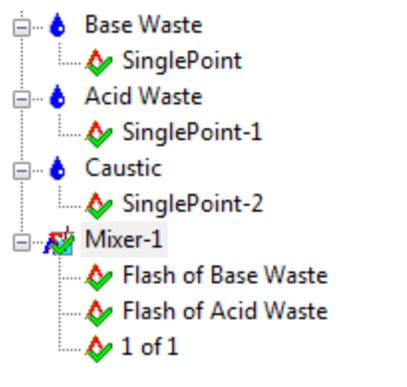


Figure 0-6 Expanded tree view

You can see that the program has performed an equilibrium calculation on each of our input streams as well as calculated the mixer. The results of the mixer are stored in the object “1 of 1”.

We will now add a second mixer from the actions panel.

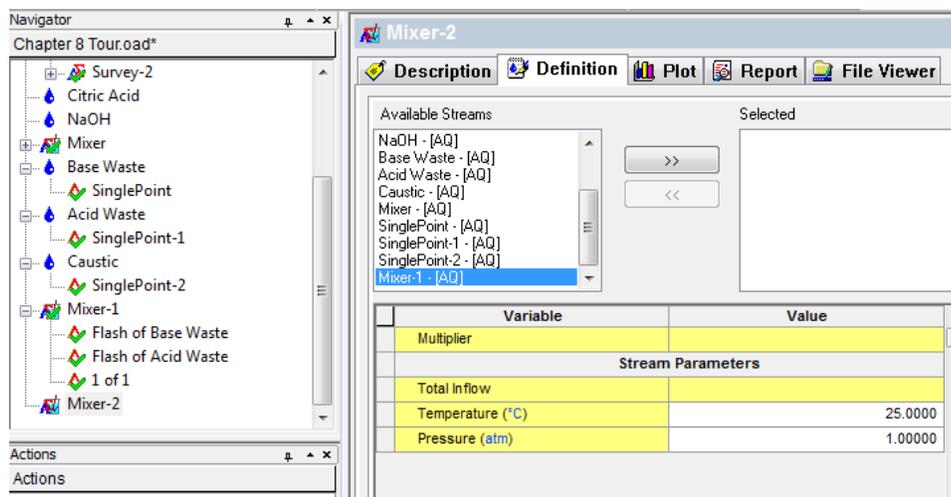


Figure 0-7 Adding the second mixer

When we add a subsequent mixer, we will see all of our previous objects still displayed. It is possible to reuse a stream that we already used (this is not possible in OLI's other simulators such as OLI Flowsheet.) We want to connect the output from our first mixer (Mixer1) to the inlet of the **Caustic** stream. Click the object **Mixer-1-(AQ)** as highlighted in Figure 0-7 above.

Then add the Caustic Reagent. Select the type of calculation as Isothermal.

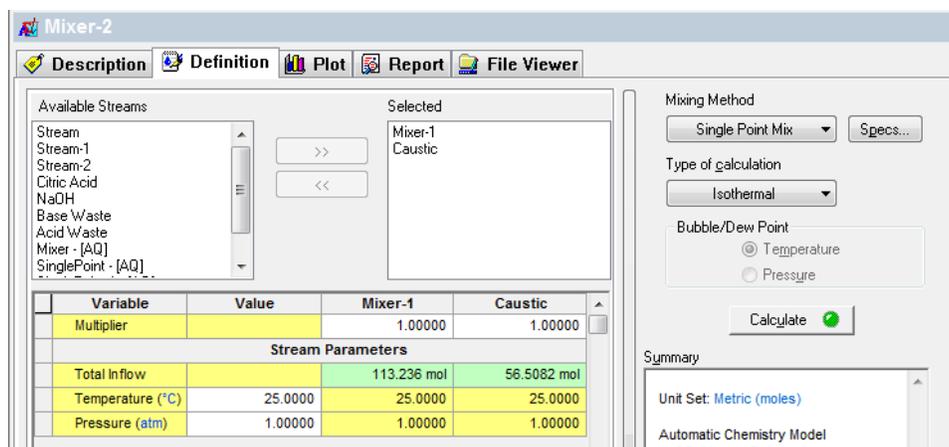


Figure 0-8 connecting the output of mixer 1 to the new mixer

We are now ready to calculate the second mixer. Press the calculate button.

The resultant pH should be approximately 1.0. We want to increase this value. Change the **Multiplier** value for Caustic Stream from 1.0 to 2.4

Variable	Value	Mixer-1	Caustic
Multiplier		1.00000	2.40000
Stream Parameters			
Total Inflow		113.236 mol	56.5082 mol
Temperature (°C)	25.0000	25.0000	25.0000
Pressure (atm)	1.00000	1.00000	1.00000

Figure 0-9 Changing the multiplier value

Click the calculate button again. The new pH should be approximately 12.4.

The real value of the cascading mixer is the quick ability to re-calculate the objects if we want to change something. Let's add some diethanolamine to the series of calculations. Click the **Acid Waste** stream (not the single point calculation below it) and add the component DEXH⁸ to the grid with a value of 10.0 moles.

⁸ This is the OLI Tag name for diethanolamine, which is easier to type if you know the name.

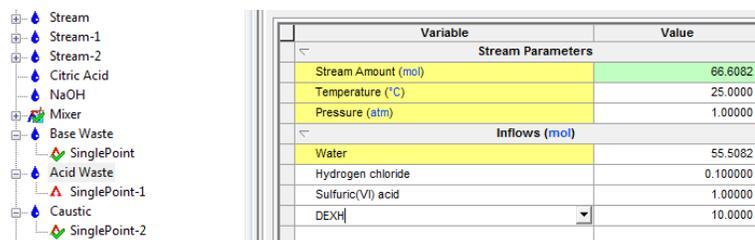


Figure 0-10 Adding diethanolamine, note that the Acid Waste Stream is highlighted.

Return to the last mixer you created (Mixer-2 in our example) and then reduce the **Caustic Multiplier** back to 1.0

To recalculate all the objects at once, press the control-F9 keys and all objects will be calculated. Now if you look at the summary of Mixer2 you will see that the pH has changed to approximately 10.

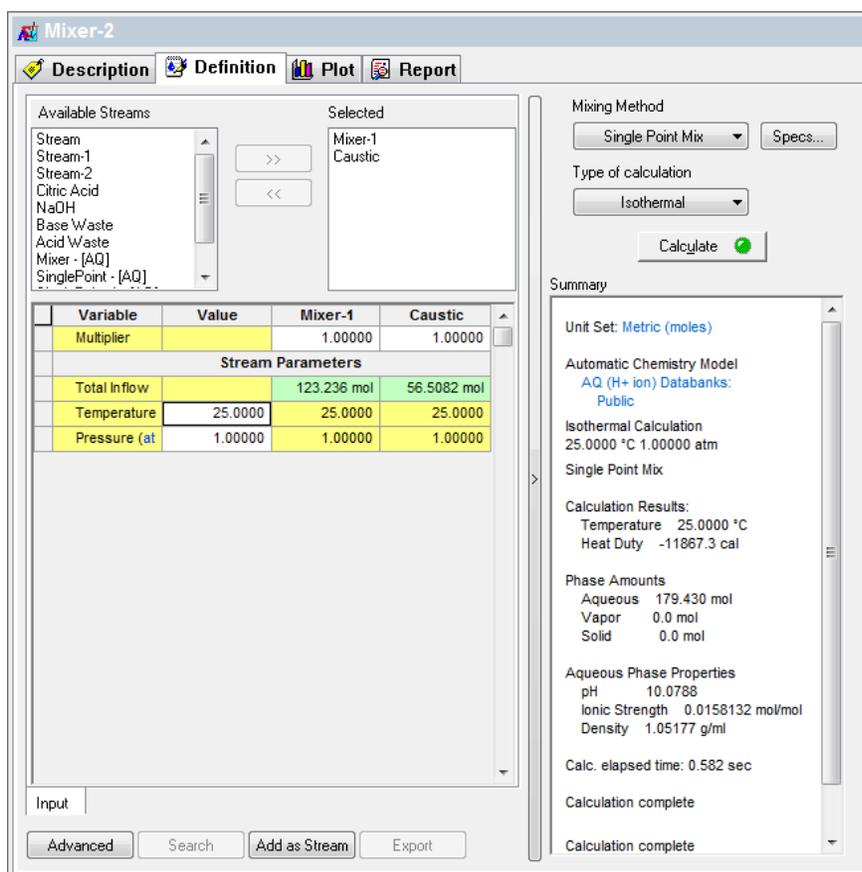


Figure 0-11

Section 6. Chemical Stability Diagrams

“Predicting the stability of chemical compounds as a function of solution chemistry is crucial towards understanding the electrochemical characteristics of materials in real-world applications. There are several commonly considered factors that affect the stability of a chemical compound, such as metal ion concentration, mixtures of ion concentrations, pH, buffering agents, complexation agents, and temperature. Chemical stability diagrams graphically describe the relative stabilities of chemical compounds, ions, and complexes of a single element as a function of bulk solution chemistry (pH and metal ion concentration) and also describe how solution chemistry changes upon the thermodynamically driven dissolution of a species into solution as the system progresses towards equilibrium”⁹.

Stream Analyzer has the capability of building chemical stability diagrams by using the *Chemical Diagram tool* that allows to study the precipitation of species as function of ion concentration and other parameters such as pH. In this section we will explore with different examples how to set up cases to use the Chemical Diagram tool.

The screenshot displays the OLI Studio software interface for creating a chemical stability diagram. The main window is titled "Chemical Diagram" and contains several panels:

- Navigator:** Shows a tree view with "Streams" and "Chemical Diagram" highlighted.
- Table:** A table with columns "Variable", "Stream Parameters", and "Value".

Variable	Stream Parameters	Value
Stream Parameters		
Stream Amount (mol)		55.5082
Temperature (°C)		25.0000
Pressure (atm)		1.00000
Inflows (mol)		
H2O		55.5082
- Configuration Panel (Right):** Contains settings for the diagram type and model.
 - Type of diagram:** A dropdown menu set to "Species vs. Species".
 - Unit Set:** Metric (moles).
 - Automatic Chemistry Model:** Aqueous (H+ ion) Databanks: Aqueous (H+ ion).
 - Using K-fit Polynomials:** T-span: 25.0 - 225.0, P-span: 1.0 - 1500.0.
 - Stability diagram:** vs. Specify an X variable component for this diagram type.
 - Specify at least 1 Y variable component for this diagram type.**
 - Calculation not done.**
- Buttons:** "Advanced", "Search", "Add as Stream", "Export", and "Save".

A status bar at the bottom indicates "Calculation Complete" and "For Help, press F1".

⁹ Santucci, R.J., McMahon, M.E. and Scully, J.R., 2018. Utilization of chemical stability diagrams for improved understanding of electrochemical systems: evolution of solution chemistry towards equilibrium. *npj Materials Degradation*, 2(1), p.1.

6.1. Building a Chemical Diagram

In this section, first we will go through the steps of building a basic chemical diagram, and then we will explore how the concentration of species and other variables such as temperature and pressure have a significant influence on the stability of chemical species.

Example 37: $\text{La}(\text{C}_2\text{H}_3\text{O}_2)_3 - \text{K}_3\text{PO}_4$ Chemical Diagram

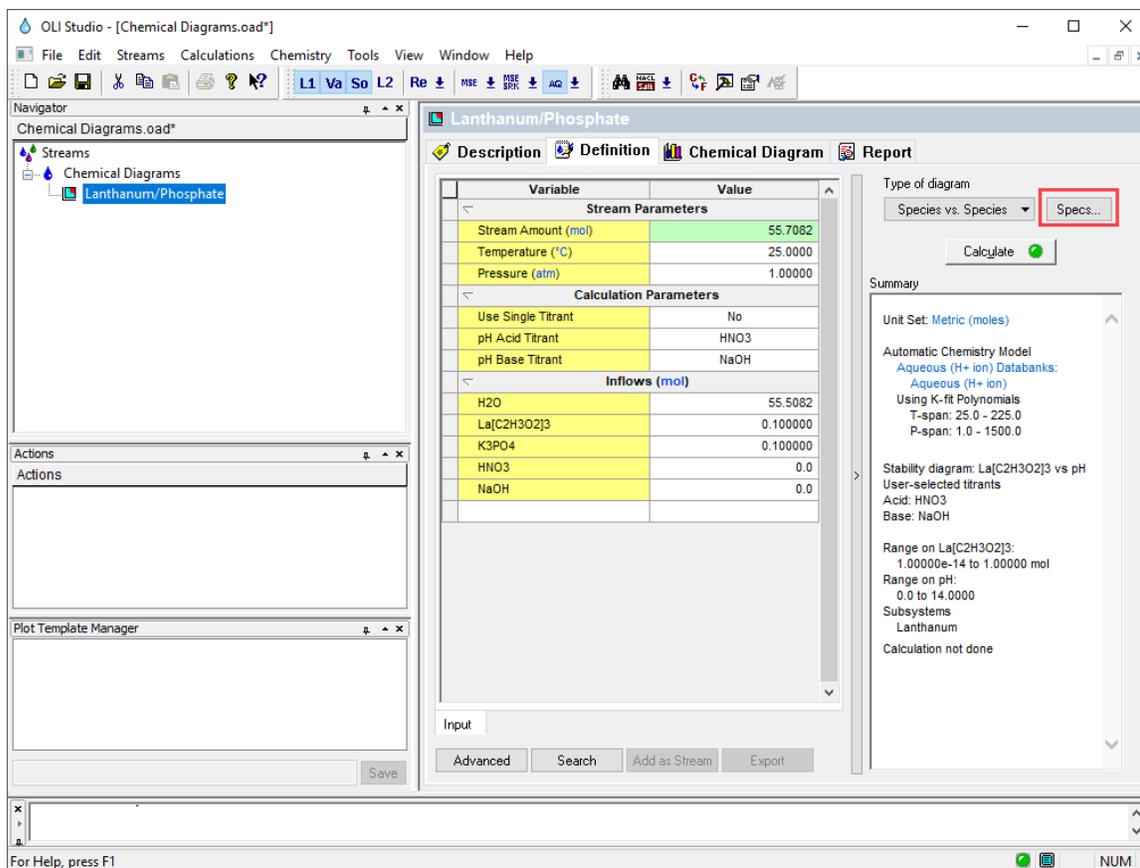
For this example, we are going to reproduce the work found in the following paper: *Andelman, T., Tan, M. C., & Riman, R. (2010). Thermochemical engineering of hydrothermal crystallization processes. Materials Research Innovations, 14(1), 9-15. <https://doi.org/10.1179/143307510X12599329343123>.*

Starting the Simulation

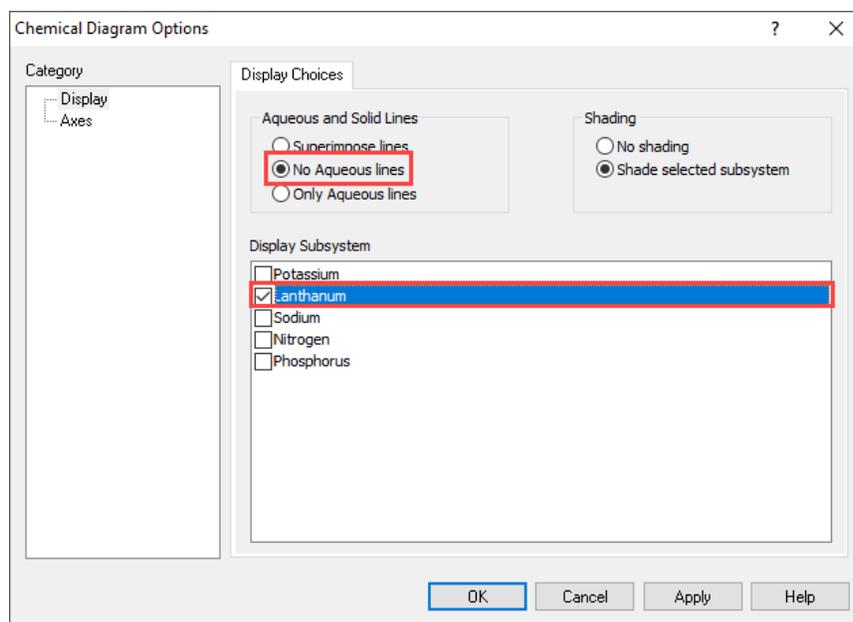
Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

La(C ₂ H ₃ O ₂) ₃ – K ₃ PO ₄ Chemical Diagram			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Chemical Diagrams	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	H ₂ O	55.5082 moles
Type of Calculation	Chemical Diagram	La[C ₂ H ₃ O ₂] ₃	0.1 moles
		K ₃ PO ₄	0.1 moles
		HNO ₃	0.0 moles
		NaOH	0.0 moles

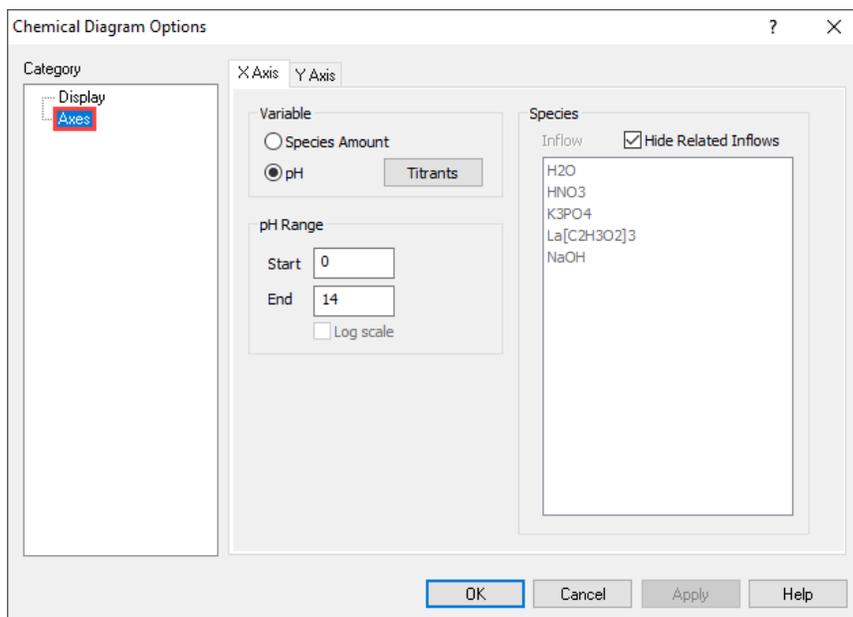
1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Chemical Diagrams*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition of the stream given in the table above. Notice that the concentrations of La(C₂H₃O₂)₃ and K₃PO₄ are held at a 1:1 molal ratio.
7. Go to the **Add Calculation** button and select **Chemical Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane
8. Select **Species vs Species** as Type of Diagram – Default
9. Change the **Chemical Diagram** name to *Lanthanum/Phosphate* using the **<F2>** key



10. Click on the **Specs** button. This will open the **Chemical Diagram Options** window
11. In the **Display Choices** tab, select the **No Aqueous lines** button and check the box for **Lanthanum** as the subsystems to display

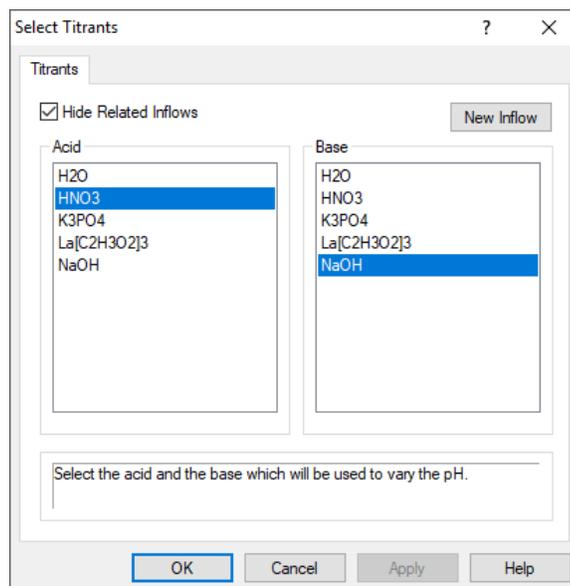


- Click on the **Axes** category. The dialog changes to display the **X Axis** tab.
- In the **Variable** section select the **pH** option. Leave the default **pH Range**: 0-14. This also enables the **Titrants** button.

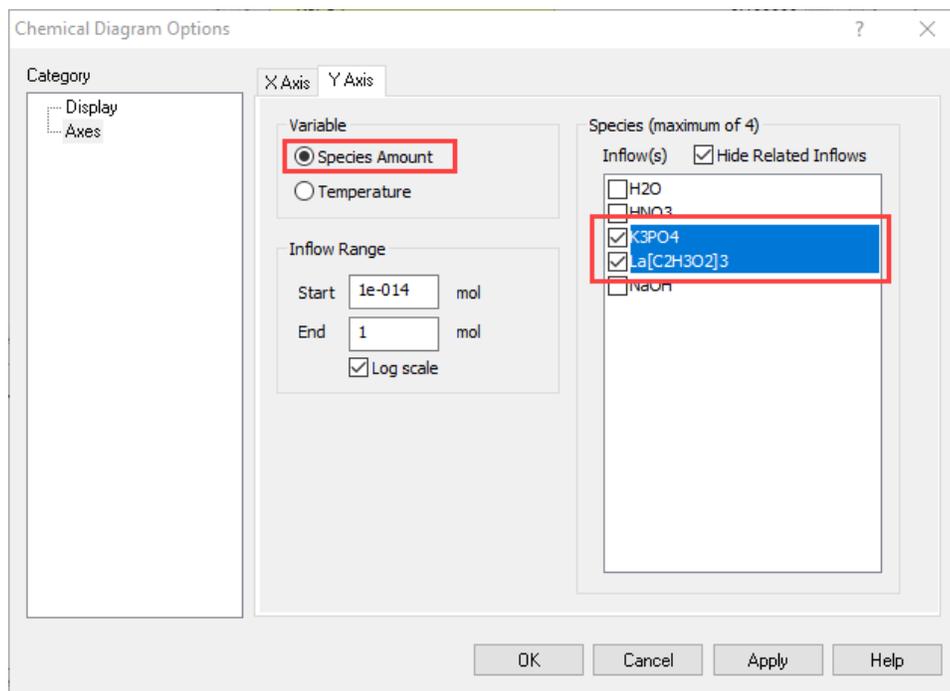


- Click on the **Titrants** button. Select **HNO3** as the **acid titrant** and **NaOH** as the **base titrant**. Then click **OK**.

Note: These titrants were added in the stream definition, and that's why they appear as possible titrants.



15. Select the **Y Axis** tab. Select the **Species Amount** button as the variable to change
16. Select $\text{La}[\text{C}_2\text{H}_3\text{O}_2]_3$ and K_3PO_4 species
17. For the Inflow Range keep the default range: from $1\text{E}-14$ to 1.0 moles on a log scale.
Note: This means we will have initially $1.0\text{E}-14$ moles of $\text{La}(\text{C}_2\text{H}_3\text{O}_2)_3$ and $1.0\text{E}-14$ moles of K_3PO_4 increasing equally until we have 1.0 moles of each.
18. Click **OK**

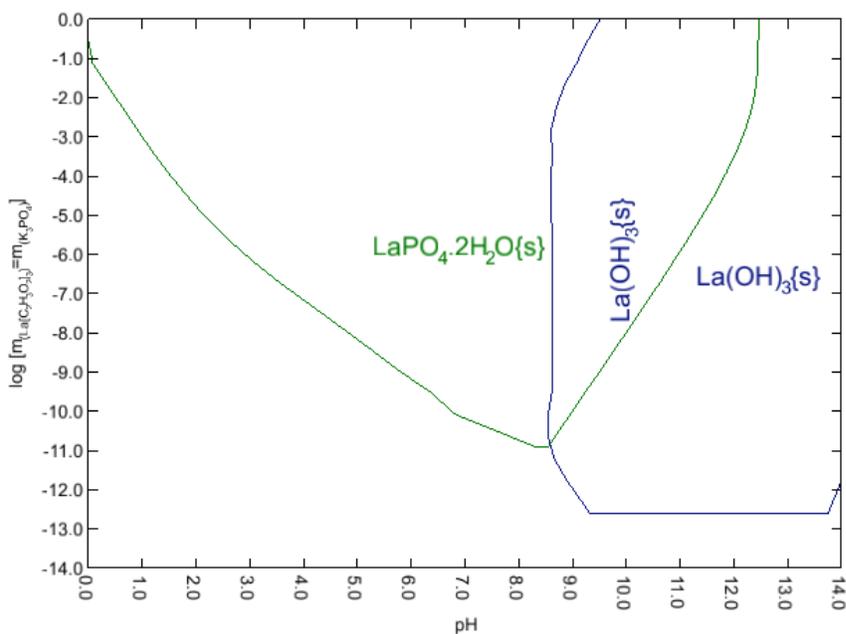


19. We are ready to perform the calculation. Click on the **Calculate** button or press the **<F9>** key
20. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it and name it *Chemical Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Chemical Diagram**). This tab displays the Species vs pH diagram for the Lanthanum species.

The X axis of the diagram is pH, varied by adding HCl or NaOH, and the Y axis variable is the concentrations of $\text{La}(\text{C}_2\text{H}_3\text{O}_2)_3$ and K_3PO_4 , held at a 1:1 molar ratio. From this figure, we can see that at room temperature there is a large pH range over which lanthanum phosphate will be the thermodynamically stable product. As pH increases, and more OH^- ions are present, $\text{La}(\text{OH})_3$ begins to form. The pH range in which $\text{La}(\text{OH})_3$ forms is the right bounded region in the diagram. The area below the lines is where only aqueous species exist.



Example 38: Adding 50% Lanthanum Acetate

In this second example we will add 50% more to the lanthanum acetate species and see the effect of this increase in concentration on the chemical diagram.

Starting the Simulation

1. **Copy** the *Lanthanum/Phosphate* chemical diagram calculated in the Example 37: $\text{La}(\text{C}_2\text{H}_3\text{O}_2)_3 - \text{K}_3\text{PO}_4$ Chemical Diagram, and **paste** it under the *Chemical Diagrams* stream.
2. **Change** the name to **Lanthanum 50% increase** using the <F2> key
3. **Change** the Lanthanum Acetate amount to 0.15 moles

The screenshot shows the OLI Studio interface for a chemical diagram titled "Lanthanum 50% increase". The main window displays a table of parameters and inflows. The "Inflows (mol)" section is highlighted with a red border, showing the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.7582
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HNO3
pH Base Titrant	NaOH
Inflows (mol)	
H2O	55.5082
La[C2H3O2]3	0.150000
K3PO4	0.100000
HNO3	0.0
NaOH	0.0

The right-hand panel shows a "Summary" section with the following details:

- Unit Set: Metric (moles)
- Automatic Chemistry Model
- Aqueous (H+ ion) Databanks: Aqueous (H+ ion)
- Using K-fit Polynomials
- T-span: 25.0 - 225.0
- P-span: 1.0 - 1500.0
- Stability diagram: La[C2H3O2]3 vs pH
- User-selected titrants: Acid: HNO3, Base: NaOH
- Range on La[C2H3O2]3: 1.00000e-14 to 1.00000 mol
- Range on pH: 0.0 to 14.0000
- Subsystems: Lanthanum
- Calculation complete

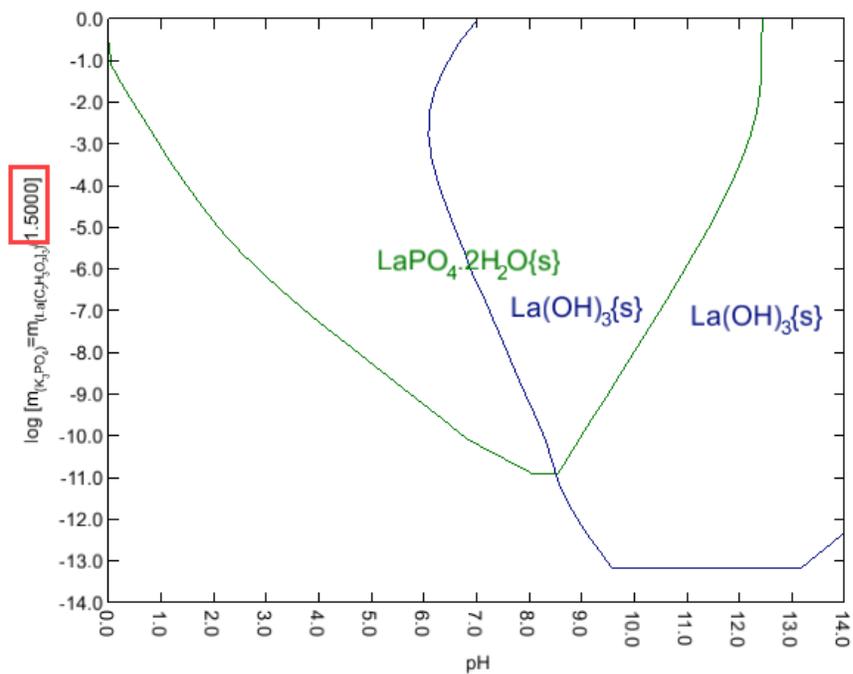
The "Calculate" button in the summary panel is highlighted with a green checkmark. A status bar at the bottom indicates "Calculation Complete!".

4. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
5. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Chemical Diagram**). It is important to note that the Y axis label has changed to reflect the increased amount of the lanthanum acetate.

From this figure, we can see that by increasing amount of Lanthanum acetate it favors the stability of $\text{La}(\text{OH})_3$ over a wider range of pH.



Example 39: Changing temperature and pressure

In this second example we will add 50% more to the lanthanum acetate species and see the effect of this increase in concentration on the chemical diagram.

Starting the Simulation

1. **Copy** the *Lanthanum/Phosphate* chemical diagram calculated in the Example 37: $\text{La}(\text{C}_2\text{H}_3\text{O}_2)_3 - \text{K}_3\text{PO}_4$ Chemical Diagram, and **paste** it under the *Chemical Diagrams* stream.
2. **Change** the name to **Lanthanum HTHP** using the <F2> key
3. **Change** the temperature to 200 °C and the pressure to 25 atmospheres

OLI Studio - [Chemical Diagrams.oad*]

File Edit Streams Calculations Chemistry Tools View Window Help

Streams

Chemical Diagrams

Lanthanum/Phosphate

Lanthanum 50% increase

Lanthanum HTHP

Lanthanum HTHP

Description Definition Chemical Diagram Report

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.7082
Temperature (°C)	200.000
Pressure (atm)	25.0000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HNO3
pH Base Titrant	NaOH
Inflows (mol)	
H2O	55.5082
La[C2H3O2]3	0.100000
K3PO4	0.100000
HNO3	0.0
NaOH	0.0

Type of diagram

Species vs. Species

Calculate

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model

Aqueous (H+ ion) Databanks:

Aqueous (H+ ion)

Using K-fit Polynomials

T-span: 25.0 - 225.0

P-span: 1.0 - 1500.0

Stability diagram: La[C2H3O2]3 vs pH

Auto-selected titrants

Acid: HNO3

Base: NaOH

Range on La[C2H3O2]3:

1.00000e-14 to 1.00000 mol

Range on pH:

0.0 to 14.0000

Subsystems

Lanthanum

Calculation not done

Input

Advanced Search Add as Stream Export

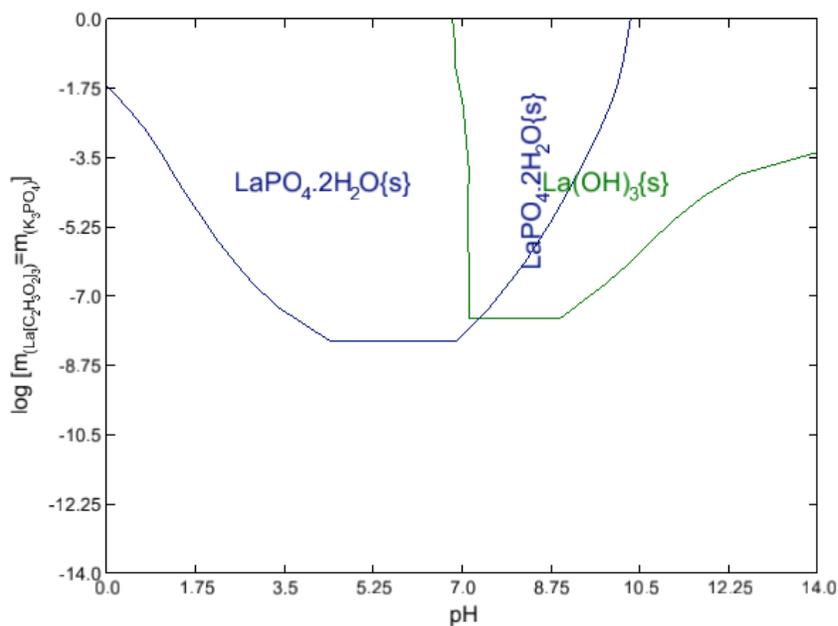
Calculation Complete!

For Help, press F1

6. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
7. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Chemical Diagram**). This figure shows the stability diagram for $\text{La}(\text{C}_2\text{H}_3\text{O}_2)_3$ and K_3PO_4 over a range of pH values at 200°C and 25 atm . Under these conditions, there is a decrease in the pH range over which LaPO_4 is the stable product. This is because as temperature increases, the insoluble rare earth hydroxides $[\text{RE}(\text{OH})_3]$ become more stable. The aqueous area of the single-phase increases at elevated temperatures due to the increased solubility of the different species. Again, at high pH values, only $\text{La}(\text{OH})_3$ will form.



Chapter III – OLI Studio: Corrosion Analyzer

Corrosion Analyzer is a module within the OLI Studio. A separate license enables this module. Corrosion Analyzer is first-principles corrosion prediction tool. As in Stream Analyzer, for all calculations we will create one or more objects, referred to as a **Streams**, which are used to define a particular chemistry, temperature and pressure.

There are two different types of calculations that can be carried out in Corrosion Analyzer: Corrosion Rates and Stability Diagrams. A brief definition of each type of calculation is given below.



Stability Diagram is used to predict the stability of metals, metal ions, oxides, etc. as a function of T, P and solution composition. With this tool you can draw conclusions about the ranges of immunity to corrosion, possible passivation and dissolution of metals in the presence of species that promote or inhibit corrosion.



Corrosion Rates is used to predict the general corrosion rate, the propensity for localized corrosion (pitting or crevice corrosion) to occur, polarization curves, and heat treatment effects of metallic materials at one specific equilibrium state. The effects of temperature, pressure, pH, concentration of species, and velocity on corrosion are also included.

In this chapter several examples will be provided to cover these calculation types.

Section 7. Stability Diagrams

In this section you are going to learn how to set up a Stability Diagram and how to interpret the results when using this tool.

The screenshot shows the OLI Studio interface for setting up a Stability Diagram. The main window is titled "OLI Studio - [Document1*]" and has a menu bar (File, Edit, Streams, Calculations, Chemistry, Tools, View, Window, Help) and a toolbar. On the left, the Navigator pane shows a tree view with "Streams" and "Stream" folders, and a "Stability Diagram" icon highlighted with a red box. Below the Navigator are panes for "Actions" and "Plot Template Manager".

The central area is titled "Stability Diagram" and has tabs for "Description", "Definition", "Stability Diagram", and "Report". Below the tabs is a table with columns "Variable" and "Value".

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Inflows (mol)	
H2O	55.5082
Contact Surface	

At the bottom of the central area is an "Input" section with buttons for "Advanced", "Search", "Add as Stream", and "Export".

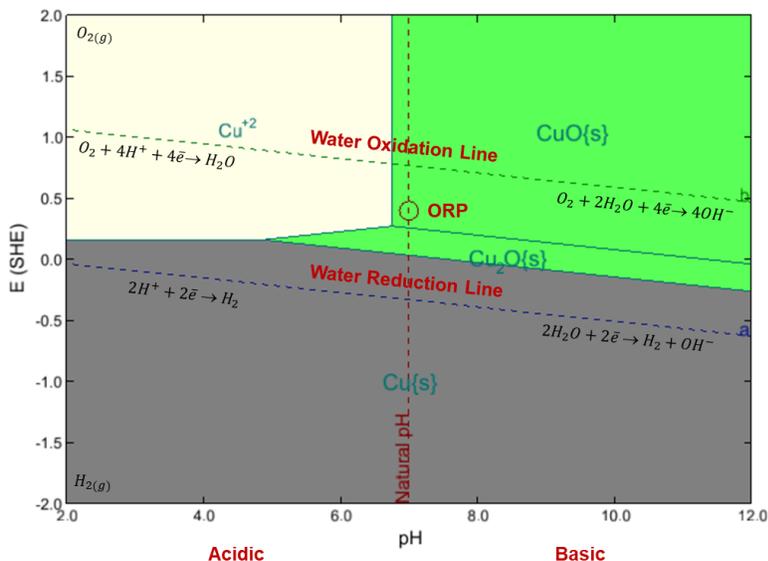
On the right, a "Summary" pane contains the following information:

- Type of diagram: Pourbaix Diagram (highlighted with a red box)
- Unit Set: Metric (moles)
- Automatic Chemistry Model:
 - Aqueous (H+ ion) Databanks:
 - Corrosion (AQ)
 - Aqueous (H+ ion)
 - Redox: selected
 - Using K-fit Polynomials
 - T-span: 25.0 - 225.0
 - P-span: 1.0 - 1500.0
- Stability diagram: Evs pH
- User-selected titrants
- Enter the contact surface for this calculation in the contact surface section of the grid.
- Alloy Activity Module: Activated
- Calculation not done

7.1. How to Interpret a Stability Diagram

A Stability Diagram also known as Pourbaix Diagram or simply Potential vs pH diagram, maps out the possible stable species in an aqueous environment at different pH and potential combinations. This diagram, however, does not provide information of reaction rates or kinetic effects.

A schematic representation of the Pourbaix diagram for copper in water at 25 °C and 1 atm is shown in the image below.



The gray color represents the immune to corrosion region. It is the stability field of the elemental metal. Cu is the base metal in the above plot.

The green color represents the range of possible passivation. It is the stability field of a sparingly soluble compound (usually an oxide or hydroxide or salt). This compound will form a layer on the surface of the metal, which may protect the metal from corrosion. Having determined that a layer is formed, it is necessary to verify whether it is protective or not because this depends on the crystalline structure of the sparingly soluble compound. In the above plot, the green area contains CuO and Cu₂O as the solid phases produced by oxidation of Cu.

The light-yellow color represents the corrosion region. It is the stability field(s) of dissolved (ionic or neutral) metal species in which neither the metal nor passivating solids are stable. In the plot above, Cu²⁺ is the ionic species that is the most stable.

The diagonal dashed lines, represented by the letters a and b are the water reduction and water oxidation lines, respectively.

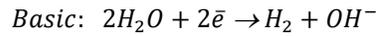
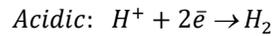
Below the water reduction line (a): Water decomposes to form H₂ gas. Above the water oxidation line (b): Water decomposes to form O₂ gas. The region within these lines (a and b) is called the stability region of water.

The lines that divide different species in the Pourbaix diagram show the equilibrium conditions. These lines represent the equilibrium for chemical and electrochemical reactions.

Finally, as a reference, the values of the Natural pH and the Oxidation Reduction Potential (ORP) are superimposed on the diagram. The natural pH line of the water sample is the water's computed pH before it is adjusted using with acid or base to create the diagram. The ORP is represented by the red circle and indicates the initial electrochemical potential of the water phase. This is the value before the potential is adjusted using a potentiostat, for example.

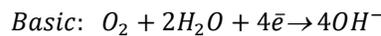
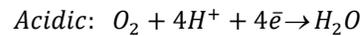
7.2. How to determine if corrosion in the absence of oxygen is possible?

In the absence of oxygen, the most common reduction reaction is the reduction of the proton to elemental hydrogen (as shown by line **a** in the plot below). Depending of the pH that reactions that can occur are the following:



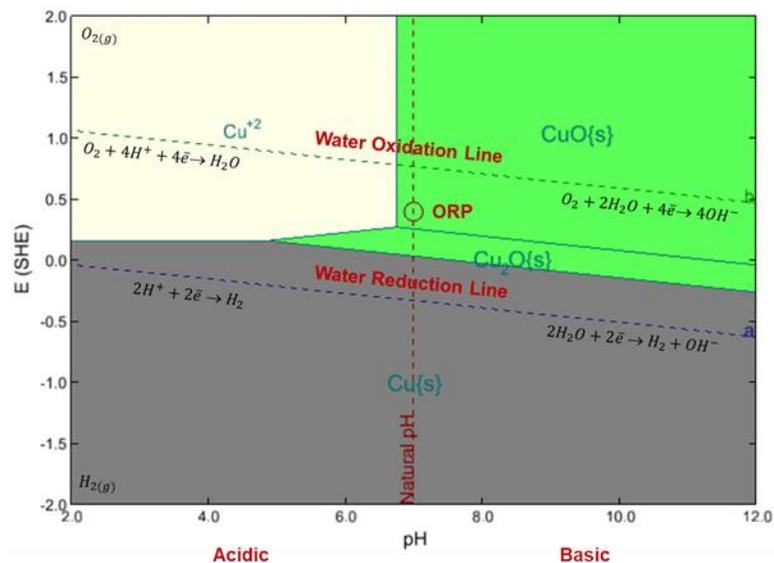
For a corrosion process to proceed, the line **a** must lie above a line that corresponds to an equilibrium between the metal and metal-containing ions.

In oxygen-containing solutions, O_2 can be reduced to H_2O (as shown by line **b**). Depending of the pH that reactions that can occur are the following:



For a corrosion process to occur, the line **b** must lie above a line that corresponds to an equilibrium between the metal and metal-containing ions.

Passivation is likely if **b** lies above a line that corresponds to an equilibrium between the metal and a sparingly soluble compound.



Stability diagram for Copper in Water at 25°C and 1 atm

7.3. Building a Pourbaix Diagram

Example 40: Pourbaix Diagram of Fe-H₂O System

After completing this example, you will learn how to set up a Pourbaix Diagram using the **Stability Diagram** tool.

Starting the Simulation

To start the software, double-click the **OLI Studio** icon on the desktop, which will take you to the OLI Studio interface where you can start creating your calculations.



Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Fe-H ₂ O System	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	2-12
Calculation Type	Stability Diagram	H ₂ O	55.5082 moles
Contact Surface	Fe		

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Fe-H₂O System*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition, temperature and pressure of the stream given in the table above
7. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane.

The screenshot shows the OLI Studio interface for a 'Fe-H₂O System' calculation. The 'Add Calculation' dropdown menu is open, showing options: Single Point, Survey, Chemical Diagram, **Stability Diagram** (highlighted), and Corrosion Rates. The 'Actions' pane on the left also has 'Add Stability Diagram' highlighted. The main window displays a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Inflows (mol)	
H ₂ O	55.5082

8. Select **Pourbaix Diagram** as Type of Survey – Default
9. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-H2O Pourbaix Diagram*

Note: Notice that two new sections appear in the **Definition** tab: **Calculation Parameters** and **Contact Surface** grids. Additionally, the Redox button is turned ON.

In the **Calculation Parameters** grid is where the pH titrants need to be defined. These default pH titrants selected by default are HCL and NaOH. You have the option to change the default titrants to your preferred titrants.

In the **Contact Surface** grid is where the metal or alloy of interest needs to be defined. E.g. Fe, Cu, carbon steel, etc.

The **Redox** button (Re) is turned ON for this calculation since reduction and oxidation reactions are need it to create the Pourbaix Diagram. This option will enable the different oxidation states of the selected metal.

The screenshot shows the OLI Studio interface for configuring a Pourbaix Diagram. The main window is titled "Fe-H2O Pourbaix Diagram" and has several tabs: "Description", "Definition", "Stability Diagram", and "Report". The "Definition" tab is selected, showing a table of parameters. The "Calculation Parameters" and "Contact Surface" sections are highlighted with red boxes. The "Summary" panel on the right shows the "Type of diagram" as "Pourbaix Diagram" and the "Redox selected" status as "Activated".

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Inflows (mol)	
H2O	55.5082
Contact Surface	

Summary:

- Unit Set: Metric (moles)
- Automatic Chemistry Model
- Aqueous (H+ ion) Databanks: Corrosion (A.Q), Aqueous (H+ ion)
- Redox selected
- Using K-fit Polynomials
- T-span: 25.0 - 225.0
- P-span: 1.0 - 1500.0
- Stability diagram: E vs pH
- User-selected titrants
- Enter the contact surface for this calculation in the contact surface section of the grid.
- Alloy Activity Module: Activated
- Calculation not done

10. Leave the default titrants for this calculation: HCl and NaOH

11. Under the **Contact Surface** grid type **Fe**

Note: You also have the option to use the drop-down arrow to search for the metal or alloy of interest.

OLI Studio - [Stability Diagrams.oad*]

File Edit Streams Calculations Chemistry Tools View Window Help

Navigator

Document1*

Stability Diagrams.oad*

Streams

Fe-H2O System

Fe-H2O Pourbaix Diagram

Actions

Actions

Plot Template Manager

Save

Fe-H2O Pourbaix Diagram

Description Definition Stability Diagram Report

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Inflows (mol)	
H2O	55.5082
Contact Surface	
Fe	
Display Name	OLI Name
OLI F2	F2
F2	F2
Fe	FEEL
OLI FEEL	FEEL
SYN Flowers of sulphur	SULFUREL
SYN Fluorine	F2

Input

Advanced Search Add as Stream Export

Type of diagram: Pourbaix Diagram Specs... Calculate

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model

Aqueous (H+ Ion) Databanks:

Corrosion (AQ)

Aqueous (H+ Ion)

Redox selected

Using K-fit Polynomials

T-span: 25.0 - 225.0

P-span: 1.0 - 1500.0

Stability diagram: E vs pH

User-selected titrants

Enter the contact surface for this calculation in the contact surface section of the grid.

Alloy Activity Module: Activated

Calculation not done

For Help, press F1

NUM

At this point all the basic inputs to create a Pourbaix Diagram have been defined. Notice that in the summary box the following default plotting settings have been defined: Potential range: -2 to 2 V vs SHE and pH range: 0-14. You can modify these default values before running the calculation.

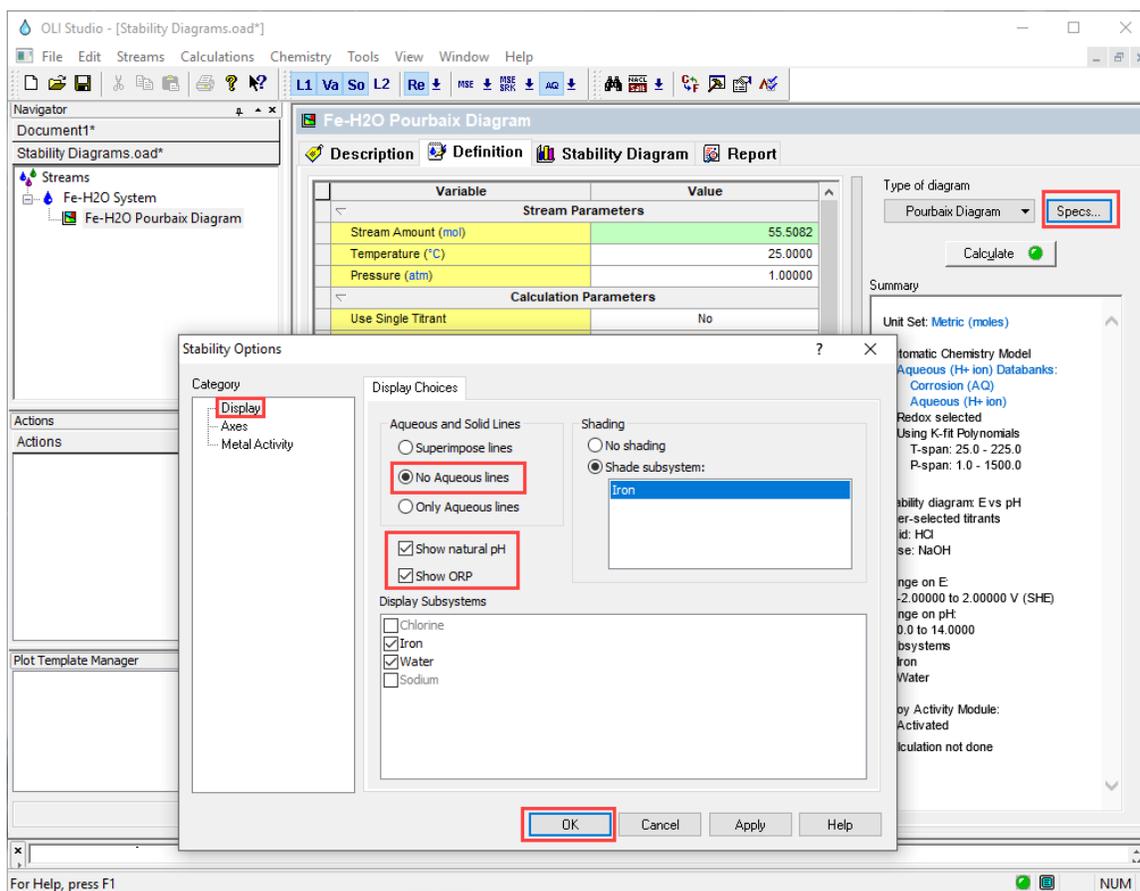
The screenshot displays the OLI Studio interface for configuring a Pourbaix Diagram. The main configuration table is as follows:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HCl
pH Base Titrant	NaOH
Inflows (mol)	
H2O	55.5082
HCl	0.0
NaOH	0.0
Fe	0.0
Contact Surface (mol)	
Fe	

The Summary panel on the right shows the following settings:

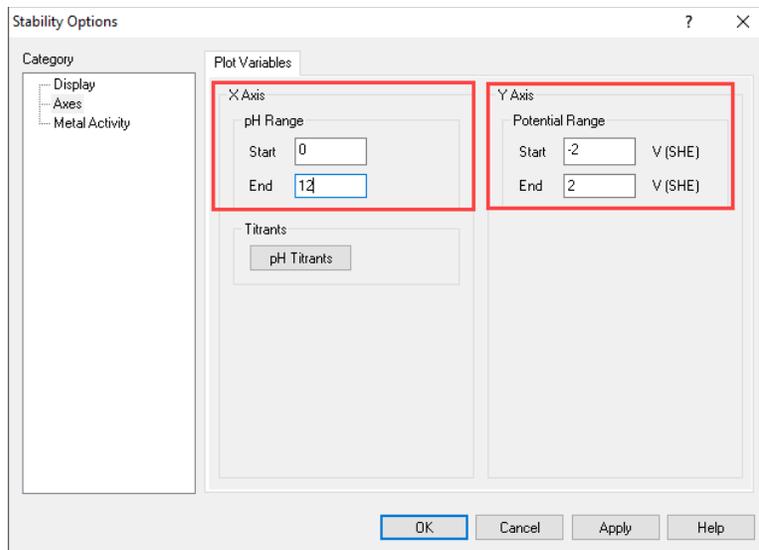
- Type of diagram: Pourbaix Diagram
- Unit Set: Metric (moles)
- Automatic Chemistry Model: Aqueous (H+ ion) Databanks: Corrosion (Aq), Aqueous (H+ ion)
- Redox selected: Using K-fit Polynomials, T-span: 25.0 - 225.0, P-span: 1.0 - 1500.0
- Stability diagram: E vs pH
- User-selected titrants: Acid: HCl, Base: NaOH
- Range on E: -2.00000 to 2.00000 V (SHE)
- Range on pH: 0.0 to 12.00000
- Subsystems: Iron, Water
- Alloy Activity Module: Activated
- Calculation not done

15. Click on the **Specs** button. This will open the **Stability Diagram Options** Window
16. Under the **Display** Category you will see the **Display Choices** tab. Under this tab make sure to select the following options:
 - i. No Aqueous lines
 - ii. Show natural pH
 - iii. Show ORP
17. Under **Display Subsystems** check the **Iron** and **Water** boxes
18. Under **Shading** select the option **Shade Subsystem** and select **Iron**.
19. Click **OK** to close the window



20. **Click** on the **Axes** Category. This will show you the Plot Variables tab.

Note: In the **Axes** Category you can modify the axes of the Pourbaix Diagram and change the default titrants.



21. **Change** the X Axis or pH range to 2-12

22. **Leave** the default values for the Y Axis of Potential Range (-2 to 2 V SHE)

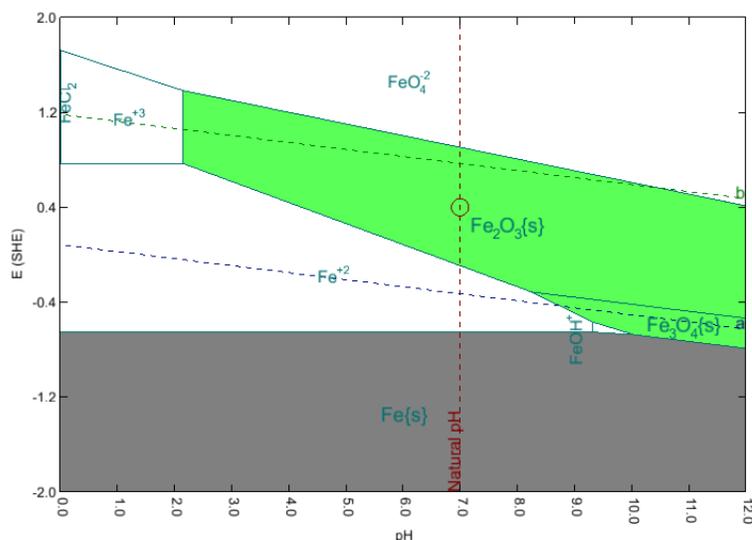
23. Click **OK** to close the window

24. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

25. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it and name it as *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Fe-H₂O system at 25 °C and 1 atm.



The obtained diagram is useful for assessing the corrosion behavior of iron in pure water.

Elemental iron (gray section) is stable from -2 to -0.6 V SHE. At a potential greater than -0.6 V SHE, Fe oxidizes to Fe²⁺. If the pH is above 10, the boundary is at a lower potential for example, -0.7 V SHE at 12 pH.

The software computes that Fe₃O₄ (magnetite) is stable between a pH range of ~8.3 and 12. This is also known as the *Passive Film* that protects the iron surface from active corrosion. At higher potentials, the software computes Fe₂O₃ (hematite). Hematite is the dehydrated form of Fe(OH)₃ and FeOOH, two forms of rust. These phases provide less corrosion protection the iron surface than the magnetite. These two phases are represented in the plot by the green color.

The white sections of the plot represent the dominant iron-containing species dissolved in solution. The species with the largest range is Fe²⁺. The software computes stability for this species from -0.6 V to 0.77 V SHE, at low pH, and it is no longer stable at pH 10. Active corrosion of the iron surface is predicted if the pH is between 0 and 10. The actual corrosion rate cannot be predicted from this plot, nor can the pH of the water film (diffusion layer) in contact with the iron surface. Therefore, the pH range of 0 to 10 is a guideline and not a direct prediction.

The natural pH and the oxidation reduction potential (ORP) of water, which is represented by the red circle, are showing that when placing Fe in pure water at 25 °C and 1 atm. The point at which the natural pH and the ORP intersects (7 pH, 0.4 V SHE) indicates that Fe₂O₃ (hematite) is the most stable species that forms.

Additionally, notice that the oxidation of iron can be coupled with the reduction of water because water reduction line (line a) lies above the lines that represent the oxidation of iron. Therefore, corrosion of iron can occur with the evolution of hydrogen and formation of soluble iron-containing ions e.g. Fe²⁺.

7.4. Selective Oxidation and Reduction Chemistry

Occasionally you may want to remove a specific oxidation state for an element when building a Stability Diagram. There are a variety of reasons to perform such an activity, one being that a specific oxidation state may be kinetically unavailable for the reaction. Another case is that perhaps you need to compare and contrast two systems. We will explore how to do this in the following example.

Example 41: Turning off the Fe⁺⁶ oxidation state in the Stability Diagram

In this example you will create a Stability diagram for iron in water at ambient conditions (see previous example for details on how to create this stream), learn how to change the default titrants and turn off/on different specific oxidation states of the metal of interest.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Fe-H2O System	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Fe	H2SO4	0 moles
		NaOH	0 moles

1. Under the *Fe-H2O System* add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane.
2. Select the **AQ** thermodynamic Framework
3. **Click** on the **Names Manager** Icon and select the **Formula** option
4. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
5. Enter the composition, temperature and pressure of the stream given in the table above. **Add** H2SO4 and NaOH as inflows. **Note:** H2SO4 and NaOH will be used as titrants to adjust pH
6. Select **Pourbaix Diagram** as Type of Survey – Default
7. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-H2O Selective Oxidation*
8. Under the **Contact Surface** grid type **Fe**

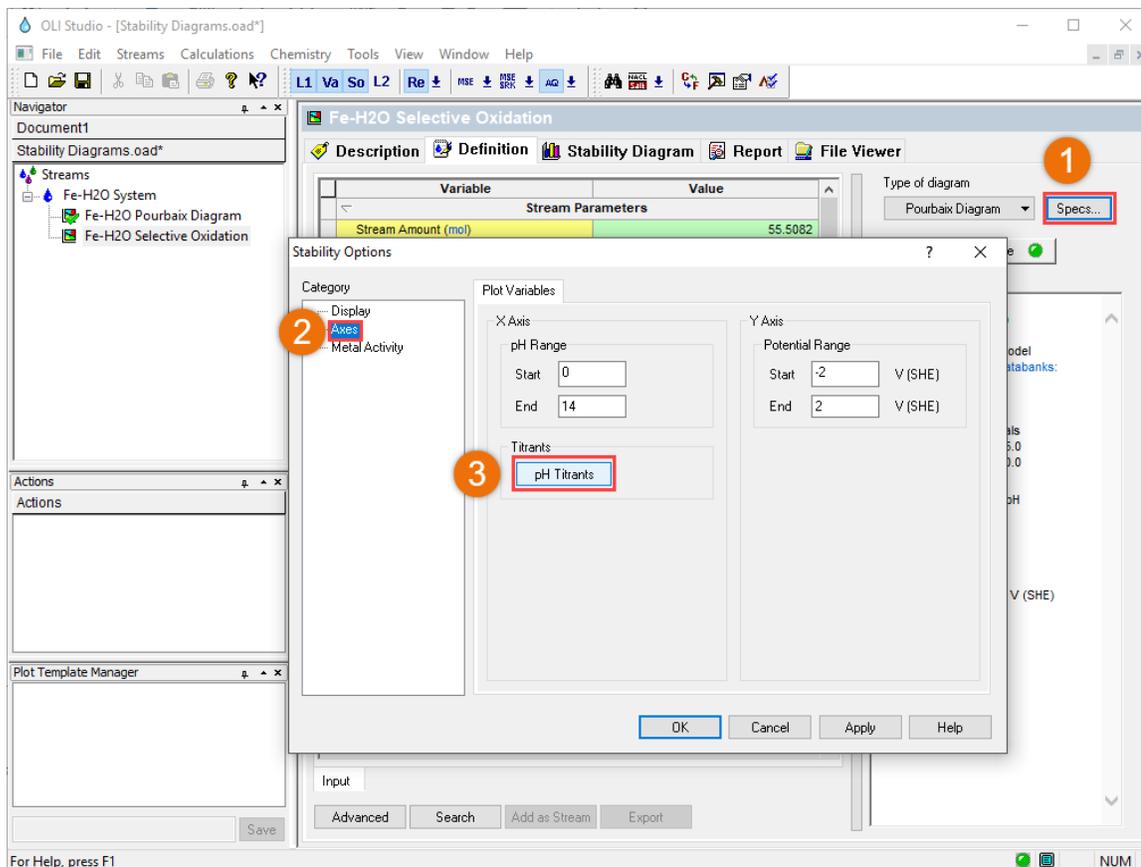
Changing the Default Titrant

9. In the **Calculation Parameters** grid, **click** on HCl (which is default titrant). A drop-down arrow appears, **click** on it and **select** H2SO4. NaOH has been selected by default.

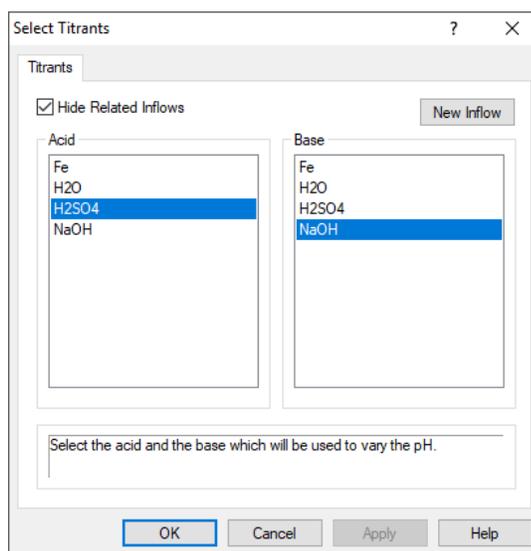
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	H2O H2SO4
Inflows	
H2O	Fe HCL
H2SO4	NAOH

Note: You can also change the default titrant using the **Specs** button

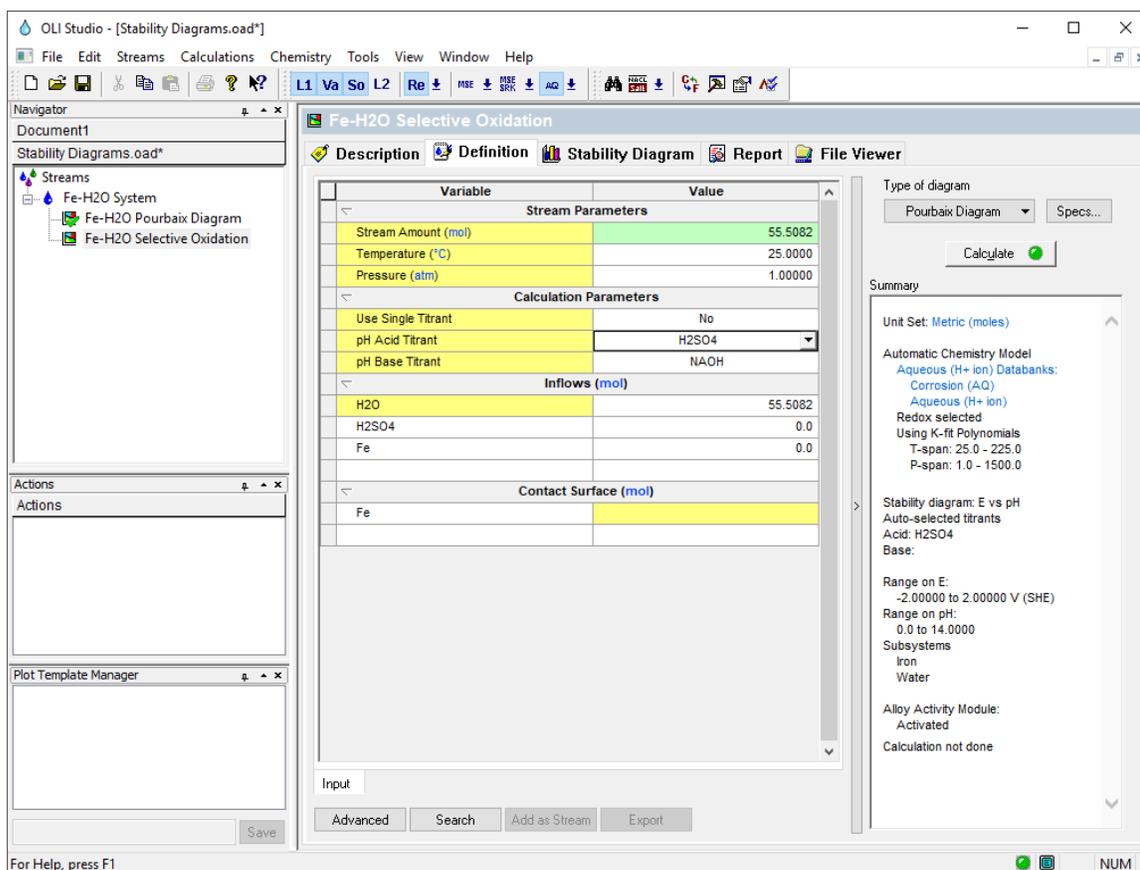
1. **Click** on the **Specs** button
2. **Select** the **Axes** option under the **Category** window
3. **Click** on **pH Titrants**. This will open a new window



4. **Select** **H2SO4** as the **Acid** titrant, and **NaOH** as the **Base** titrant. Then **click** **OK** to exit both windows.



The screen should look like the image below after all the inputs and definitions have been entered:

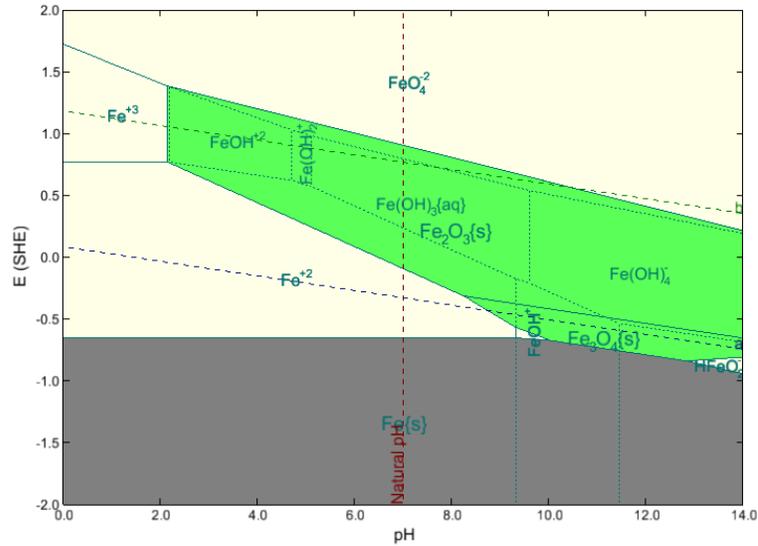


10. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

11. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

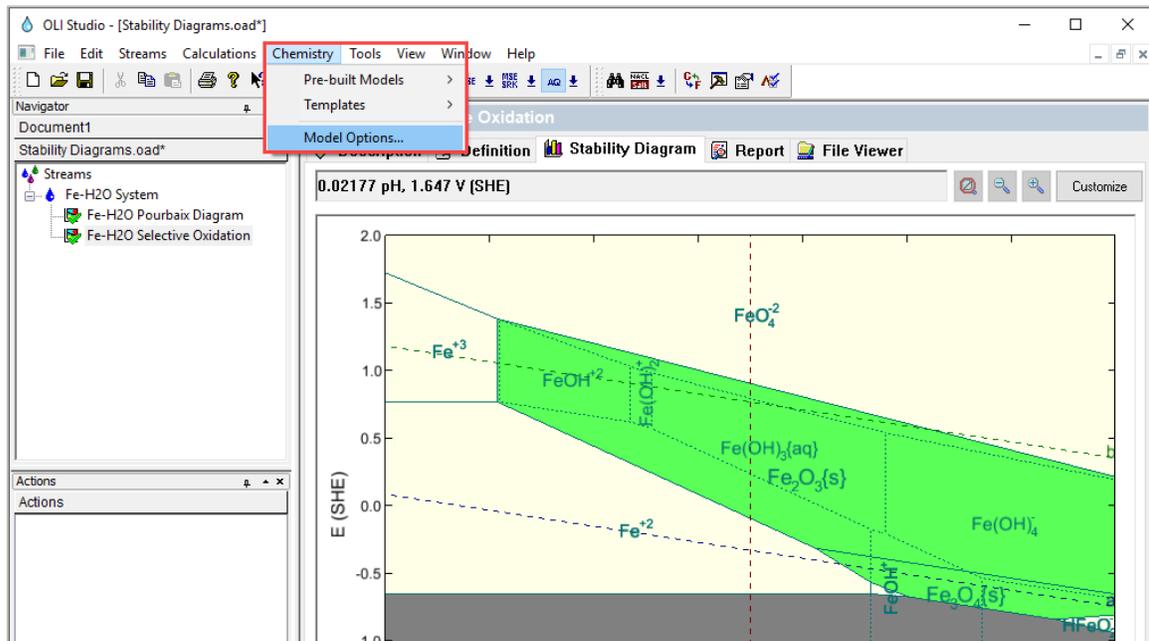
Click on the **Chemical Diagram** tab (Stability Diagram). This tab displays the Pourbaix Diagram for the Fe-H₂O system at 25 °C and 1 atm.



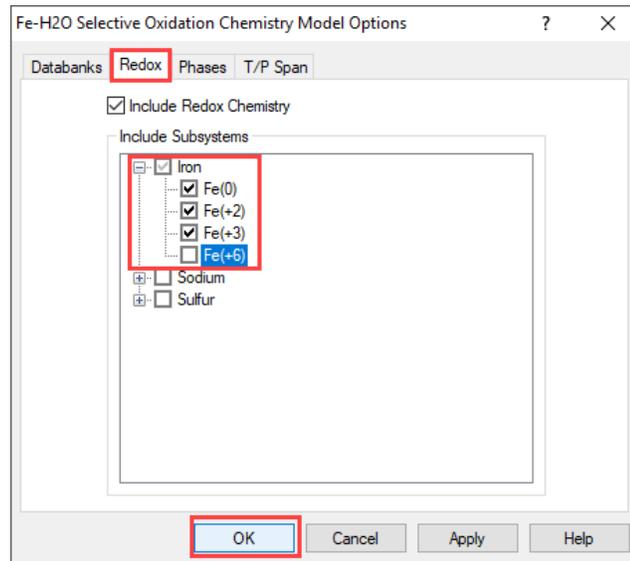
Marcell Pourbaix did not consider the FeO_4^{2-} ion in his work. This is iron in the +6 oxidation state for which there was little thermodynamic data available in the 1960s. To reproduce his work, we need to remove the redox subsystem that pertains to Fe(+6).

Selective Redox, removing an undesired oxidation state

1. In the Menu bar go to **Chemistry > Model Options**. This will open a new window



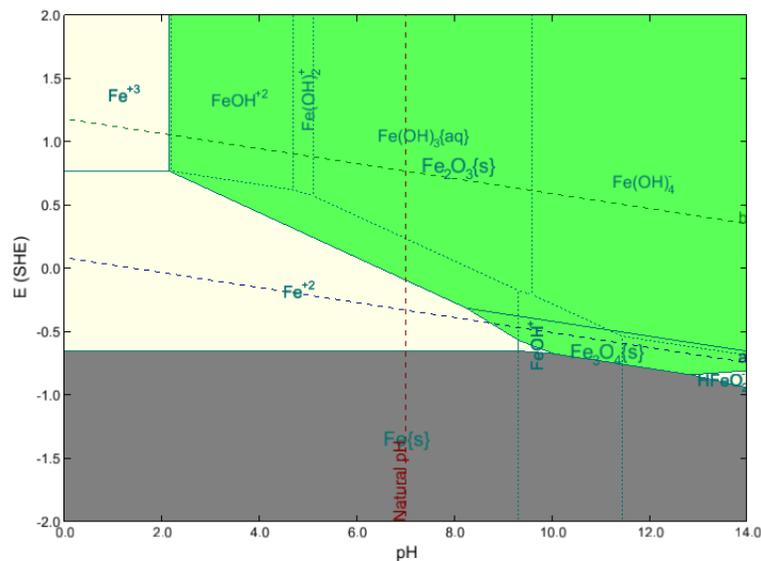
- Select the **Redox** tab, expand the Iron Subsystems by clicking on the '+' icon, and **uncheck** the **Fe(+6)** oxidation state. Note that if you have an inflow component with this oxidation state it will remain in the calculation. Click the **OK** button to save your changes and close the window.



- We are ready to recalculate to consider the changes. Press the **<F9>** key or go to the **Definition** tab and click on the **Calculate** button.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). In the figure below, you can see that the region dominated by the FeO_4^{2-} ion is not present.



7.5. Modeling the Effects of Hydrogen Sulfide on Corrosion

Example 42: The Effect of Hydrogen Sulfide on the Corrosion of Iron

The H₂S (S⁻²) forms a relatively insoluble precipitate with Fe⁺². This precipitate has the potential to cover the metal surface and enhance the pH region where iron is protected from the water. We will model this using the Stability Diagram tool.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

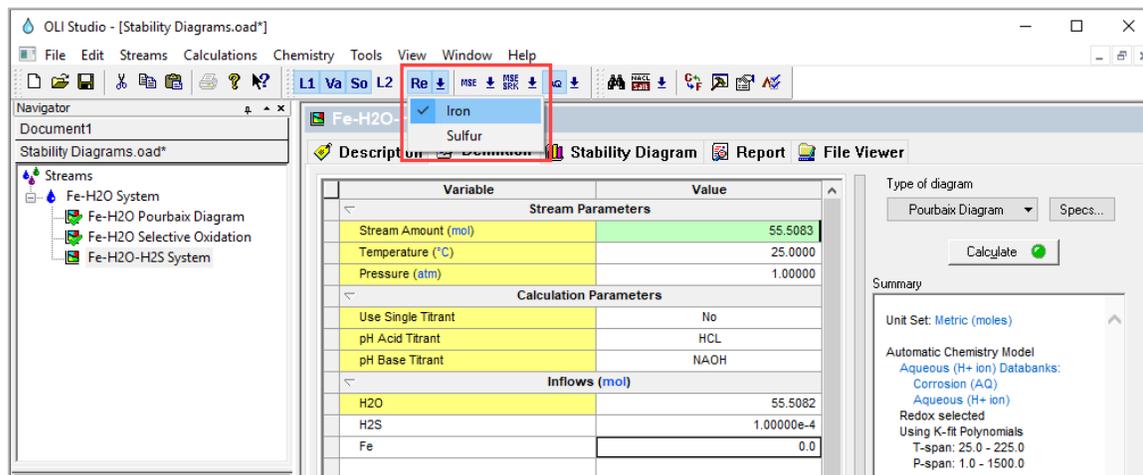
Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Fe-H2O System	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Fe	H2S	1e-4 moles

1. Under the *Fe-H2O System* add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane.
2. Select the **AQ** thermodynamic Framework
3. **Click** on the **Names Manager** Icon and select the **Formula** option
4. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
5. Enter the composition, temperature and pressure of the stream given in the table above. **Add 1e-4 moles of H2S** as an inflow.
6. Select **Pourbaix Diagram** as Type of Survey – Default
7. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-H2O-H2S System*
8. Under the **Contact Surface** grid type **Fe**

The screen should look like the image below after all the inputs and definitions have been entered:

Note: By default, only the transition metals are turned ON. The different oxidation states of elements that are not transition metals are not turned on automatically. You need to turn them ON manually.

9. Go to the **Redox** button (**Re**), and **click** on the drop-down arrow
10. **Select Sulfur**. This will turn the oxidation states of sulfur ON

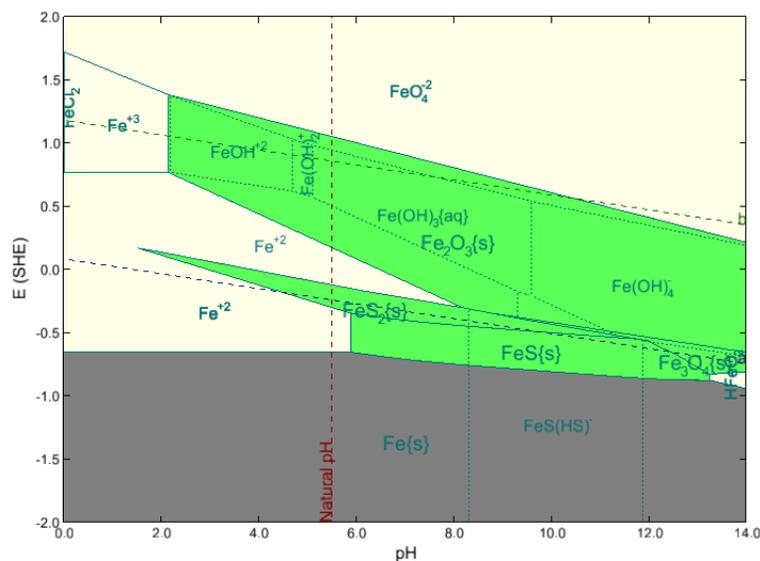


11. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
12. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab (Stability Diagram). This tab displays the Pourbaix Diagram for the Fe-H2O-H2S system at 25 °C and 1 atm.

Inspection of the diagram reveals a profound effect of H₂S on the corrosion of iron. New stability fields of FeS and FeS₂ are observed. Elemental iron is found to be in equilibrium with FeS over for pH values ranging from ca. 6.0 to 12.5.



Since the Fe/FeS equilibrium line lies below the H⁺ reduction line (a), a process consisting of the reduction of H⁺ to H⁰ and oxidation of Fe to FeS is likely to occur in de-aerated environments. FeS forms a passive film and offers some protection against corrosion.

In fact, the protection due to the formation of FeS is possible over a much wider pH range than that due to the formation of Fe₃O₄ (magnetite) in the absence of H₂S. This has important implications for corrosion in refinery installations, where H₂S is frequently present.

7.6. Modeling Corrosion at High Temperature

Example 43: High Temperature Iron in Water

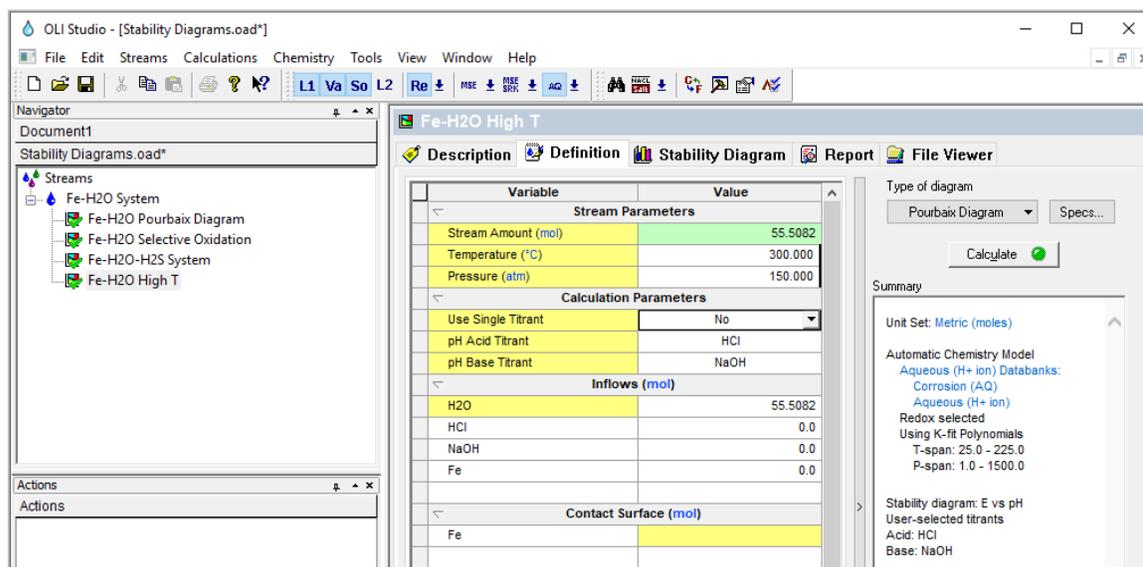
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Fe-H2O System	Stream Amount	Calculated
Name Style	Display Formula	Temperature	300 °C
Unit Set	Metric, Batch, Moles	Pressure	150 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Fe		

1. Under the *Fe-H2O System* add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane.
2. Select the **AQ** thermodynamic Framework
3. **Click** on the **Names Manager** Icon and select the **Formula** option
4. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
5. Enter the composition, temperature and pressure of the stream given in the table above
6. Select **Pourbaix Diagram** as Type of Survey – Default
7. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-H2O High T*
8. Under the **Contact Surface** grid type **Fe**

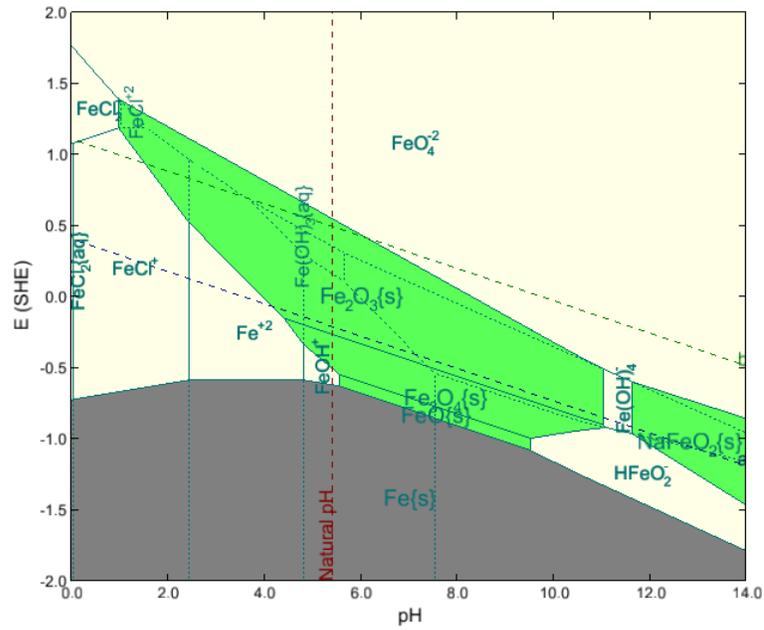
The screen should look like the image below after all the inputs and definitions have been entered:



9. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
10. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Fe-H₂O system at 300 °C and 150 atm.



We can see from the diagram above that passivation is only possible at moderate pH's.

Example 44: Neutralization of Refinery Streams with Alkanolamines

In this example you will create a stability diagram for alkaline neutralization in an oil refinery.

Starting the Simulation

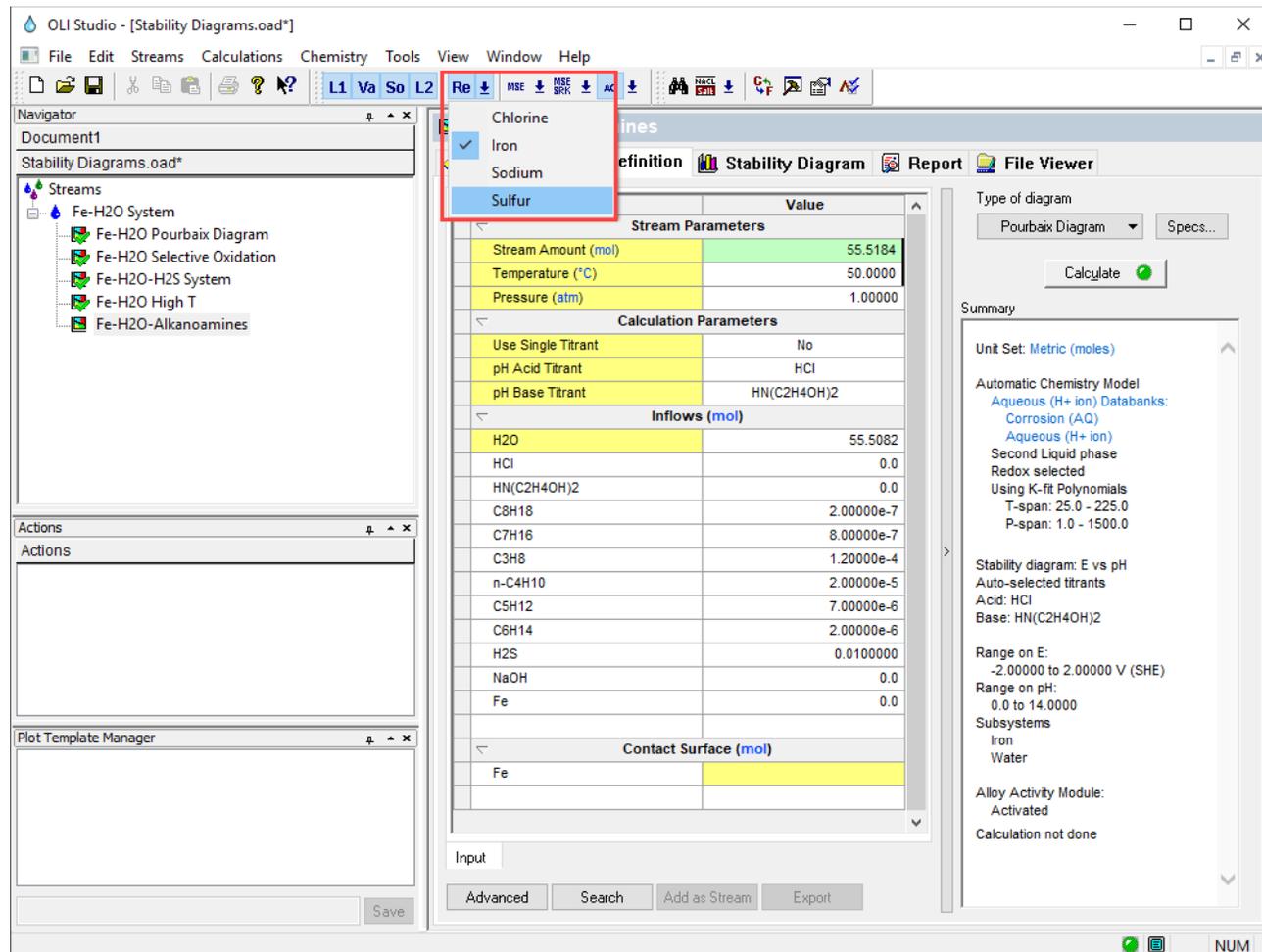
Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Fe-H2O System	Stream Amount	Calculated
Name Style	Display Formula	Temperature	50 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Fe	HCl	0 moles (Acid Titrant)
		DEA ¹⁰	0 moles (Base Titrant)
		C8H18	2E-07 moles
		C7H16	8E-07 moles
		C3H8	1.2E-04 moles
		C4H10	2E-05 moles
		C5H12	7E-6 moles
		C6H14	2E-6 moles
		H2S	0.01 moles

1. Under the *Fe-H2O System* add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane
2. Select the **AQ** thermodynamic Framework
3. **Click** on the **Names Manager** Icon and select the **Formula** option
4. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
5. Enter the composition, temperature and pressure of the stream given in the table above
6. Select **Pourbaix Diagram** as Type of Survey – Default
7. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-H2O-Alkanoamines*
8. Under the **Contact Surface** grid type **Fe**
9. **Change** the **Base Titrant** to **DEA**
10. **Turn Redox ON** for Sulfur. **Click** on the drop-down arrow next to the **Re** button and select **Sulfur**
Note: You can also enable Redox reactions via the menu bar: **Chemistry > Model Options > Redox** tab.
Make sure that Sulfur is checked.

¹⁰ The “ESP” name for this species is DEXH, which can be used as an input to make your life easier. The formula name is: HN(C2H4OH)2

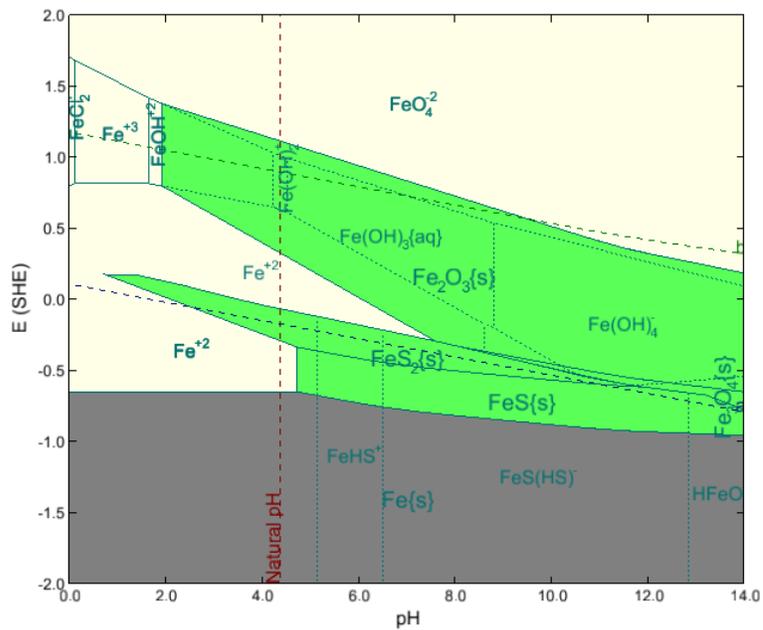
The screen should look like the image below after all the inputs and definitions have been entered:



11. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
12. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Fe-H₂O system at 50 °C and 1 atm.



7.7. Modeling the Effects of Complexation on Corrosion

In this section we will simulate the reaction of Copper with Ammonia and Gold metal with Cyanide. This section attempts to answer the question of how strong complexing agents affect the passivation of these metals.

Example 45: Copper and Ammonia

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Cu-H2O System	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Cu	NH3	0 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Cu-H2O System*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition, temperature and pressure of the stream given in the table above
7. Under the *Cu-H2O System* Stream add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane
8. Select **Pourbaix Diagram** as Type of Survey – Default
9. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Cu-H2O-NH3*
10. Under the **Contact Surface** grid type **Cu**

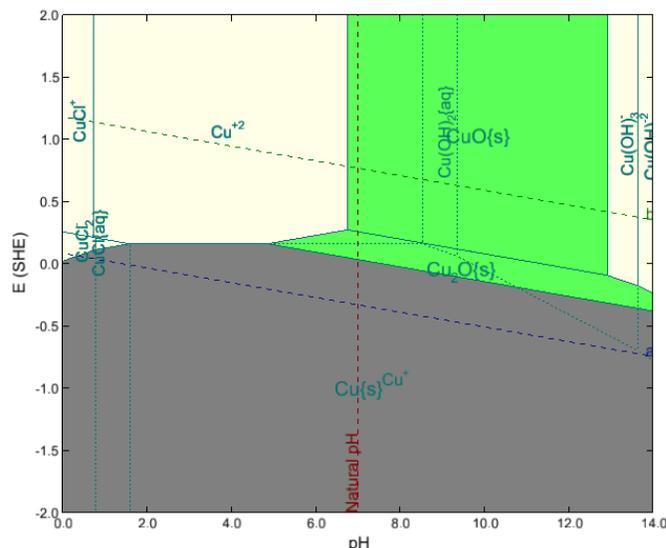
The screen should look like the image below after all the inputs and definitions have been entered:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Inflows (mol)	
H2O	55.5082
NH3	0.0
Cu	0.0
Contact Surface (mol)	
Cu	

- We are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key
- It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Cu-H₂O system at 25 °C and 1 atm.



In the absence of oxygen (looking at only the **a** line), we can see that the copper equilibrium line lays above the hydrogen **a** line. This means there is insufficient oxidizing power in the water to corrode copper metal in pure water.

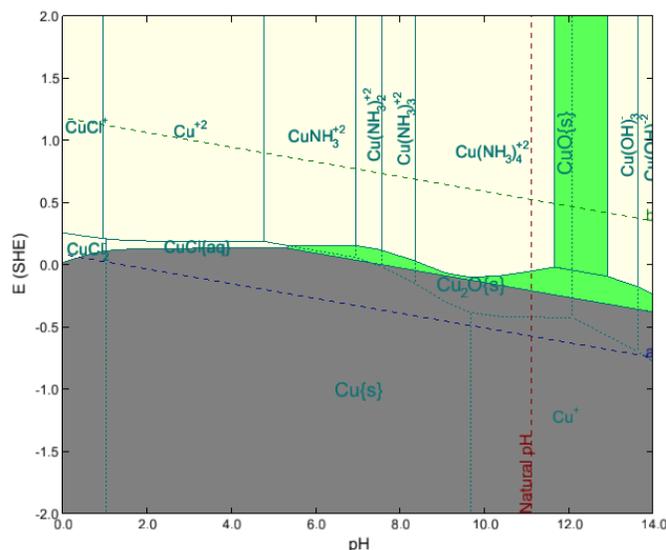
What happens if Ammonia (NH₃) is added to the solution? The next step is to understand the effect of NH₃ on the stability of copper.

Effect of NH₃ on the Stability of Copper

- Go to the **Definition** tab, and change the amount of NH₃ from 0 to 0.1 moles
- Click on the **Calculate** button or press the <F9> key

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Cu-H₂O-NH₃ system at 25 °C and 1 atm in a 0.1 m of NH₃ solution.



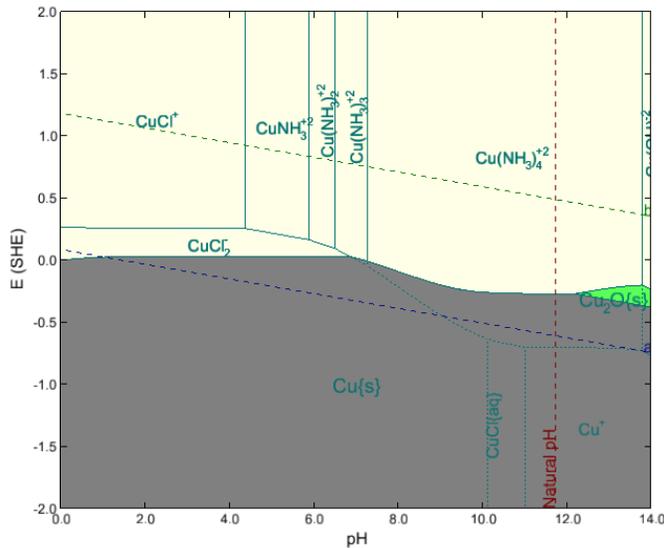
Notice that a large area of corrosive liquid has appeared in the stability field for the copper oxides. This means that it is thermodynamically possible for the ammonia to break down the passivation layer of copper oxide in the presence of oxygen. Notice that in the absence of oxygen (the **a** line only), copper is still stable.

Now repeat the exercise with **1.5 moles of NH3**

1. Go to the **Definition** tab, and change the amount of NH3 from 0 to 1.5 moles
2. **Click** on the **Calculate** button or press the **<F9>** key

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Cu-H2O-NH3 system at 25 °C and 1 atm in a 1.5 m of NH3 solution.



At this concentration of ammonia, most, if not all the passivating copper oxide has been reacted away. Only at very high pH values are there any stable oxides.

Example 46: Gold in the presence of Cyanides

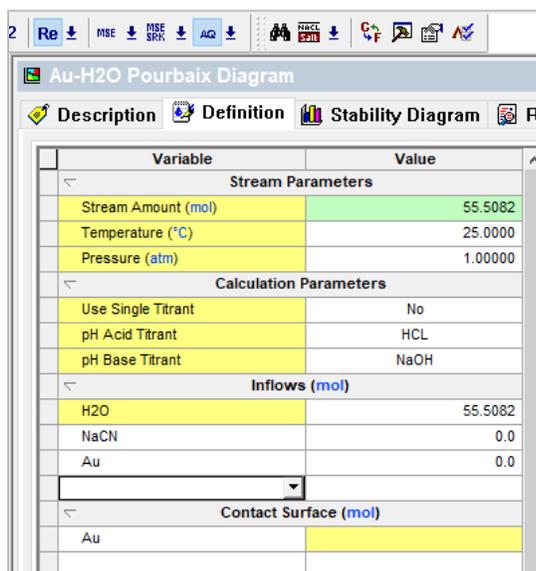
Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Au-H2O System	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Au	NaCN	0 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Au-H2O System*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition, temperature and pressure of the stream given in the table above
7. Under the *Au-H2O System* Stream add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane
8. Select **Pourbaix Diagram** as Type of Survey – Default
9. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Au-H2O*
10. Under the **Contact Surface** grid type **Au**

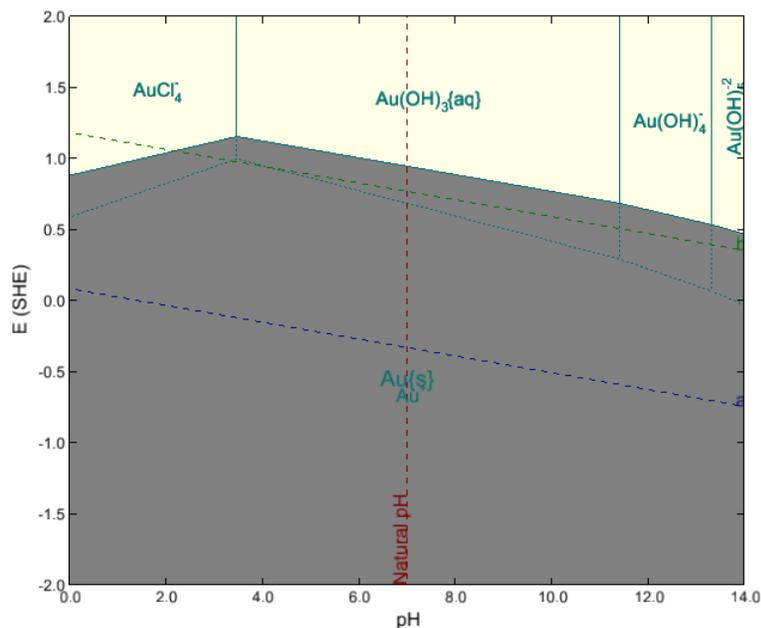
The screen should look like the image below after all the inputs and definitions have been entered:



11. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
12. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Au-H₂O system at 25 °C and 1 atm.



You can see that without oxygen, gold metal is immune to corrosion. The hydrogen line **a** is below the gold equilibrium line. In the presence of oxygen, gold is still immune to corrosion except at very low pH.

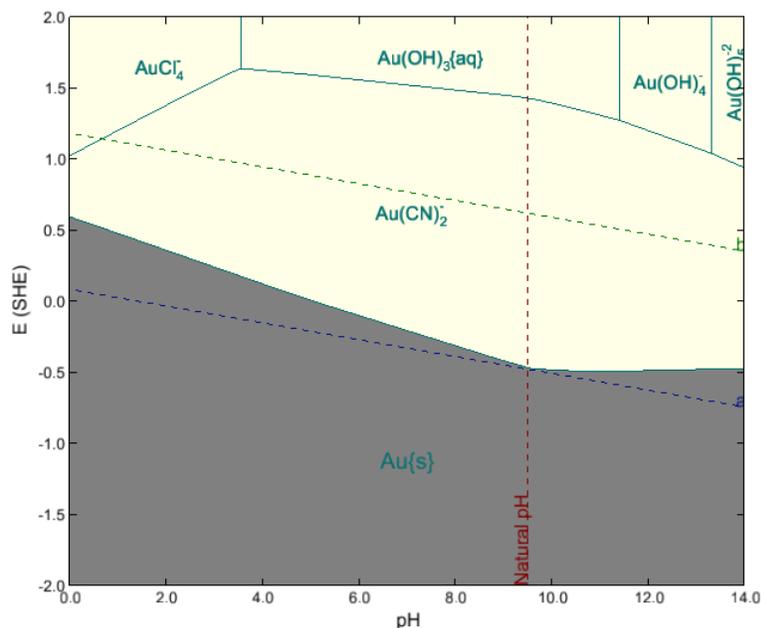
One of the most commonly used leaching processes for **gold extraction** is the **cyanidation** process. This process is a hydrometallurgical technique for extracting gold from low-grade ores by converting the gold to a water-soluble coordination complex. Basically, this approach adds cyanide salts to water. We are going to simulate this using the software.

Effect of Cyanide on the Stability of Gold

1. Go to the **Definition** tab, and change the amount of NaCN from 0 to 1e-4 moles
2. **Click** on the **Calculate** button or press the **<F9>** key

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Au-H₂O-NaCN system at 25 °C and 1 atm.



In the presence of oxygen, gold completely corrodes with cyanide. This is primarily due to the formation of the gold complex: $Au(CN)_2^-$. This complex is stable over all regions where water is also stable. This means that now gold can be processed in water in a variety of conditions.

7.8. Modeling the Effect of Oxidizing Inhibitors on Corrosion

In this chapter we will look at the effect of modeling corrosion inhibitors. We will do this by superimposing two stability diagrams over one another. If one solid field overlaps the corrosion range of the other system, then passivation is likely.

Example 47: Iron in the presence of chromates

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

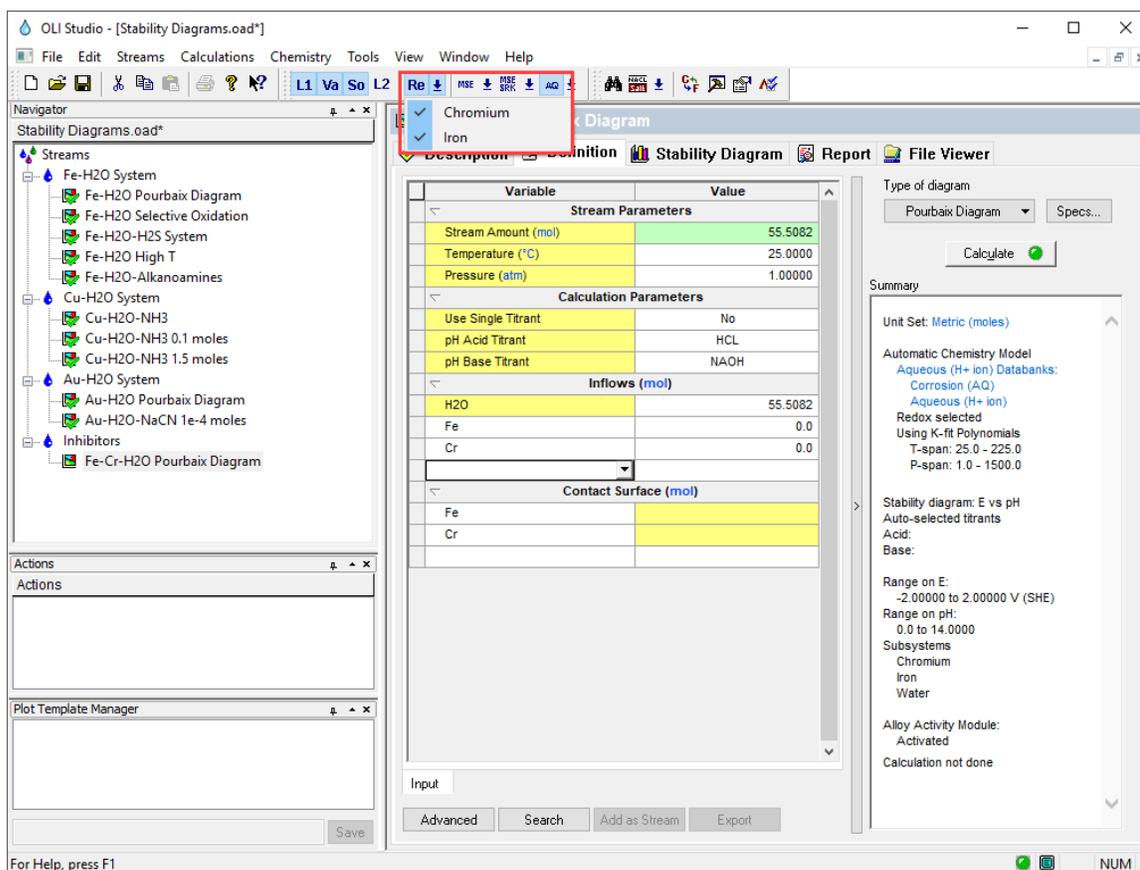
Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Inhibitors	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Fe		
Contact Surface	Cr		

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Inhibitors*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition, temperature and pressure of the stream given in the table above
7. Under the *Inhibitors* Stream add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane
8. Select **Pourbaix Diagram** as Type of Survey – Default
9. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-Cr-H2O Pourbaix Diagram*
10. Under the **Contact Surface** grid type **Fe** and then **Cr**

Note: Make sure that both **Fe** and **Cr** are enabled for Redox reactions. Use the arrow next to the **Re** button to expand the list.

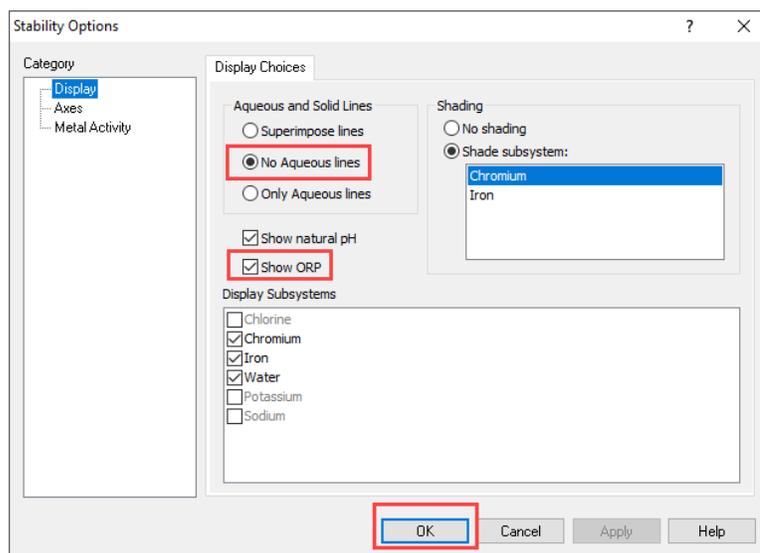
You can also enable Redox reactions via the menu bar: **Chemistry > Model Options > Redox** tab. Make sure that Fe and Cr boxes are checked.

The screen should look like the image below after all the inputs and definitions have been entered:



11. Click the **Specs** button and under the Display Choices tab check the following options:

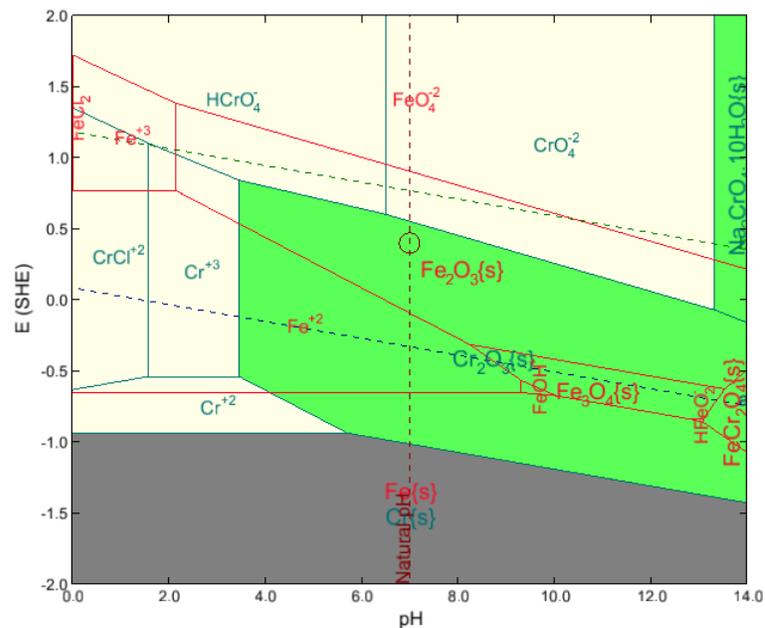
- No aqueous lines
- Show ORP



12. Click **OK** to close the Stability Options window
13. We are ready to perform the calculation. Click on the **Calculate** button or press the **<F9>** key
14. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Fe-Cr-H₂O system at 25 °C and 1 atm.



As you can see in this diagram, the shaded chrome passivating solid ($\text{Cr}(\text{OH})_{3\text{ppt}}$) overlays the corrosive region of the iron system. This means that there is potential for passivating the metal in that region.

The $\text{Cr}(\text{OH})_3$ field overlaps with the corrosion range of Fe in most of the pH range. This causes inhibition because of the coupling of: Oxidation of Fe to Fe^{2+} , reduction of chromates to $\text{Cr}(\text{OH})_3$, and the deposition of a protective layer of $\text{Cr}(\text{OH})_3$.

Example 48: Iron in the presence of arsenates

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Inhibitors	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H2O	55.5082 moles
Contact Surface	Fe		
Contact Surface	As		

1. Under the *Inhibitors* Stream add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane
2. Select **Pourbaix Diagram** as Type of Survey – Default
3. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-As-H2O Pourbaix Diagram*
4. Under the **Contact Surface** grid type **Fe** and then **As**

Note: Make sure that both **Fe** and **As** are enabled for Redox reactions. Use the arrow next to the **Re** button to expand the list.

You can also enable Redox reactions via the menu bar: **Chemistry > Model Options > Redox** tab. Make sure that Fe and As boxes are checked.

The screen should look like the image below after all the inputs and definitions have been entered:

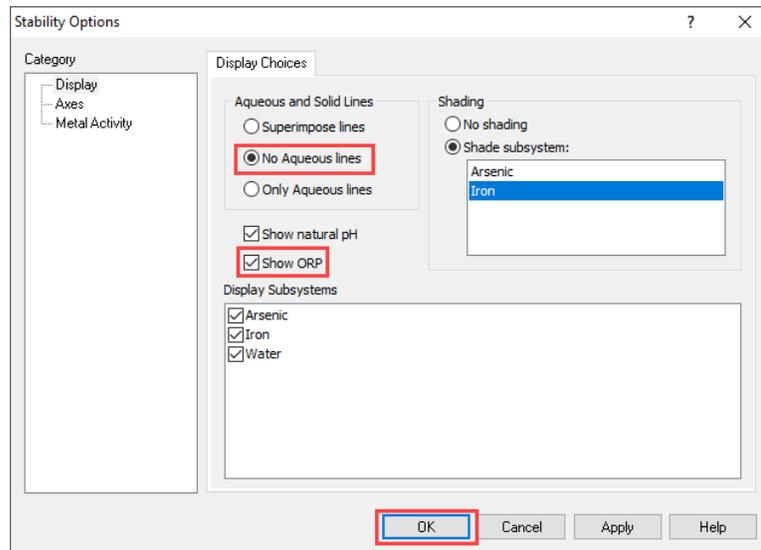
The screenshot displays the OLI Studio interface for configuring a Pourbaix Diagram. The main window shows the following configuration:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	NAOH
Inflows (mol)	
H2O	55.5082
Fe	0.0
As	0.0
Contact Surface (mol)	
Fe	
As	

The right-hand summary panel shows the following details:

- Type of diagram: Pourbaix Diagram
- Unit Set: Metric (moles)
- Automatic Chemistry Model: Aqueous (H+ Ion) Databanks: Corrosion (AQ), Aqueous (H+ Ion)
- Redox selected: Using K-fit Polynomials, T-span: 25.0 - 225.0, P-span: 1.0 - 1500.0
- Stability diagram: E vs pH
- User-selected titrants: Acid: As, Base:
- Range on E: -2.00000 to 2.00000 V (SHE)
- Range on pH: 0.0 to 14.0000
- Subsystems: Arsenic, Iron

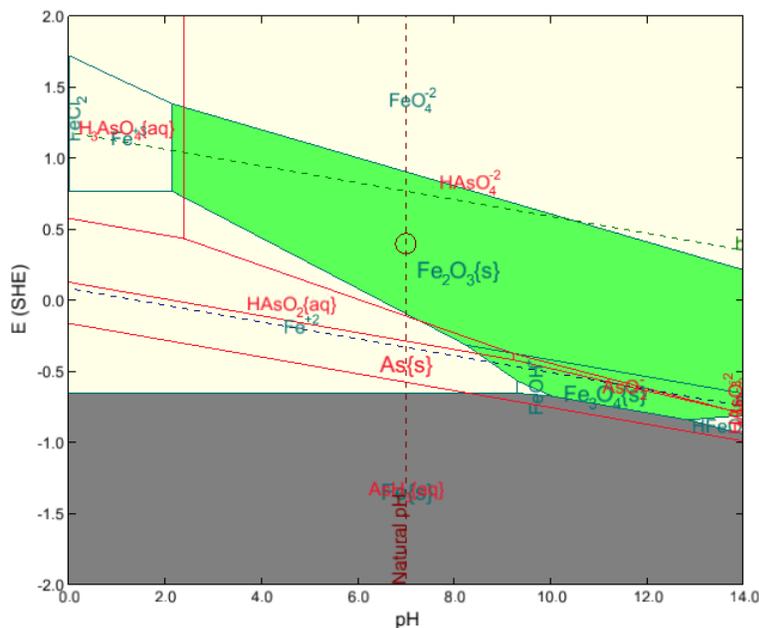
5. Click the **Specs** button and under the Display Choices tab check the following options:
 - c) No aqueous lines
 - d) Show ORP



6. Click **OK** to close the Stability Options window
7. We are ready to perform the calculation. Click on the **Calculate** button or press the **<F9>** key
8. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Stability Diagrams*.

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Fe-As-H₂O system at 25 °C and 1 atm.



The elemental arsenic field overlaps with the corrosion range of Fe in most of the pH range provided that the conditions are reducing (absence of oxygen). This promotes inhibition because of the coupling of: Oxidation of Fe to Fe⁺² and the reduction of arsenates to elemental As. This promotes the deposition of a protective layer of As. This can only work in reducing environments; otherwise the protective layer of As will oxidize and dissolve.

7.9. Implications of Stability Diagrams on Cathodic Protection

Cathodic protection works by shifting the potential of the metal into its immunity range. Stability diagrams can help you to answer the following questions:

- What is the potential range that ensures that the metal stays in the immunity range?
- What is the effect of environmental variables on the immunity domain?

We will explore the Fe-H₂O system at different temperatures and pressures to answer these questions.

Example 49: Effect of Temperature and Pressure on the Pourbaix Diagram of Fe-H₂O System

Starting the Simulation

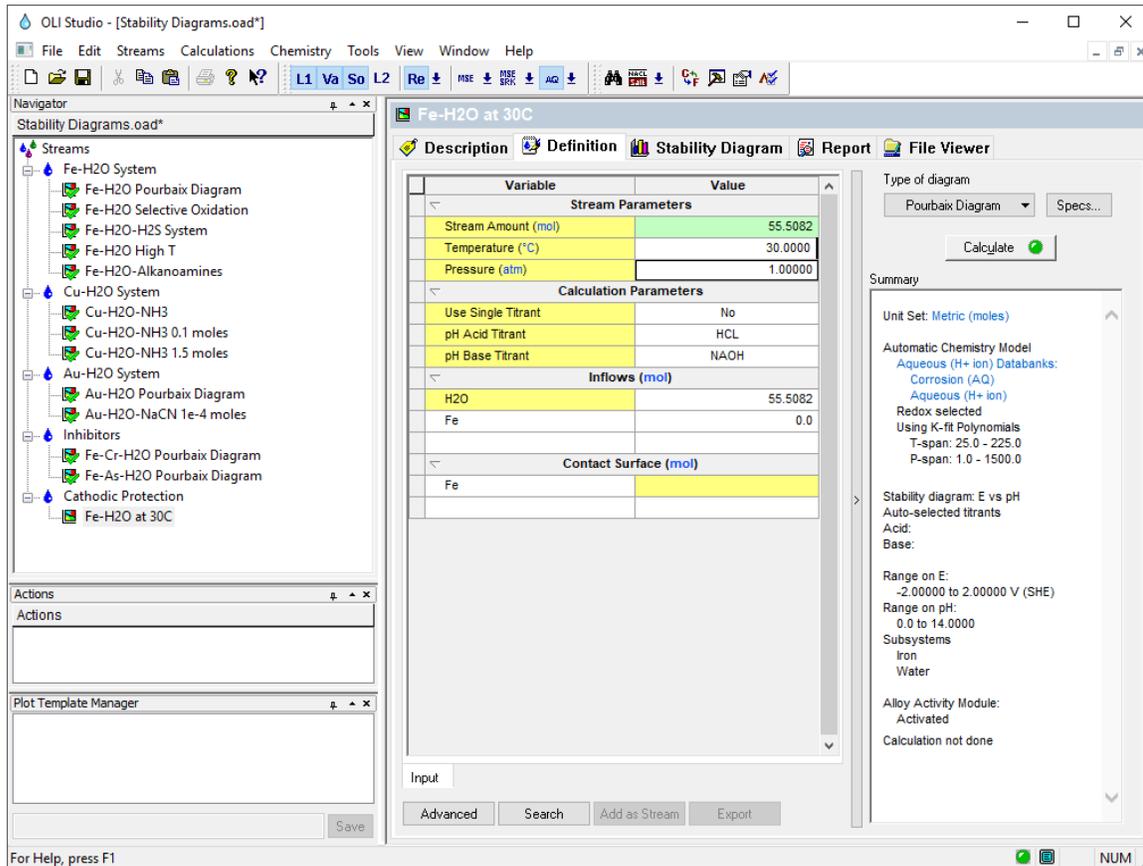
Iron at 30 °C and 1 atm

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Stability Diagram Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Cathodic Protection	Stream Amount	Calculated
Name Style	Display Formula	Temperature	30 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	pH Range	0-14 (Default)
Calculation Type	Stability Diagram	H ₂ O	55.5082 moles
Contact Surface	Fe		

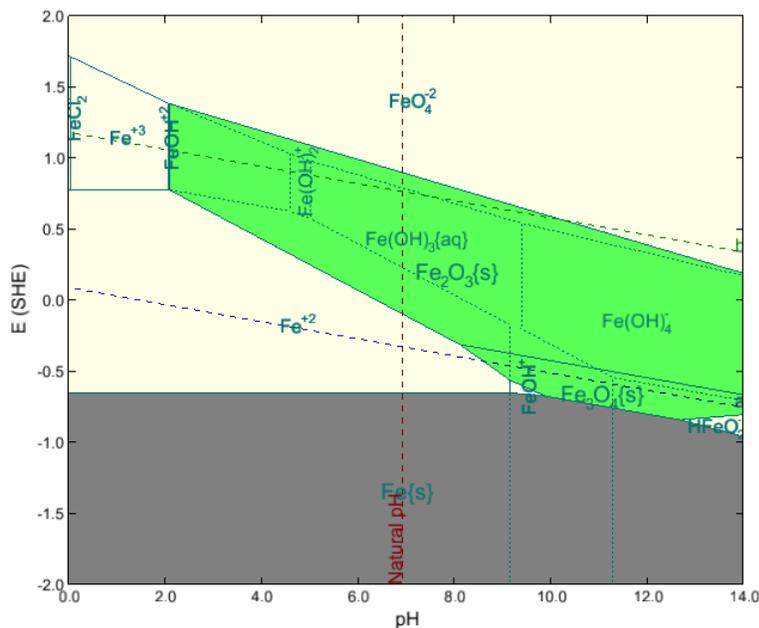
1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Cathodic Protection*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition, temperature and pressure of the stream given in the table above
7. Under the *Cathodic Protection* Stream add a new Stability Diagram calculation. Go to the **Add Calculation** button and select **Stability Diagram** calculation or by selecting the **Chemical Diagram** icon in the Actions Pane
8. Select **Pourbaix Diagram** as Type of Survey – Default
9. **Click** on the new *Stability Diagram* and press **<F2>** to change the name to *Fe-H₂O at 30C and 1 atm*
10. Under the **Contact Surface** grid type **Fe**

The screen should look like the image below after all the inputs and definitions have been entered:



Analyzing the Results

Click on the **Chemical Diagram** tab (Stability Diagram). This tab displays the Pourbaix Diagram for the Fe-H2O system at 30 °C and 1 atm.



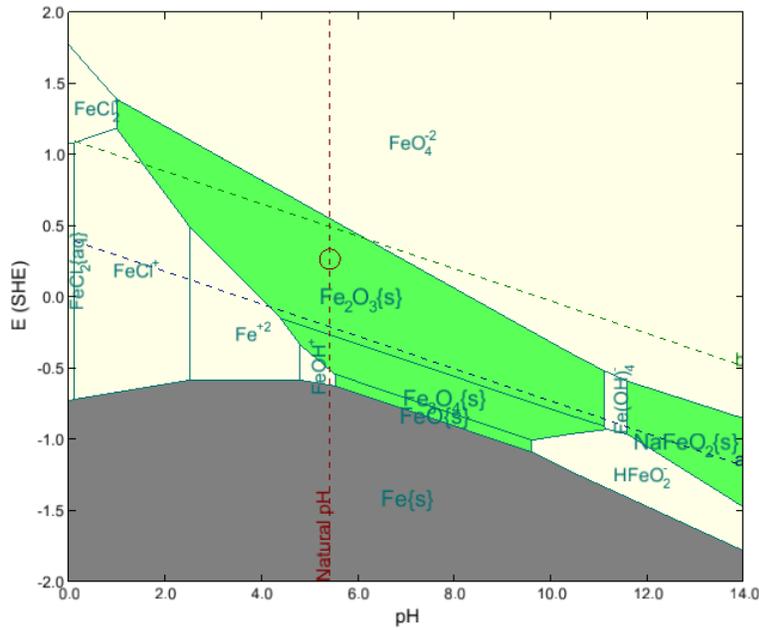
In the whole pH range, cathodic protection will require shifting the potential to moderately negative values.

Iron at 300 °C and 100 atm

1. Go to the **Definition** tab, and change the Temperature and Pressure to 300°C and 100 atm
2. **Click** on the **Calculate** button or press the **<F9>** key

Analyzing the Results

Click on the **Chemical Diagram** tab ( **Stability Diagram**). This tab displays the Pourbaix Diagram for the Cu-H₂O-NH₃ system at 300 °C and 100 atm.



The immunity range in acidic and neutral solutions is weakly affected by temperature. However, the immunity range in alkaline solutions is shifted to much lower potentials which makes cathodic protection much more difficult.

Section 8. Introduction to Rates of Corrosion

In this section you are going to learn how to set up a Corrosion Rate calculation, how to study the effect of different variables on the corrosion rates of different alloys, such as temperature, pH, flow velocity, etc., and how to interpret the results when using this tool.

We will also explore how to interpret the results for the propensity to localized corrosion, polarization curves and heat treatment effects.

The screenshot displays the OLI Studio software interface. The main window is titled "Rates" and contains a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Static
Effect of FeCO ₃ / FeS Scales	Include
Inflows (mol)	
H ₂ O	55.5082
Fe	0.0
Contact Surface	
Carbon steel G10100 (generic)	

On the right side of the "Rates" window, there are several controls:

- Survey by:** Temperature (dropdown), Specs...
- Then by (optional):** None (dropdown), Specs...
- Vary:** Independently, Together
- Calculate:** (button with a green checkmark)
- Summary:**
 - Unit Set: Metric (moles)
 - Automatic Chemistry Model
 - Aqueous (H+ ion) Databanks:
 - Corrosion (AQ)
 - Aqueous (H+ ion)
 - Redox selected
 - Using K-fit Polynomials
 - T-span: 25.0 - 225.0
 - P-span: 1.0 - 1500.0
 - Isothermal Calculation
 - 25.0000 °C 1.00000 atm
 - Calculation not done
 - Temperature survey:
 - Range 25.0 to 100.0 °C
 - Step size 5.0 °C
 - No. steps 15
 - No secondary survey selected
 - Polarization Curve Range
 - Range -2.0 to 2.0 V (SHE)

At the bottom of the "Rates" window, there are buttons for "Advanced", "Search", "Add as Stream", and "Export".

8.1. Basics Terminology

The basic theory and reference the papers...

Kinetics-polarization curves

Localized corrosion etc.

8.2. A Basic General Corrosion Rate Calculation

A brief introduction to the corrosion rate tool will be shown in the example below. As we go through the example, the basic definitions, functionalities and reporting for the *Corrosion rate* tool will be introduced.

Example 50: Corrosion rate of an oxygenated 0.1 m NaCl solution

Starting the Simulation

To start the software, double-click the **OLI Studio** icon on the desktop, which will take you to the OLI Studio interface where you can start creating your calculations.



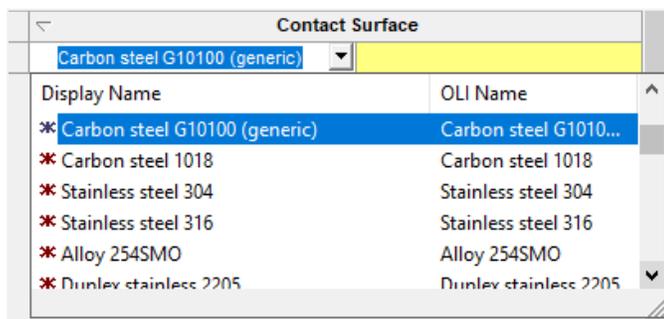
Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Corrosion Rate Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	CR of carbon steel	Stream Amount	Calculated
Name Style	Display Formula	Temperature	25 °C
Unit Set	Metric, Batch, Moles	Pressure	1 atm
Framework	AQ	H2O	55.5082 moles
Calculation Type	Corrosion Rates	O2	2.5e-4 moles
Contact Surface	Carbon Steel G10100 (generic)	NaCl	0.1 moles

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *CR of carbon steel*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
6. Enter the composition, temperature and pressure of the stream given in the table above
7. Go to the **Add Calculation** button and select **Corrosion Rates** calculation or by selecting the **Add Corrosion Rates** icon in the Actions Pane. Your screen should look like the image below.

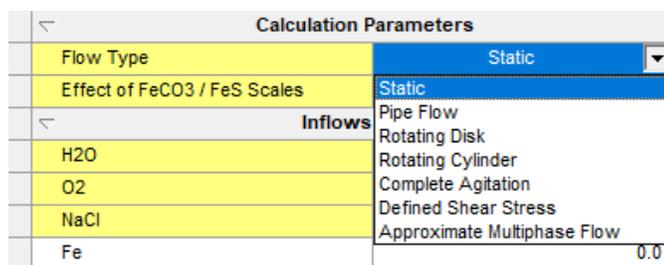
The screenshot shows the OLI Studio interface for a 'Single CR' calculation. The main window displays a table of variables and their values, organized into sections: Stream Parameters, Calculation Parameters, Inflows (mol), and Contact Surface. The 'Stream Parameters' section includes Stream Amount (mol) at 55.5085, Temperature (°C) at 25, and Pressure (atm) at 1.00000. The 'Calculation Parameters' section includes Flow Type (Static) and Effect of FeCO3 / FeS Scales (Include). The 'Inflows (mol)' section lists H2O (55.5082), O2 (2.50011e-4), and NaCl (0.100000). The 'Contact Surface' is set to Carbon steel G10100 (generic). On the right, there are controls for 'Survey by' (Temperature), 'Then by' (None), and 'Vary' (Independently). A 'Calculate' button is visible. The bottom right shows the 'Summary' section with 'Unit Set: <Custom>' and 'Automatic Chemistry Model: Aqueous (H+ Ion) Databanks'.

Note: By default, the software has selected **Carbon steel G10100 (generic)** as the default contact surface to perform the corrosion rates on. You can click on the white space of the **Carbon steel G10100 (generic)** name, and it will show a drop-down arrow. You can then click on the dropdown arrow, and you will be able to see and select any alloy present in the **Alloy** database.



Additionally, the **Calculation Parameters** grid shows two options: (1) Flow Type and (2) Effect of FeCO₃ /FeS scales on corrosion rates.

By default, the software selects **Static** as **Flow Type**. There are 7 options for Flow Type, and a brief description of the first five options will be given below.



Static

The solution is not flowing in this calculation.

Pipe Flow

The fluid is flowing through a pipe. The pipe diameter and flow velocity must be defined. The default pipe diameter is 0.1 meters and the default flow velocity is 2 m/s.

Rotating disk

This reproduces a type of experiment that is used quite frequently in the laboratory. A disk is rotated to bring fluid to the surface of the electrode in a predictable manner. The diameter of the disk is specified as well as the revolutions per minute (RPM). The default diameter is 0.01 meters and the default RPM is 5000 RPM.

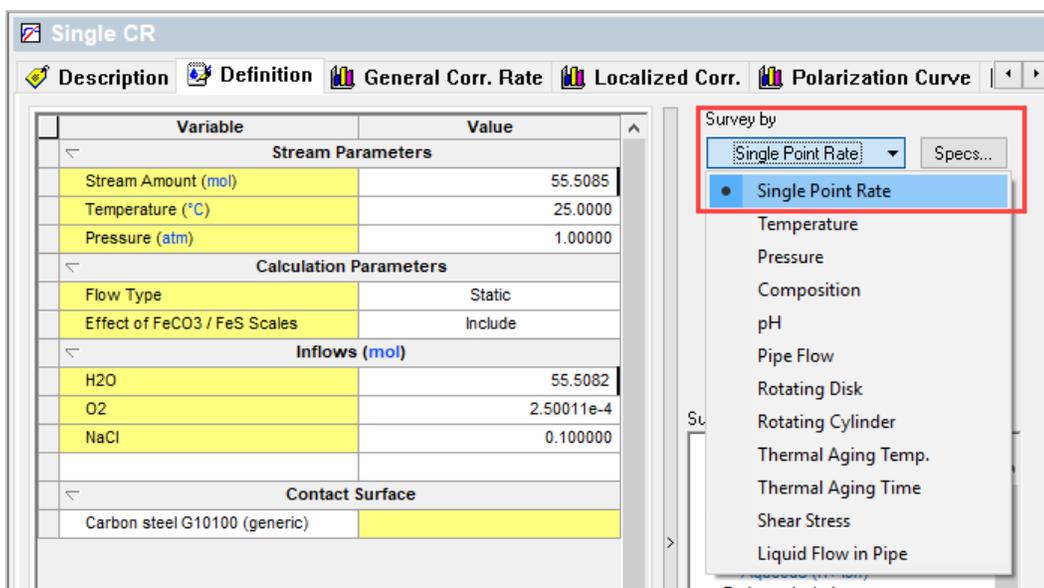
Rotating Cylinder

This reproduces a type of experiment that is used quite frequently in the laboratory. A cylindrical rotor is rotated to bring fluid to the surface of the electrode in a predictable manner. The diameter of the rotor is specified as well as the revolutions per minute (RPM). The default diameter is 0.01 meters and the default RPM is 5000 RPM.

Complete Agitation

In this calculation, the liquid phase is completely agitated, and no mass transfer limitations apply.

8. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface
9. **Go** to the **Survey by** option and select **Single Point Rate**. This option will allow you to calculate the corrosion rate at the temperature and pressure specified.



Note: You can also study the effect of other variables such as temperature, pressure, (chemical species) composition, pH, pipe flow, etc. on the corrosion rate. The effect of these variables can be set up as a survey calculation. In the upcoming corrosion rate examples, survey calculations to study corrosion rates will be shown in more detail.

A brief description of the most common survey types for studying corrosion rates are given below.

pH Survey – This calculation is similar to the pH survey available in OLI Studio: Stream Analyzer. The specification requires a titrant acid and base to change the pH.

Temperature Survey – The default range is from 25-100 °C. Any range may be used by changing the Range option. The user should consider that some points in the survey may not converge due to phase changes (e.g., boiling off of aqueous liquids).

Composition Survey – The composition of a chemical compound, for example NaCl, can be varied to study its effects on corrosion rates. The range of the chemical compound defaults from 0 to 1 mole with an increment of 0.1 moles. This range can be changed via the Range option.

Care should be taken when adding salts that can form hydrates (e.g., CaCl₂·6H₂O). When these hydrated salts begin to precipitate from solution, large amounts of water may be complexed with the crystal. The solution may dehydrate, and non-convergence may be the result.

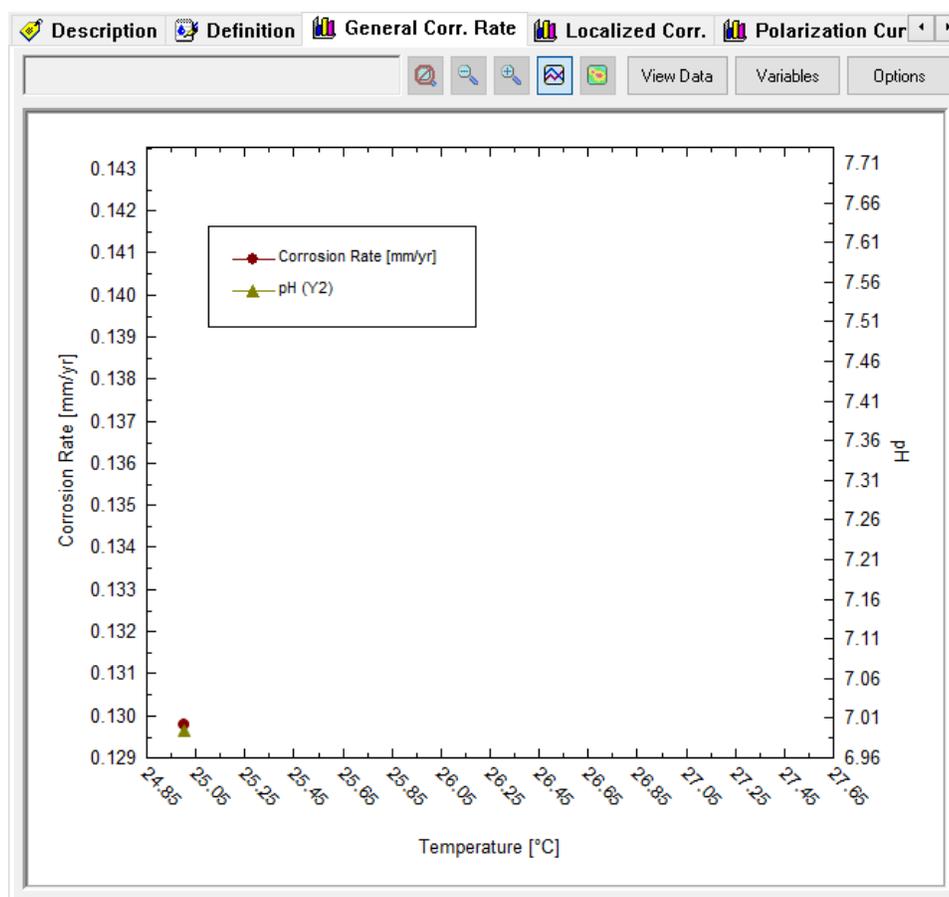
Pressure Survey – The pressure of the system can also be varied. The default range can be changed via the Range option. Care should be taken when working at very low pressures since the solution may inadvertently boil off the liquid and non-convergence may result.

Flow Velocity Survey – In systems that are flowing, the flowrate of the stream can be varied.

- Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
- It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. Create a new file and name it: *Corrosion Rates*.

Analyzing the Results

- Click on the **General Corr. Rate** tab ( General Corr. Rate). This tab displays a plot showing the results of corrosion rate and pH.

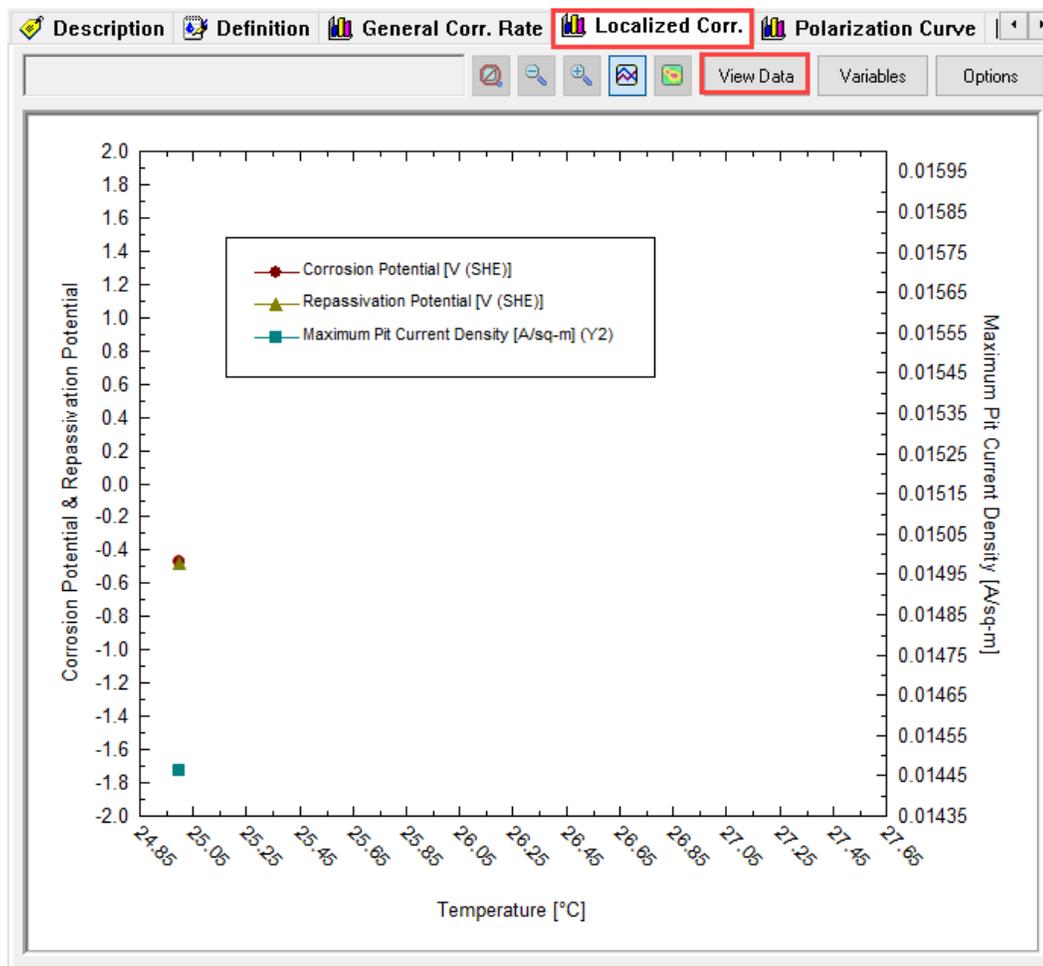


- Click on the **View Data** button to see the results in tabulated form.

	Temperature	Corrosion Rate	pH
	°C	mm/yr	
1	25.0000	0.129801	6.99516

The predicted corrosion rate of carbon steel at 25 °C and 1 atm is ~0.13 mm/year when exposed to an oxygenated 0.1 m NaCl solution. It is important to highlight that this predicted corrosion rate is the corrosion rate once the system has reached a steady state.

- Click on the **Localized Corr. Rate** tab (Localized Corr.). This tab displays a plot showing the results of three different calculated data:
 - Corrosion Potential (red dot)
 - Repassivation Potential (yellow triangle)
 - Maximum Pit Current Density (blue square)

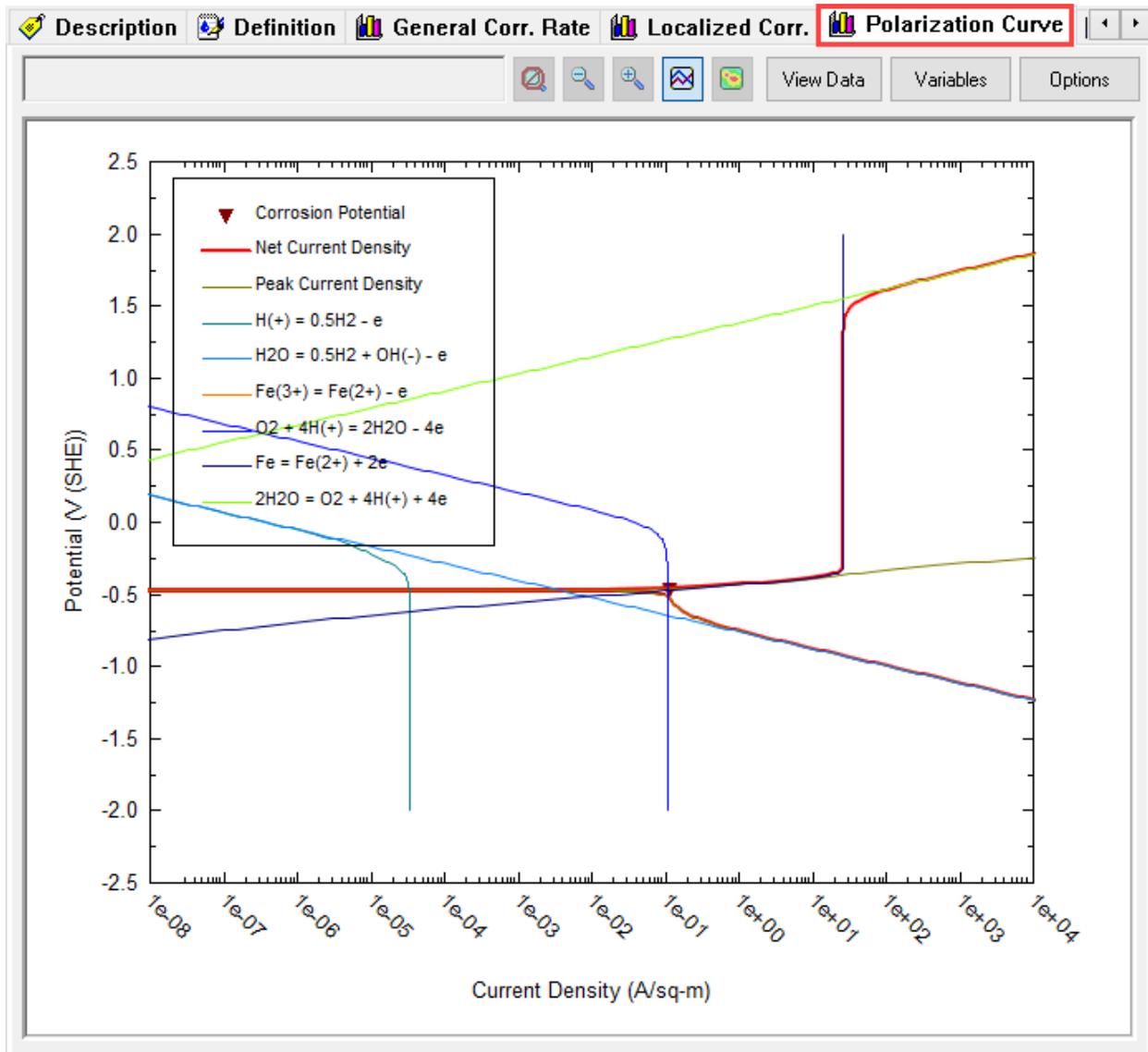


- Click on the **View Data** button to see the results in tabulated form.

	Temperature	Corrosion Potential	Repassivation Potential	Maximum Pit Current Density
	°C	V (SHE)	V (SHE)	A/sq-m
1	25.0000	-0.472418	-0.481902	0.0144636

Notice that in this case, the corrosion potential has a higher value than the repassivation potential. This indicates that carbon steel at 25 °C and 1 atm when exposed to an oxygenated 0.1 m NaCl solution will likely suffer localized corrosion (pitting or crevice corrosion). The maximum pit current density gives the worst-case pitting rate for these conditions.

5. Now, click on the **Polarization Curve** tab ( **Polarization Curve**). This tab displays a plot showing the calculated polarization curve of carbon steel.



The net polarization curve is given by the red curve. This red curve is obtained by adding up all the currents of the half reactions at a given potential. The corrosion potential is calculated by applying the mixed potential theory, and it is represented by this red triangle. Once the corrosion potential is obtained, the corrosion current density also is computed and subsequently the corrosion rate.

8.3. Exploring corrosion rate calculation options

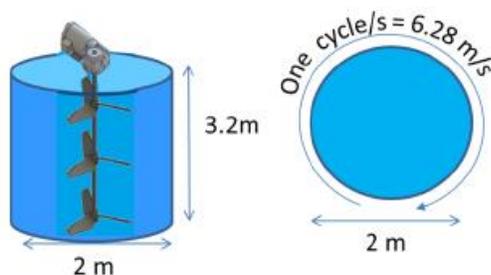
Example 51: Corrosion in a Water-Filled Carbon Steel Tank

In the following example you are going to study the corrosion rate of a carbon steel tank with a volume of 10 m³ tank (3.2 m high and 200 cm in diameter) that is filled to the top with water. The tank's wall thickness is 1.27 cm.

These are the operation conditions:

1. Sometimes the water in the tank remains static (mixer off), closed to the atmosphere
2. Some other times the tank is fully mixed (complete agitation)
3. The tank when operating has a variable speed mixer with a rotation speed between 0 and 12,000 rpm
4. At other times, the tank is open to the atmosphere. The effects of O₂, CO₂ and flow will be studied.

We will evaluate each instance to compute the corrosion risk.



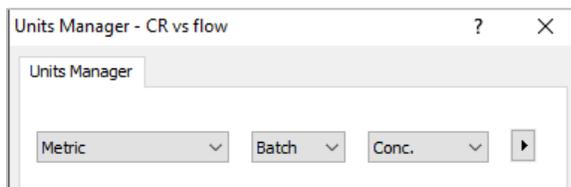
Starting the Simulation

First operation condition: Static flow, tank closed to the atmosphere at ambient conditions

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Corrosion rate calculation of tank as a function of flow			
Calculation Settings		Stream Composition and Conditions	
Stream Name	CR vs flow	Stream Amount	10000 L
Calculation Type	Corrosion Rates	Temperature	25 °C
Name Style	Display Name	Pressure	1 atm
Unit Set	Metric, Batch, Concentration	Water	Calculated
Framework	AQ		
Contact surface	Carbon Steel G10100 (generic)		

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *CR vs flow*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon, and select the **Display Name** option, and click **OK**
5. **Click** on the **Units Manager** Icon, and select the **Metric, Batch, Conc.** option, and click **OK**



In the Definition tab, notice that the units of the Stream Amount changed from moles (mol) to liters (L).

6. Enter the composition, temperature and pressure of the stream given in the table above
7. Go to the **Add Calculation** button and select **Corrosion Rates** calculation or by selecting the **Add Corrosion Rates** icon in the Actions Pane.
8. Change the **Rates** name to **Static Flow, 25C** using the <F2> key.
9. Leave the default Flow Type as **Static**
10. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface
11. Go to the **Survey by** option and select **Single Point Rate**. This option will allow you to calculate the corrosion rate at the temperature and pressure specified.

Your screen should look like the image below.

Variable	Value
Stream Parameters	
Stream Amount (L)	10000.0
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Static
Effect of FeCO ₃ / FeS Scales	Include
Inflows (mg/L)	
H ₂ O	
Fe	0.0
Contact Surface	
Carbon steel G10100 (generic)	

Summary:

- Unit Set: Metric (mass concentration)
- Automatic Chemistry Model
- Aqueous (H+ ion) Databanks:
 - Corrosion (AQ)
 - Aqueous (H+ ion)
- Redox selected
- Using K-fit Polynomials
 - T-span: 25.0 - 225.0
 - P-span: 1.0 - 1500.0
- Isothermal Calculation
 - 25.0000 °C 1.00000 atm
- Calculation not done

12. We are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key.
13. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

Analyzing the Results

Click on the output tab labeled **1** (next to the input tab), and check the results located in the **Corrosion Values** tab.

Variable	Value
Stream Parameters	
Stream Amount (L)	10000.0
Volume - Aqueous (L)	10000.0
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Corrosion Values	
Repassivation Potential (V (SHE))	99.9000
Corrosion Rate (mm/yr)	7.12696e-3
Corrosion Potential (V (SHE))	-0.552268
Corrosion Current Density (A/sq-)	6.14631e-3
Inflows (mg/L)	
H2O	9.96987e5
Contact Surface	
Carbon steel G10100 (generic)	

The corrosion rate is 7.13×10^{-3} mm/yr. This is a negligible rate, since the thickness of the tank is ~ 12.7 mm, then corroding half the wall thickness would take about 900 years.

Second operation condition: Turbulent flow, tank closed to the atmosphere at ambient conditions

1. Under the stream 'CR vs Flow' add new corrosion rate calculation. Go to the **Add Calculation** button and select **Corrosion Rates** calculation or by selecting the **Add Corrosion Rates** icon in the Actions Pane
2. Change the **Rates** name to **Turbulent Flow, 25C** using the <F2> key.
3. Change the default Flow Type to **Complete Agitation**
4. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface
5. Go to the **Survey by** option and select **Single Point Rate**.

Your screen should look like the image below.

Variable	Value
Stream Parameters	
Stream Amount (L)	10000.0
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Complete Agitation
Effect of FeCO3 / FeS Scales	Include
Inflows (mg/L)	
H2O	
Fe	0.0
Contact Surface	
Carbon steel G10100 (generic)	

Analyzing the Results

Click on the output tab labeled **1** (next to the input tab), and check the results located in the **Corrosion Values** tab.

Variable	Value
Stream Parameters	
Stream Amount (L)	10000.0
Volume - Aqueous (L)	10000.0
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Corrosion Values	
Repassivation Potential (V (SHE))	99.9000
Corrosion Rate (mm/yr)	0.0196420
Corrosion Potential (V (SHE))	-0.535169
Corrosion Current Density (A/sq-)	0.0169394
Inflows (mg/L)	
H2O	9.96987e5
Contact Surface	
Carbon steel G10100 (generic)	

Input: 1

The corrosion rate increased 0.0196 mm/year, still a relatively low value.

Third operation condition: Varying flow, tank closed to the atmosphere at ambient conditions

1. Under the stream 'CR vs Flow' add new corrosion rate calculation. Go to the **Add Calculation** button and select **Corrosion Rates** calculation or by selecting the **Add Corrosion Rates** icon in the Actions Pane
2. Change the **Rates** name to **Varying Flow, 25C** using the <F2> key
3. Go to the **Survey by** button and select **Rotating Disk**
4. Under the **Calculation Parameters** grid. change the **Disk Diameter** to **200 cm**

Note: At this point the vertical dimensions of the tank are unimportant. We will assume that the tank can be modeled like a rotating cylinder. The propeller rotates at 1200 rpm, although it is not expected that the wall velocity will approach this value, and so a lower value will be used (we still want it to be high enough to see the effects of shear).

5. The next step is to set the speed of the mixer. Go to the **Specs** button next to the **Rotating Disk** option
6. Change the Disk Rotation Speed Range from 0 to 300 cycles/min with an increment of 10 cycles/min. Then click **OK**.

Category: Var. 1 - Disk Rotation Speed

Survey Range

Disk Rotation Speed Range Unit: cycle/min

Selected Range: 0.0 to 300.0 in 30 steps of 10.0

Linear (selected) Log Point List

End Points: Start 0.0 End 300.000

Step Size: Increment 10.0000 Number Steps 30

Select one, the other is calculated

7. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface

Your screen should look like the image below.

The screenshot displays the OLI Studio interface for a corrosion simulation. The main window is titled 'Varying Flow, 25C'. The 'Calculation Parameters' table is as follows:

Variable	Value
Stream Parameters	
Stream Amount (L)	10000.0
Density correlation	Fixed condition
Fixed: Temperature (°C)	25.0000
Fixed: Pressure (atm)	1.00000
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Rotating Disk
Disk Diameter (cm)	200.000
Disk Rotation Speed (cycle/min)	
Effect of FeCO ₃ / FeS Scales	Include
Inflows (mg/L)	
H ₂ O	
Fe	0.0
Contact Surface	
Carbon steel G10100 (generic)	

The 'Summary' panel on the right shows the following details:

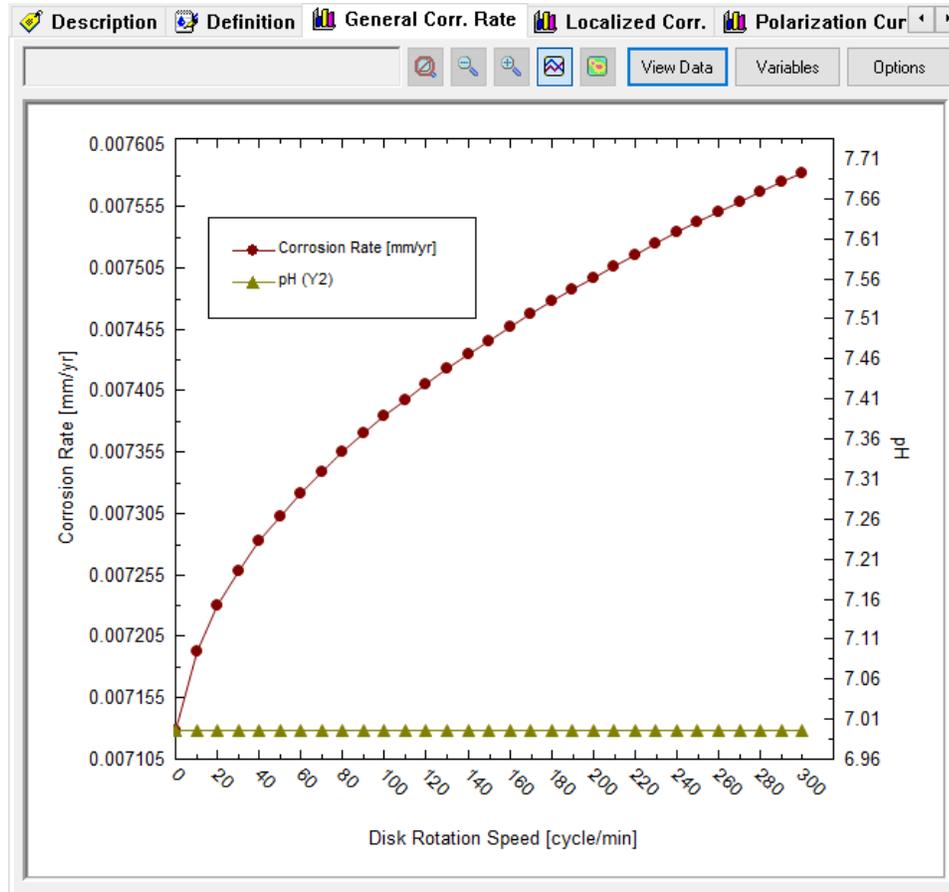
- Unit Set: Metric (mass concentration)
- Automatic Chemistry Model: Aqueous (H⁺ ion) Databanks: Corrosion (AQ), Aqueous (H⁺ ion)
- Redox selected: Using K-fit Polynomials, T-span: 25.0 - 225.0, P-span: 1.0 - 1500.0
- Isothermal Calculation: 25.0000 °C 1.00000 atm, Calculation not done
- Rotating Disk survey: Range 0.0 to 300.0 cycle/min, Step size 10.0 cycle/min, No. steps 30
- No secondary survey selected
- Polarization Curve Range: Range -2.0 to 2.0 V (SHE)

8. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

9. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

Analyzing the Results

Click on the **General Corr. Rate** tab ( **General Corr. Rate**). This tab displays a plot showing the results of corrosion rate and pH.



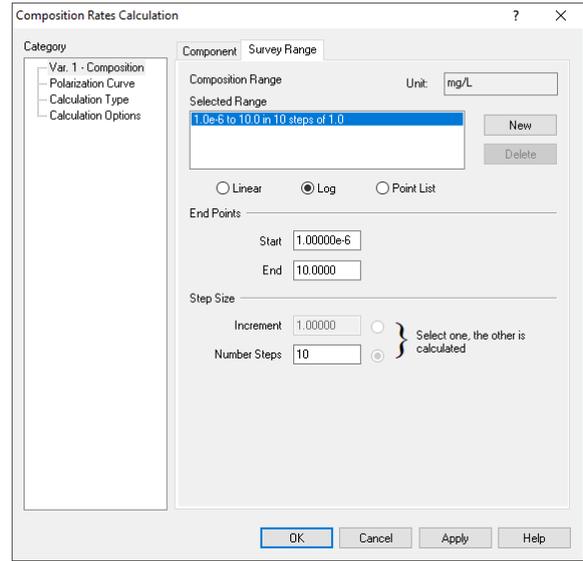
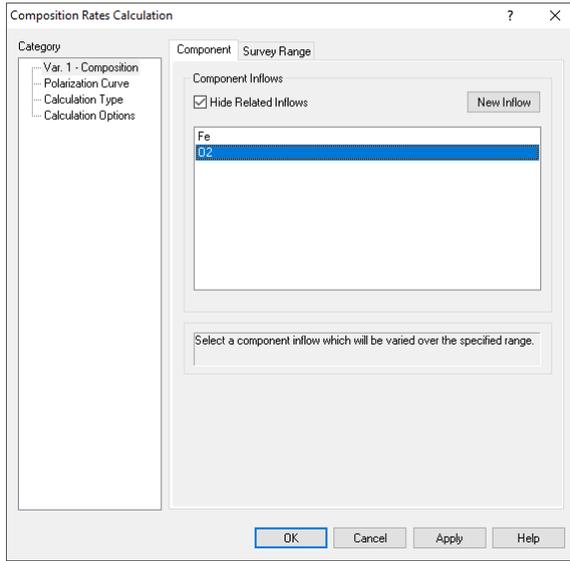
The corrosion rate is computed to increase as the bulk liquid velocity increases from 0 to 300 rpm near the wall surface. The reason is straightforward; the higher velocity reduces the static water film thickness on the metal surface. This *diffusion layer* film limits the mass transfer of corrosion products and bulk chemicals to and from the surface. As the liquid velocity (and therefore shear force) increases, the film thickness decreases, and the concentration gradient increase. This increases the flux of materials to and from the surface, which increase corrosion rates.

Fourth operation condition: Static flow, tank open to the atmosphere (aerated with O₂ only) at ambient conditions

Open steel tanks are in contact with oxygen in the air. To simulate this, follow the steps below.

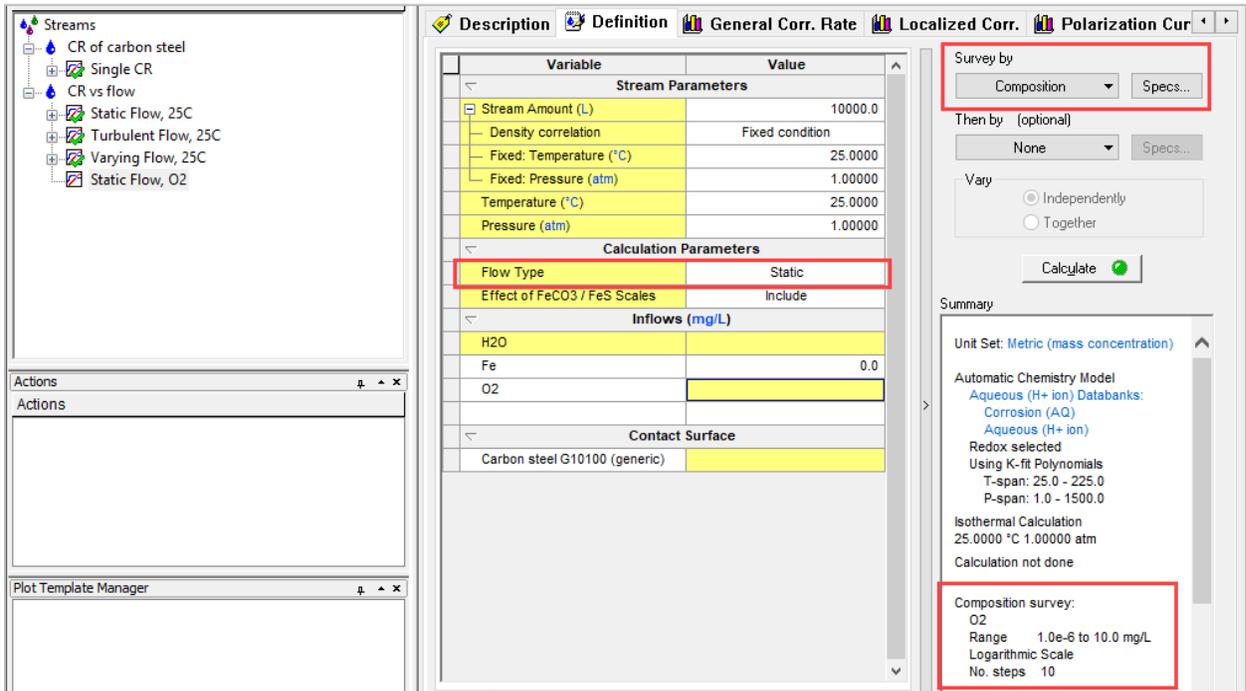
1. Under the stream 'CR vs Flow' add new corrosion rate calculation. Go to the **Add Calculation** button and select **Corrosion Rates** calculation or by selecting the **Add Corrosion Rates** icon in the Actions Pane
2. Change the **Rates** name to **Static Flow, O₂** using the <F2> key
3. **Add** Oxygen (O₂) to the inflow grid
4. Leave the default Flow Type as **Static**

- Go to the *Survey by* button and select **Composition**
- Change the **Disk Diameter** to **200 cm**
- The next step is the concentration range of oxygen. Go to the **Specs** button next to the **Composition** option. This will open a new window.
- Under **component** select (click on) O2. Then select the **Survey Range** tab and enter the Survey Range as follows: Log Scale, Start=1e-6, End=10, Steps=10. Then click **OK**.



- Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface

Your screen should look like the image below.

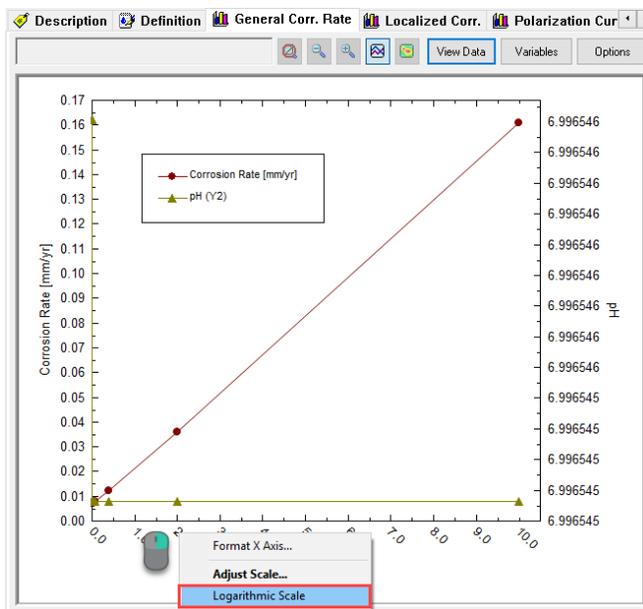


10. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
11. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

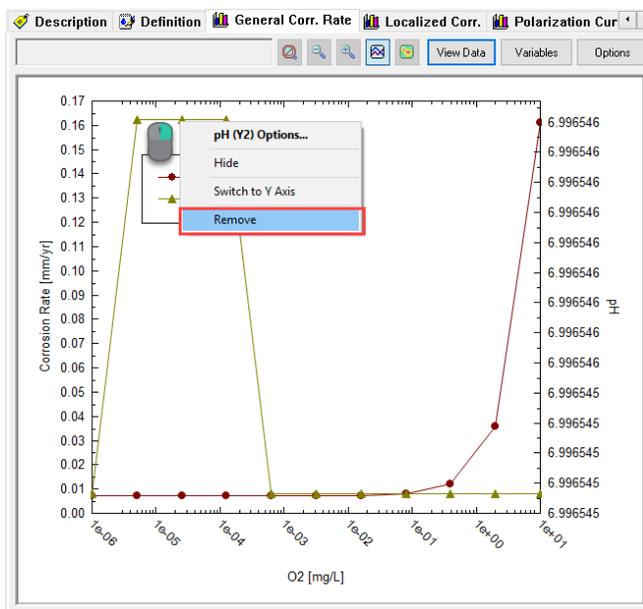
Analyzing the Results

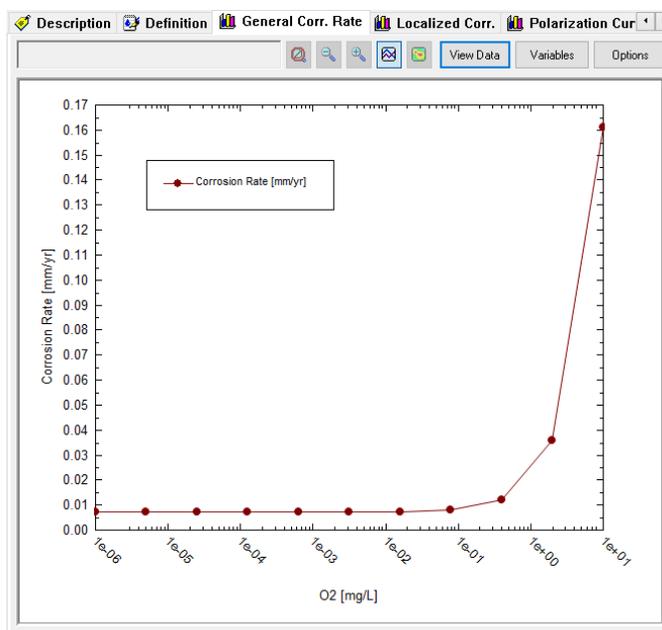
Click on the **General Corr. Rate** tab ( General Corr. Rate). This tab displays a plot showing the results of corrosion rate and pH.

1. **Right-mouse click** on the **X-axis** and change it to **Logarithmic Scale**



2. **Right-mouse click** on the **pH curve** and select **Remove**

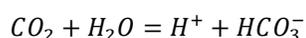




The resulting plot shows the impact of oxygen on the corrosion rate. Corrosion increases by a factor of 20 once the concentration increases beyond 100 µg/l. Aerated water contains approximately 8 mg/l O₂. Corrosion on the tank wall is 0.16 mm/yr. At this rate, 50% of the 12.3 mm wall will be dissolved in 40 years.

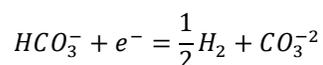
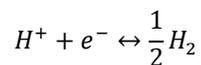
Fifth operation condition: Static flow, tank open to the atmosphere (aerated with O₂ and CO₂) at ambient conditions

The atmosphere contains ~400 ppmV CO₂. At this concentration 0.6 mg/l CO₂ is dissolved in water as molecular CO₂, this CO₂ hydrolyzes water to form the following reactants:



The resulting pH is about 5.6 at ambient conditions.

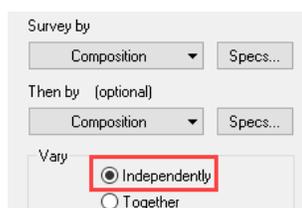
The impact of CO₂ on corrosion is two-fold, as two separate reactions occur at the metal surface:



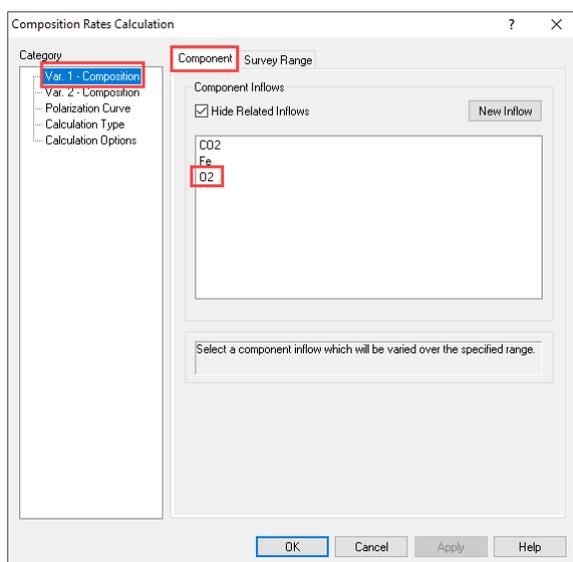
To test the CO₂ impact, you will recalculate the corrosion rate using two CO₂ concentrations: 0 and 0.6 ppm.

- I. Under the stream 'CR vs Flow' add new corrosion rate calculation. Go to the **Add Calculation** button and select **Corrosion Rates** calculation or by selecting the **Add Corrosion Rates** icon in the Actions Pane
- II. Change the **Rates** name to **Static Flow, O2 and CO2** using the <F2> key
- III. **Add** Oxygen (O₂) and carbon dioxide (CO₂) to the inflow grid
- IV. Leave the default Flow Type as **Static**

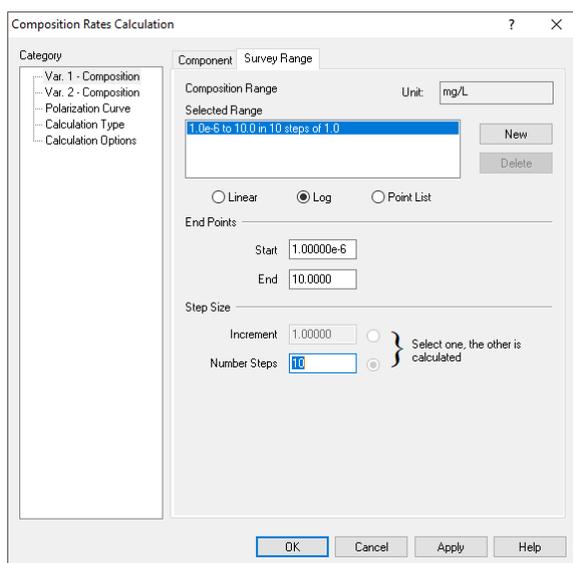
- V. Go to the *Survey by* button and select Survey by **Composition** and then by **Composition** (as shown below)



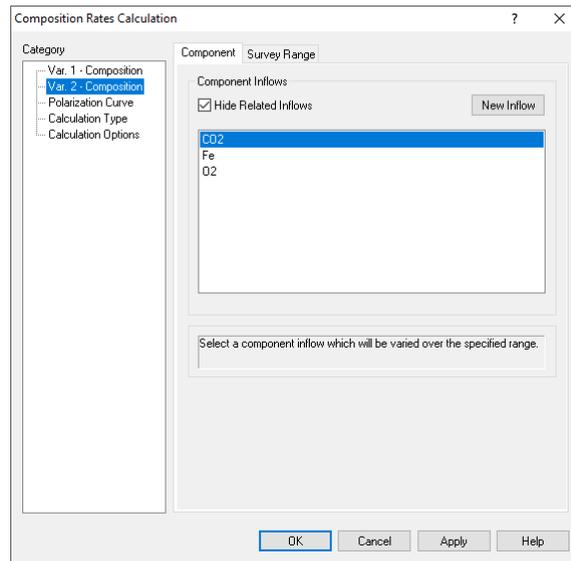
- VI. The next step is the concentration range of oxygen and carbon dioxide. Go to the **Specs** button next to the **Composition** option. This will open a new window.
- VII. Under the **Category** section, make sure to select **Var. 1 -Composition**. Go to the **Component** tab, and select O2



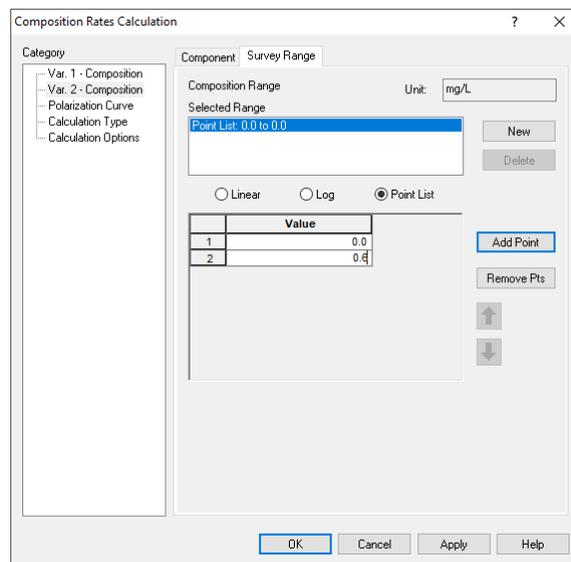
- VIII. Then select the **Survey Range** tab and enter the Survey Range as follows: Log Scale, Start=1 e-6, End=10, Steps=10. Then click **OK**.



IX. Under the **Category** section, select **Var. 2 -Composition**. Go to the **Component** tab, and select CO2

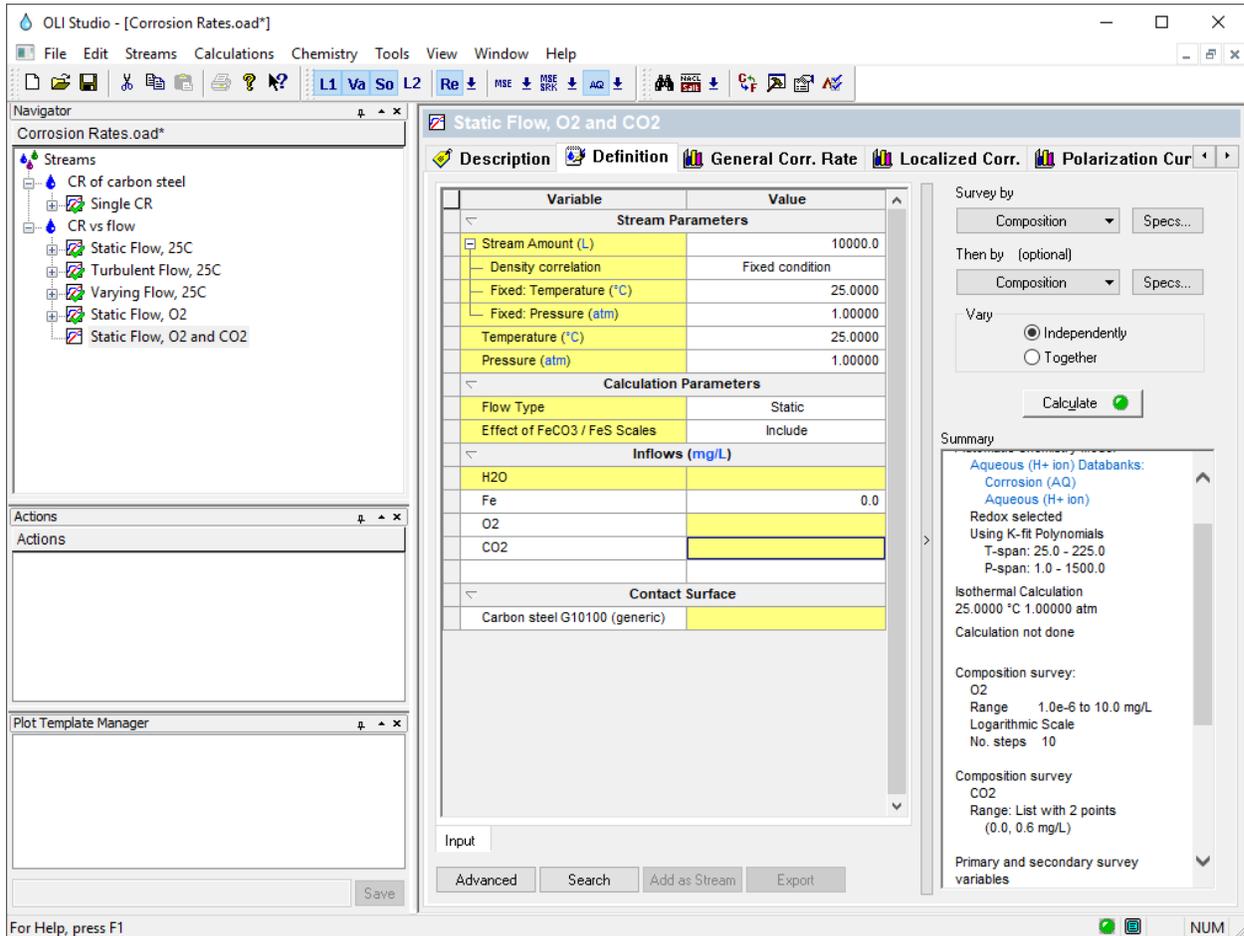


X. Then select the **Survey Range** tab. Select the Point List option. Create two point with values of 0 and 0.6 mg/L. Then click **OK**.



XI. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface

Your screen should look like the image below.



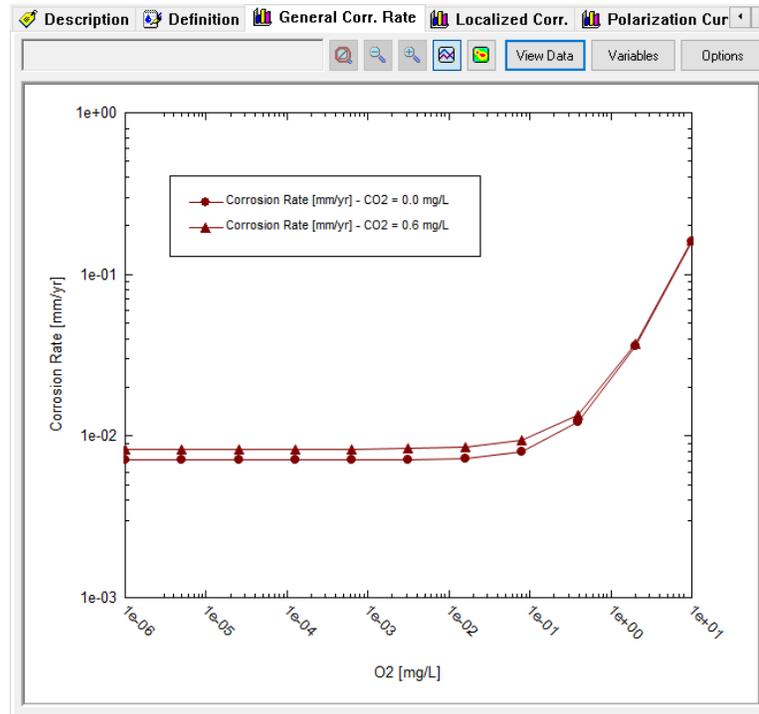
12. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

13. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

Analyzing the Results

Click on the **General Corr. Rate** tab ( General Corr. Rate). This tab displays a plot showing the results of corrosion rate and pH.

1. **Right-mouse click** on the **X-axis** and change it to **Logarithmic Scale**
2. **Right-mouse click** on the **Y-axis** and change it to **Logarithmic Scale**
3. **Right-mouse click** on the **pH** curve and select **Remove Series**

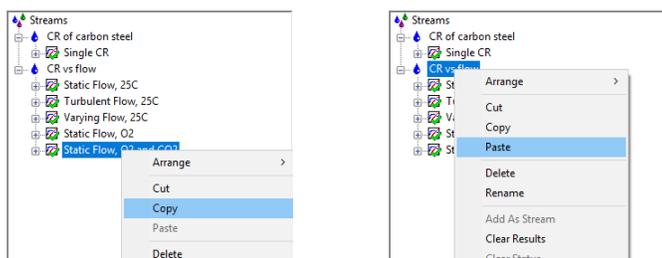


The effects of CO₂ are small, particularly in relation to the oxygen effects. The Corrosion rates at low O₂ content are about 0.0071 mm/yr with no CO₂ and 0.0083 mm/yr with 0.6 mg/l CO₂; a small difference between two small rates. At 10 mg/l O₂ the corrosion rate is 0.16 mm/y and it is the same with and without CO₂. Thus, CO₂ has no effect on corrosion at high O₂ concentrations meaning that the surface is corroded by oxygen and small concentrations of CO₂ does not change this rate.

Sixth operation condition: 300 cycles/min flow, tank open to the atmosphere (aerated with O₂ and CO₂) at ambient conditions

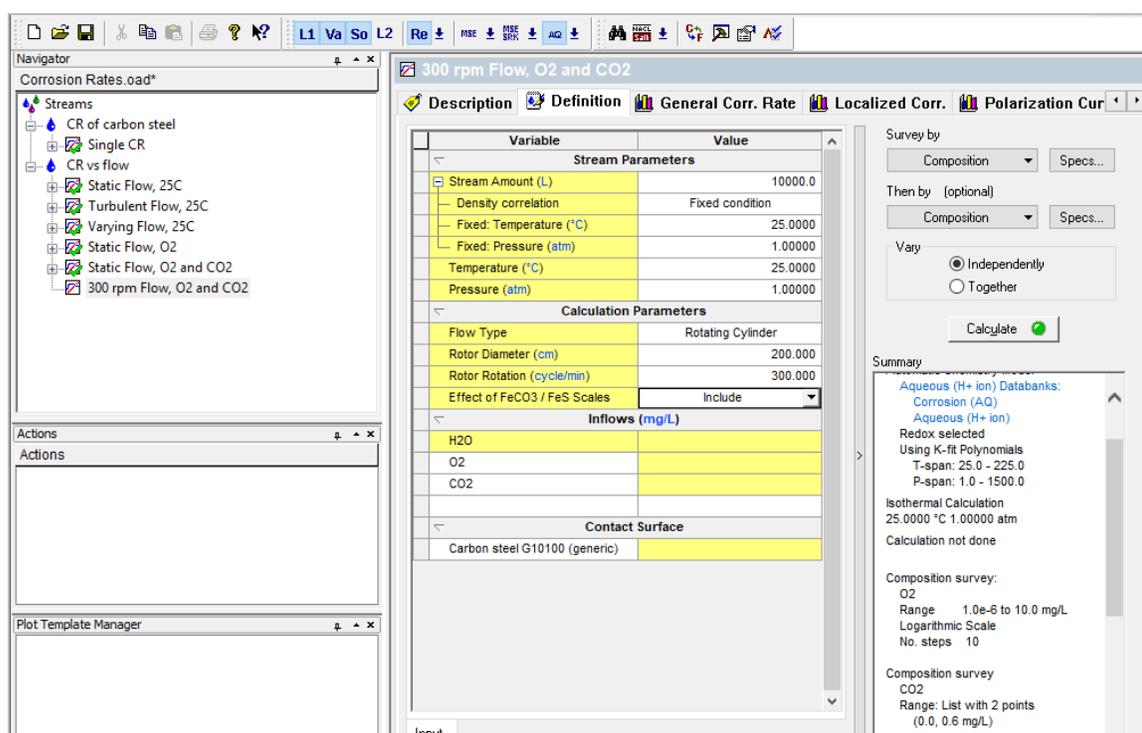
Lastly, you will look at the effects of shear rates on the tank in contact with CO₂ and O₂.

1. **Copy** (right-mouse click or Ctrl+C) 'Static Flow, O₂ and CO₂' corrosion calculation, and **paste** (right-mouse click or Ctrl+V) under the stream 'CR vs Flow'



2. Change the **Static Flow, O₂ and CO₂-1** name to **300 rpm flow, O₂ and CO₂** using the <F2> key
3. **Add Oxygen (O₂) and carbon dioxide (CO₂)** to the inflow grid
4. Change the Flow Type from **Static** to **Rotating Cylinder**
5. **Set the Rotor Diameter** to 200 cm
6. **Set the Rotor Rotation** to 300 cycles/min
7. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface

Your screen should look like the image below.

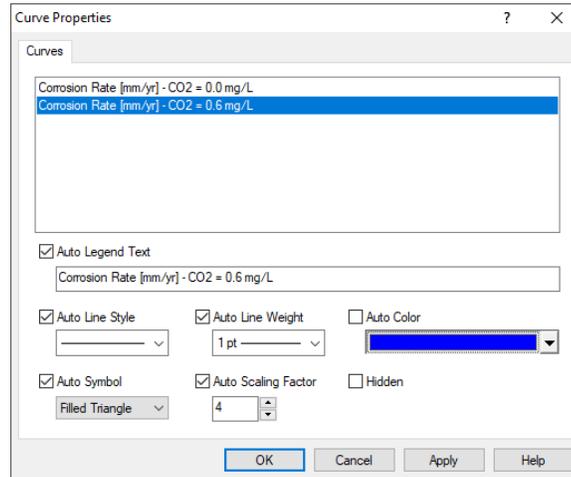


8. We are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
9. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

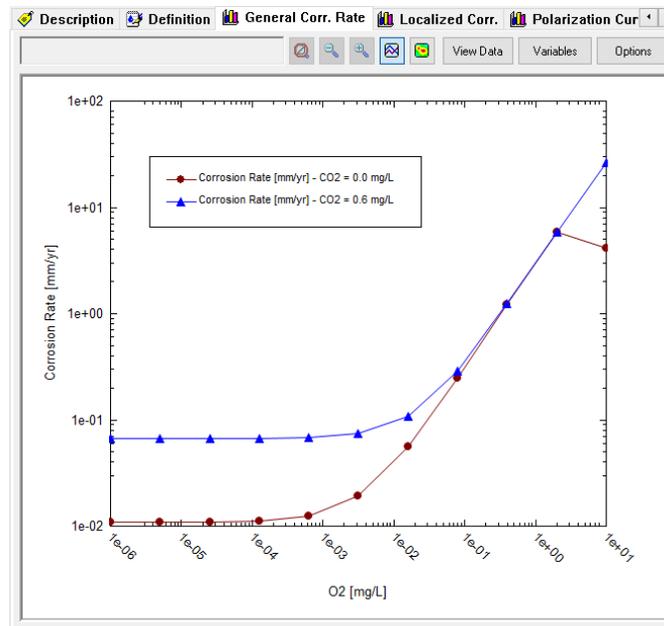
Analyzing the Results

Click on the **General Corr. Rate** tab ( **General Corr. Rate**). This tab displays a plot showing the results of corrosion rate and pH.

1. **Right-mouse click** on the **X-axis** and change it to **Logarithmic Scale**
2. **Right-mouse click** on the **Y-axis** and change it to **Logarithmic Scale**
3. **Right-mouse click** on the **pH** curve and select **Remove Series**
4. **Double click** on the CO₂=0.6 mg/L. This will open a new window. Change the color to **blue**.



The plot should look like the image below.



The 0.6 mg/L CO₂ curve shifted to higher values at low O₂ concentrations compared to no CO₂ presence. Now, when comparing the corrosion rate for the 0.6 mg/L CO₂ concentration at 300 rpm vs static conditions, the rates are 0.067 mm/year and 0.008 mm/year respectively. The effect of shear at high O₂ concentrations (right side of the plot) is also pronounced. Corrosion is still dominated by O₂ attack, but the rate is now over 10 mm/year, about 100x greater than the static conditions.

8.4. Gas condensate corrosion

Example 52: Condensed overhead gas and mitigation strategies

An alkanolamine gas sweetening plant has corrosion problems in the condensed overhead gas.

Diethanolamine is used to neutralize an acid gas containing carbon dioxide (CO₂) and hydrogen sulfide (H₂S). The diethanolamine is regenerated and the acid gases are driven off in a stripper. The off gas from this stripper is saturated with water vapor. As these gases cool, they will condense. This condensate can be very corrosive. The plant's service life can be shortened considerably due to these condensed acid gases.

In this example, you will calculate the gas dew point temperature, remove the condensed aqueous phase and perform a Corrosion Rate calculation with the condensed water. Lastly, you will consider mitigation strategies for the pipes.

You are introducing *fluid velocity* and *liquid condensation* into the calculation. The software uses a diffusion layer model to compute mass transfer to and from corroding surfaces. Higher rates produce thinner layers, resulting in faster mass transfer rates, and thus higher corrosion rates. The liquid condensation point is straightforward; it calculates the temperature (or pressure) where the first liquid drop forms.

Starting the Simulation

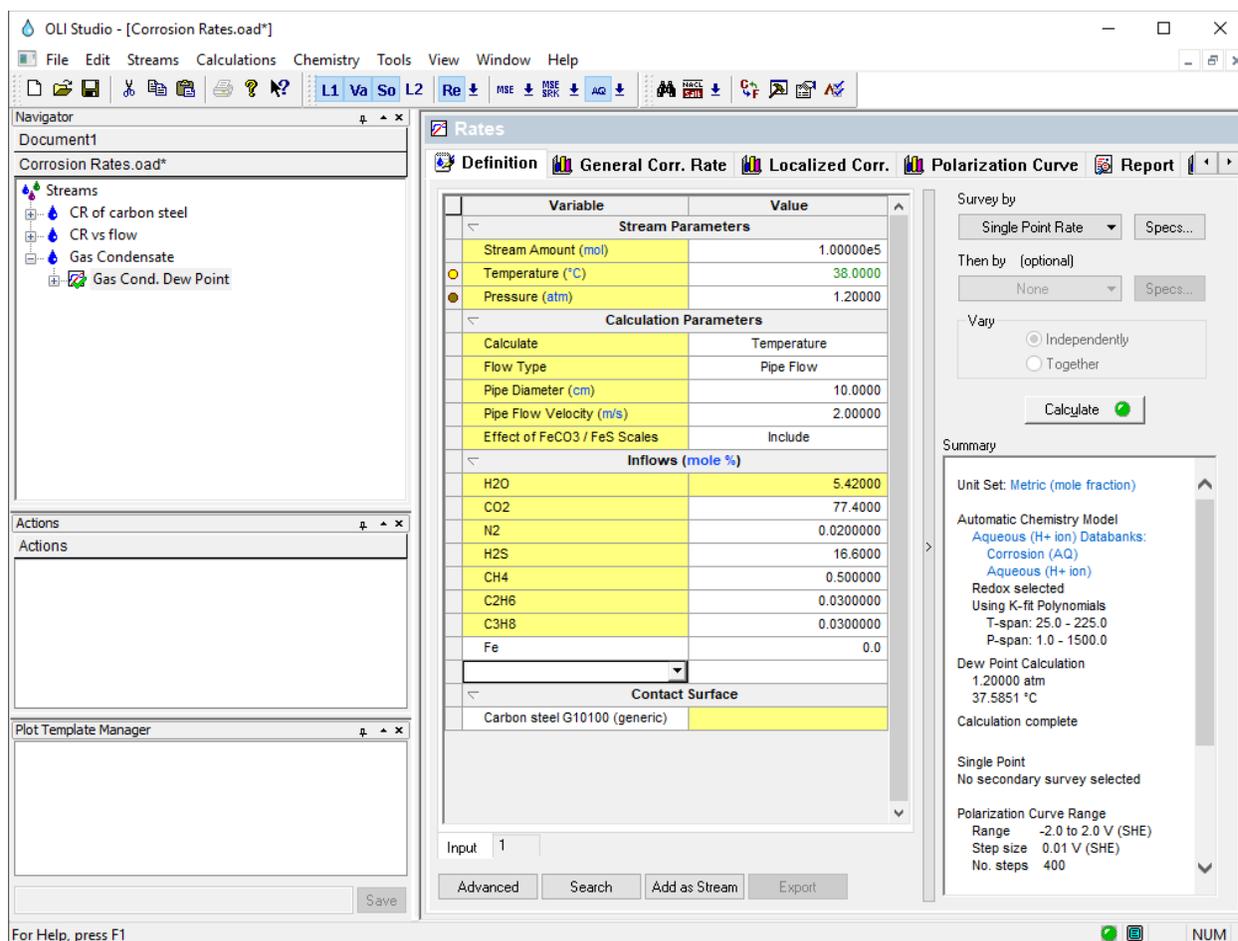
Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Corrosion Rate Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Gas condensate	Stream Amount	1e5 moles
Name Style	Display Formula	Temperature	38 °C
Unit Set	Metric, Batch, Mole Fraction	Pressure	1.2 atm
Framework	AQ	H2O	Calculated (mole%)
Calculation Type	Corrosion Rates	CO2	77.4
Survey	Single Point Rate	N2	0.02
Flow Type	Pipe Flow	H2S	16.6
Pipe Diameter	10 cm	CH4	0.5
Pipe Flow Velocity	2 m/s	C2H6	0.03
Contact Surface	Carbon Steel G10100 (generic)	C3H8	0.03

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Gas Condensate*
3. Select the **AQ** thermodynamic Framework
4. **Click** on the **Names Manager** Icon and select the **Formula** option
5. **Click** on the **Units Manager** Icon, and select Metric, Batch, Mole Fraction
6. Enter the composition, temperature and pressure of the stream given in the table above
7. Go to the **Add Calculation** button and select **Corrosion Rates** calculation or by selecting the **Add Corrosion Rates** icon in the Actions Pane.
8. **Go** to the **Survey by** option and select **Single Point Rate**. Change the name to **Gas Cond. Dew Point**.

9. **Change** the Flow Type from Static to **Pipe Flow**.
10. **Specify** the **Pipe Diameter** = 10 cm and the **Pipe Flow Velocity** = 2 m/s.
11. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface

Your screen should look like the image below.



Now that the gas condensate stream is created, the next task is to isolate the condensed water at the dew point temperature.

12. **Click** on the **Specs** button. This will open a new window
13. Under the **Category** section, select **Calculation Type**
14. Change the Type of Calculation from Isothermal to **Dew Point**. Make sure that radio button for temperature is selected since we are going to calculate the Dew Point temperature for this example. Then click **OK**.
15. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
16. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

Analyzing the Results

1. Click on the **General Corr. Rate** tab ( General Corr. Rate).
2. **Click** on the **View Data** button to see the results in tabulated form.

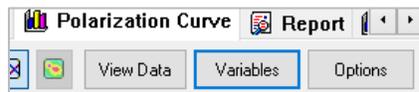
	Temperature	Corrosion Rate	pH
	°C	mm/yr	
1	37.5851	0.704502	3.92719

Notice that the calculated dew temperature is 37.6°C, corrosion rate is 0.7 mm/year, and the dew point pH is 3.9. To further interpret the results of this calculation, we are going to study the polarization curve.

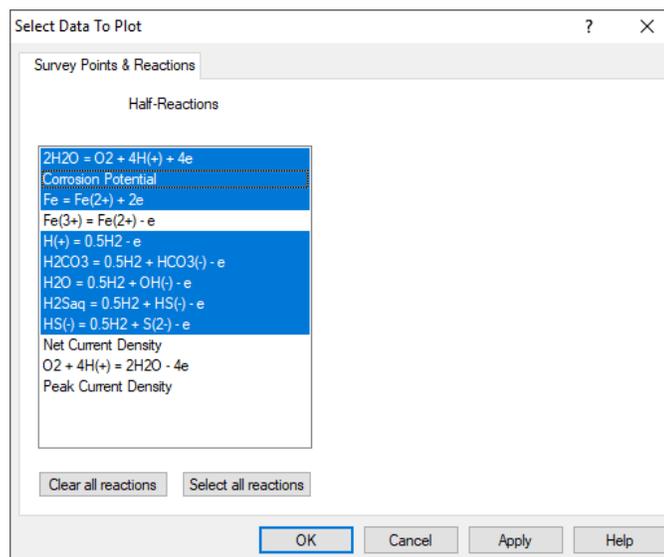
3. Click on the **Polarization Curve** tab ( Polarization Curve). Before interpreting this plot, we will format it for easy viewing.
4. Click on the **Options** button. This will open a new window.



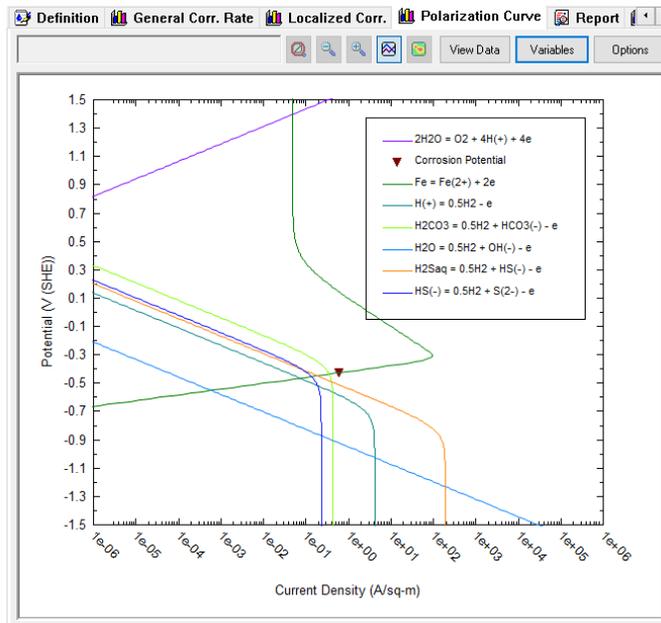
5. Under the **Category** section select **X axis**. Change the **Minimum** to 1e-6 and **Maximum** to 1e6.
6. Now, select **Y axis**. Change the **Minimum** to -1.5 and **Maximum** to 1.5. Then **click OK**.
7. Click on the **Variables** button. This will open a new window.



8. Remove the following variables by unchecking them. See image below. Then **Click OK**.



9. Your polarization curve should look like the image below.



You can click and drag the legend of the polarization curve to your desired position.

This is a measured potential vs. current density plot. The anodic portion (**green curve**) is the carbon steel. There are cathodic reactions. The sum of the cathodic currents adds up to the anode curve at a single point: The corrosion potential (represented by the inverted red triangle ▼) with a value of -0.43 V vs SHE. At the corrosion potential, the anodic and cathodic currents are equal, and this value is also known as the i_{corr} . For this example, $i_{\text{corr}}=0.61 \text{ A/m}^2$.

Notice that the cathodic reaction that contributes the most to corrosion is H_2CO_3 (**light green line**). The next contributors are H_2S (**orange line**) and HS^- (**blue line**) equally. After that is H^+ (**turquoise line**). Water reduction (**light blue line**), contributes the least to corrosion.

Mitigation Strategies

There are several mitigating solutions to this corrosion problem.

One is adding insulation to prevent temperature drops. The dew point is very close to the overhead gas temperature so this may not be a suitable option. Adding heat to keep the temperature above the dew point is usually considered along with insulation.

Changing the chemistry to change the partial oxidation and reduction processes is also an option.

Changing alloys could mitigate the corrosion problems as well.

We will explore the change of chemistry and change of alloys for this example.

Adjusting the solution chemistry

The condensate pH is approximately 3.9. We can try to add a base to increase the pH. In this section, we will add Diethanolamine to raise the pH to 7.5.

Single Point– Set pH Calculation

1. **Click** on the 'Gas Condensate' stream and **go** to the **Add Calculation** button and select **Single Point** calculation or by selecting the **Add Single Point** icon in the Actions Pane.
2. Change the name to **DEA** using the **<F2>** key.
3. **Add DEA** in the inflows grid. (It should have changed to the formula name: HN(C2H4OH)2)
4. **Go** to the **Type of Calculation** option and select **Set pH**
5. **Change** the **Target pH** to 7.5
6. Click on the drop-down arrow for the pH Base Titrant and select DEA (or HN(C2H4OH)2)

We have set up the calculation to adjust the amount of DEA to match the target value of pH=7.5.

Your screen should look like the image below.

The screenshot shows the OLI Studio interface for a calculation named 'DEA'. The main window contains a table with the following data:

Variable	Value
Stream Parameters	
Stream Amount (mol)	1.00000e5
Temperature (°C)	38.0000
Pressure (atm)	1.20000
Calculation Parameters	
Target pH	7.50000
Use Single Titrant	No
pH Acid Titrant	HCL
pH Base Titrant	HN(C2H4OH)2
Inflows (mole %)	
H2O	5.42000
CO2	77.4000
N2	0.0200000
H2S	16.6000
CH4	0.500000
C2H6	0.0300000
C3H8	0.0300000
HN(C2H4OH)2	0.0

The right-hand panel shows the 'Type of calculation' set to 'Set pH' and a 'Calculate' button. The summary section on the right indicates the unit set is 'Metric (mole fraction)' and lists the calculation parameters: 'Set pH Calculation 38.0000 °C, 1.20000 atm, Target pH 7.50000, Acid Titrant: HCL, Base Titrant: HN(C2H4OH)2'. The status at the bottom right says 'Calculation not done'.

7. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
8. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

Analyzing the Results

1. Check the summary box to analyze the results.

Summary	
Unit Set:	Metric (mole fraction)
Automatic Chemistry Model	
Aqueous (H+ ion) Databanks:	
Aqueous (H+ ion)	
Using K-fit Polynomials	
T-span: 25.0 - 225.0	
P-span: 1.0 - 1500.0	
Set pH Calculation	
38.0000 °C	
1.20000 atm	
Target pH	7.50000
Acid Titrant:	HCl
Total:	0.0 mole %
Base Titrant:	HN(C2H4OH)2
Total:	5.96844e-4 mole %
Added:	5.96844e-4 mole %
Phase Amounts	
Aqueous	31.6062 mol
Vapor	99968.5 mol
Solid	0.0 mol
Aqueous Phase Properties	
pH	7.50001
Ionic Strength	0.0160370 mol/mol
Density	1.02648 g/ml

The pH is set to 7.5 and the inflow of DEA to the total gas is approximately 5.97e-4 mole%.

The DEA concentration in the condensing water and the amount remaining in the vapor phase can both be viewed in the Report tab.

2. Click on the **Report Tab** and go to the **Total and Phase Flows** and **Species Output** tables

Total and Phase Flows (Amounts)

column Filter Applied: Only Non Zero Values

	Total	Aqueous	Vapor
	mol	mol	mol
Mole (True)	1.00000e5	31.6062	99968.5
Mole (App)	1.00001e5	32.0477	99968.5
	g	g	g
Mass	4.08064e6	642.188	4.08000e6
	L	L	L
Volume	2.11456e6	0.625619	2.11456e6

Species Output (True Species)

Row Filter Applied: Only Non Zero Values

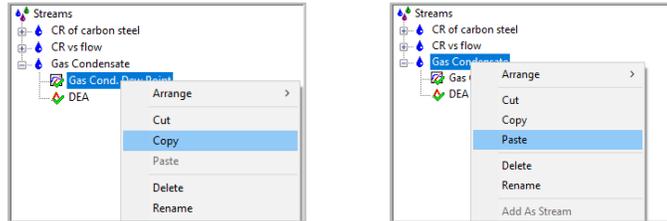
column Filter Applied: Only Non Zero Values

	Total	Aqueous	Vapor
	mole %	mole %	mole %
CO2	77.3994	0.0416672	77.4239
H2S	16.5999	0.0271211	16.6052
H2O	5.41962	96.6827	5.39076
CH4	0.499999	1.37153e-5	0.500157
C2H6	0.03	9.08534e-7	0.0300094
C3H8	0.03	7.06434e-7	0.0300094
N2	0.02	2.56549e-7	0.0200063
NH2(C2H4OH)2(+1)	5.02996e-4	1.59145	
HCO3-1	3.689e-4	1.16718	
C5H10NO4-1	6.87352e-5	0.217474	
HS-1	5.7612e-5	0.182281	
HN(C2H4OH)2	2.51153e-5	0.0778779	5.01249e-7
CO3-2	3.86988e-6	0.0122441	
S-2	3.93925e-9	1.24636e-5	
OH-1	6.55471e-10	2.07387e-6	
H+1	2.47871e-11	7.8425e-8	
Total (by phase)	100.0	100.0	100.0

Recalculating the corrosion rate with DEA

We now can recalculate the corrosion rate with DEA in the stream. This represents some DEA entrained in the vapor phase as the gas leaves the regenerator.

1. **Copy** 'Gas Cond. Dew Point' corrosion calculation, and **paste** it under the stream 'Gas Condensate'



2. Change the name to **Gas Cond. Dew Point DEA** using the <F2> key
3. **Add DEA** to the inflows grid and give it the value computed in the set pH calculation. (DEA =5.96844e-4 mole%)
4. Leave the default alloy **Carbon steel G10100 (generic)** as the contact surface

Your screen should look like the image below.

Variable	Value
Stream Parameters	
Stream Amount (mol)	1.00000e5
Temperature (°C)	38.0000
Pressure (atm)	1.20000
Calculation Parameters	
Calculate	Temperature
Flow Type	Pipe Flow
Pipe Diameter (cm)	10.0000
Pipe Flow Velocity (m/s)	2.00000
Effect of FeCO ₃ / FeS Scales	Include
Inflows (mole %)	
H ₂ O	5.41940
CO ₂	77.4000
N ₂	0.0200000
H ₂ S	16.6000
CH ₄	0.500000
C ₂ H ₆	0.0300000
C ₃ H ₈	0.0300000
HN(C ₂ H ₄ OH) ₂	5.96844e-4
Fe	0.0
Contact Surface	
Carbon steel G10100 (generic)	

9. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the <F9> key
10. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

Analyzing the Results

1. Click on the **General Corr. Rate** tab ( **General Corr. Rate**).
2. **Click on the View Data button to see the results in tabulated form.**

	Temperature	Corrosion Rate	pH
	°C	mm/yr	
1	33.5105	1.10650	7.59719

Notice that the corrosion rate has decreased from 0.7 mm/year to 0.48 mm year. The pH is 7.6, and it remained similar to the target value of 7.5. Based on these results neutralizing the pH had a partial effect on corrosion reduction.

Changing the Alloy

Since treating the acid gas with a base is probably not a good idea for metal hydroxides, perhaps we can change the alloy. We will add a new corrosion rates calculation and test different alloys.

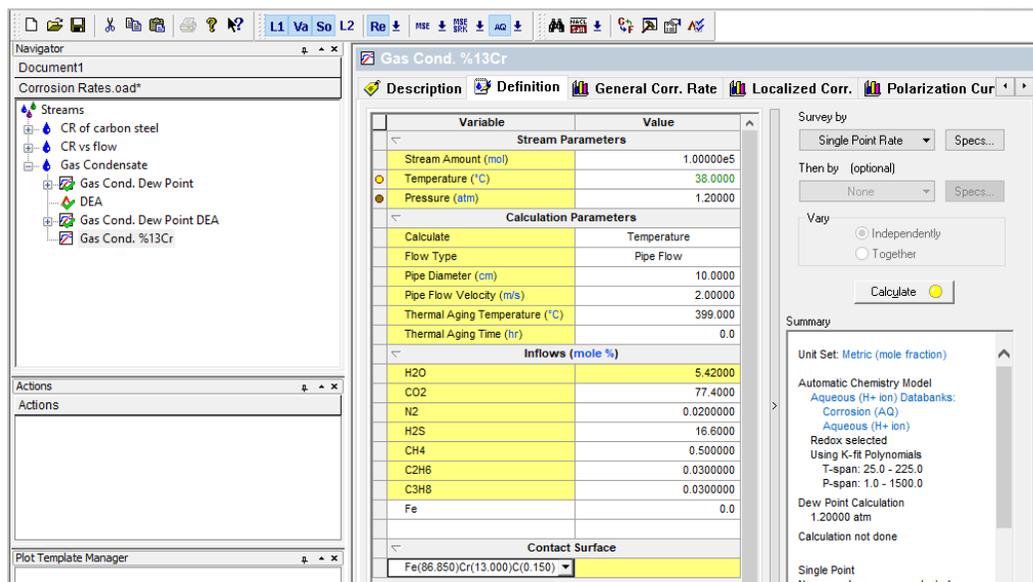
13%Cr Stainless Steel

1. **Copy** 'Gas Cond. Dew Point DEA' corrosion calculation, and **paste** it under the stream 'Gas Condensate'
2. Change the name to **Gas Cond. 13%Cr** using the **<F2>** key.

Notice that in the inflows, copying and pasting does not bring the DEA and its composition to this corrosion calculation. The reason why is because the DEA was added at the corrosion rate calculation level, and not at the stream level.

3. **Change** the **contact surface** to 13%Cr stainless steel

Your screen should look like the image below.

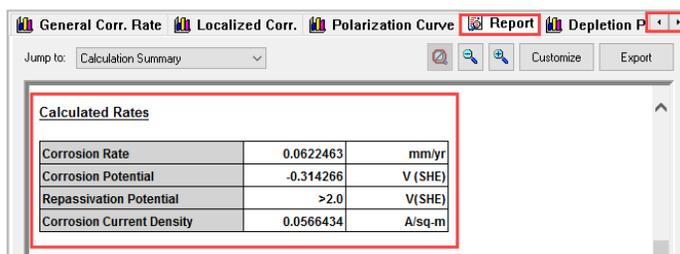


Variable	Value
Stream Parameters	
Stream Amount (mol)	1.00000e5
Temperature (°C)	38.0000
Pressure (atm)	1.20000
Calculation Parameters	
Calculate	Temperature
Flow Type	Pipe Flow
Pipe Diameter (cm)	10.0000
Pipe Flow Velocity (m/s)	2.00000
Thermal Aging Temperature (°C)	399.000
Thermal Aging Time (hr)	0.0
Inflows (mole %)	
H2O	5.42000
CO2	77.4000
N2	0.0200000
H2S	16.6000
CH4	0.500000
C2H6	0.0300000
C3H8	0.0300000
Fe	0.0
Contact Surface	
Fe(86.850)Cr(13.000)C(0.150)	

4. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
5. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

Analyzing the Results

- i. Click on the **Report** tab to see the results. (You may need to use the **◀▶** buttons to move the tabs and find the Report tab).
- ii. Go to the **Calculated Rates** table



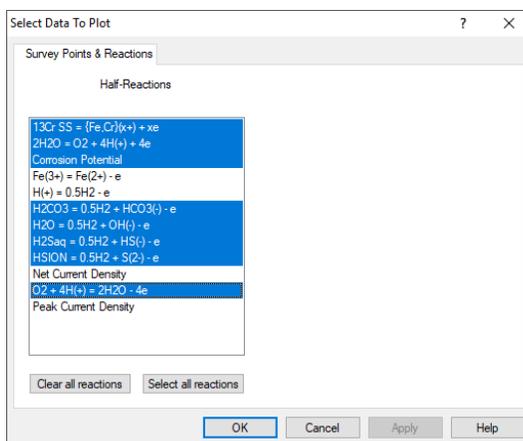
Calculated Rates		
Corrosion Rate	0.0622463	mm/yr
Corrosion Potential	-0.314266	V (SHE)
Repassivation Potential	>2.0	V(SHE)
Corrosion Current Density	0.0566434	A/sq-m

The corrosion rate of 13%Cr is one order of magnitude lower when compared to the corrosion rate for Carbon Steel, i.e. at 0.06 mm/year for 13%Cr vs 0.7 mm/year for Carbon Steel. This is consistent with the use of 13% Cr to protect against CO₂ corrosion.

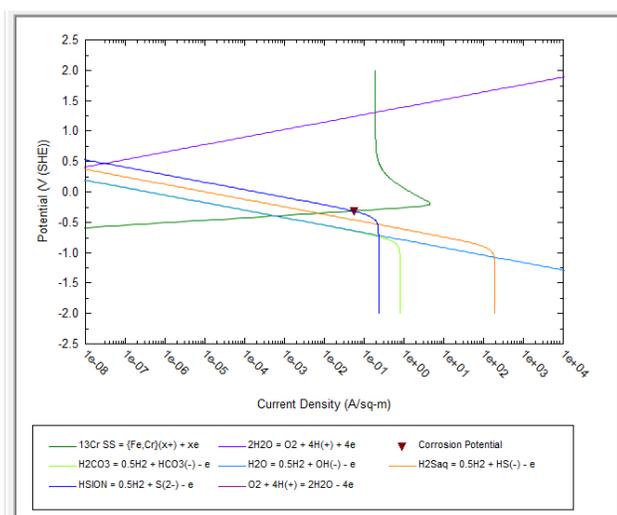
- iii. Click on the **Polarization Curve** tab ( Polarization Curve).
- iv. Click on the **Variables** button. This will open a new window.



- v. Remove the following variables by unchecking them. See image below. Then **Click OK**.



- vi. The polarization curve (after some layout modifications) should look like the image below.



The layout of the plot was changed for easy reading. To change layout, you can right click on any part of the plot and select the option *Alloy Layout Changes* to modify the appearance of your plot.

The corrosion potential of 13%Cr is -0.31 V vs SHE and the corresponding corrosion current $i_{\text{corr}}=0.06 \text{ A/m}^2$. The i_{corr} for Carbon Steel was 0.61 A/m^2 , this means that 13%Cr is 10x more resistant to corrosion under the same conditions.

Stainless Steel 304

1. **Copy** 'Gas Cond. Dew Point DEA' corrosion calculation, and **paste** it under the stream 'Gas Condensate'
2. Change the name to **Gas Cond. SS304** using the **<F2>** key
3. **Change** the **contact surface** to Stainless Steel 304

Your screen should look like the image below.

Variable	Value
Stream Parameters	
Stream Amount (mol)	1.00000e5
Temperature (°C)	38.0000
Pressure (atm)	1.20000
Calculation Parameters	
Calculate	Temperature
Flow Type	Pipe Flow
Pipe Diameter (cm)	10.0000
Pipe Flow Velocity (m/s)	2.00000
Thermal Aging Temperature (°C)	399.000
Thermal Aging Time (hr)	0.0
Inflows (mole %)	
H2O	5.42000
CO2	77.4000
N2	0.0200000
H2S	16.6000
CH4	0.500000
C2H6	0.0300000
C3H8	0.0300000
Fe	0.0
Contact Surface	
Fe(71.930)Cr(19.000)Ni(9.000)C	

Survey by: Single Point Rate

Then by (optional): None

Vary: Independently Together

Calculate

Summary

Unit Set: Metric (mole fraction)

Automatic Chemistry Model: Aqueous (H+ ion) Databanks: Corrosion (AQ), Aqueous (H+ ion)

Redox selected

Using K-fit Polynomials

T-span: 25.0 - 225.0

P-span: 1.0 - 1500.0

Dew Point Calculation: 1.20000 atm

Calculation not done

Single Point: No secondary survey selected

4. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
5. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous example named *Corrosion Rates*.

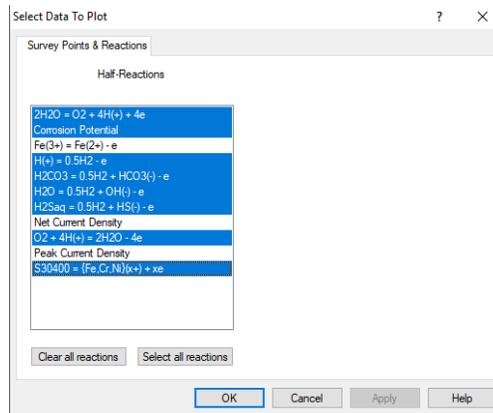
Analyzing the Results

1. Click on the **Report** tab to see the results. (You may need to use the ◀▶ buttons to move the tabs and find the Report tab).
2. Go to the **Calculated Rates** table

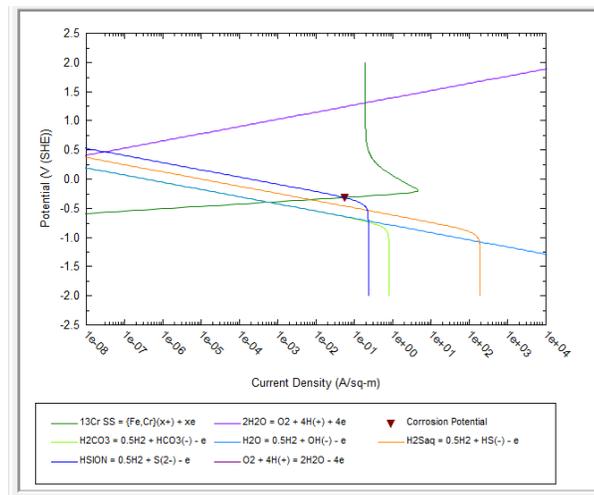
Corrosion Rate	3.57108e-3	mm/yr
Corrosion Potential	-0.172583	V (SHE)
Repassivation Potential	>2.0	V(SHE)
Corrosion Current Density	3.29499e-3	A/sq-m

The corrosion rate of 304 SS is now 0.0036 mm/year. This is a negligible value.

3. Click on the **Polarization Curve** tab ( Polarization Curve).
4. Click on the **Variables** button. This will open a new window.
5. Remove the following variables by unchecking them. See image below. Then **Click OK**.



The polarization curve (after some layout modifications) should look like the image below.



The layout of the plot was changed for easy reading. To change layout, you can right click on any part of the plot and select the option Alloy Layout Changes to modify the appearance of your plot.

The corrosion potential of SS304 is -0.17 V vs SHE and the corresponding corrosion current $i_{corr}=3.3e-3$ A/m². With this low corrosion current density, sour gas regeneration can be remedied using a higher-grade alloy such as SS304.

8.5. Surveys and localized corrosion this exercise is very important for the next section!

Section 9. Thermal Aging and Variations in Alloy Composition

9.1. Overview and Basic Terminology

Localized corrosion of engineering alloys is a complex function of metallurgical factors and environmental conditions. Among metallurgical factors, effects of thermal instabilities are of interest for assessing the performance and expected service life of industrial components fabricated from nominally corrosion-resistant stainless steels and nickel-base alloys.

Fabrication processes such as heat treatment and welding are known to introduce microstructural changes that may affect both the mechanical and corrosion performance of an alloy. In particular, thermal instability of stainless steels and nickel-base alloys may lead to the formation of complex metal carbides of the type M_3C_2 , M_7C_3 , M_6C , or $M_{23}C_6$ in which the metallic component M represents Cr, Mo, W, and Fe. The carbide is chromium- or molybdenum-rich depending on the carbide type, which in turn depends on the alloy composition and temperature. Also, various chromium-rich intermetallic phases can form in many alloys. Precipitation of such phases may occur at temperatures ranging from 500 to 900 °C depending on alloy composition. Formation of grain boundary carbides often results in the depletion of chromium and, possibly, molybdenum in the vicinity of the grain boundary because of the slow diffusion of substitutional elements such as chromium relative to the interstitial carbon.

Similarly, the corrosion resistance of welded components may be affected by the segregation of alloying elements and precipitation of intermetallic phases, carbides or nitrides in the solidified weld and unmixed zones as well as the precipitation of carbides and other phases in the heat-affected zone adjacent to the weld.

Sensitization of Fe-Ni-Cr-Mo alloys and its effects on intergranular attack and intergranular stress corrosion cracking is the most directly observed effect of Cr depletion. It may result in intergranular attack and intergranular stress corrosion cracking. Localized corrosion can be also affected by Cr and Mo depletion.

Corrosion Analyzer contains the following technology that can help address these issues:

- A grain boundary microchemistry model for predicting the chromium and molybdenum depletion in the vicinity of grain boundaries as a result of carbide formation;
- An electrochemical model for calculating the repassivation potential of Fe-Ni-Cr-Mo-W alloys as a function of alloy composition and environmental conditions including temperature and concentrations of aqueous solution species;
- A procedure for calculating the observable repassivation potential that corresponds to macroscopic localized corrosion by applying the electrochemical model to the depletion profiles and performing suitable integration.

More details about this technology are described by [Anderko et al. \(2008\)](#), [Tormoen et al. \(2009\)](#), [Anderko et al. \(2009\)](#), and [Sridhar et al. \(2009\)](#).

Alloy Chemistry

Simulations can be performed, in general, for alloys that belong to the Fe-Ni-Cr-Mo-W-N-C family (i.e., for stainless steels and nickel-base alloys).

Depletion profiles in the vicinity of grain boundaries and depletion parameters can be obtained for austenitic alloys (including stainless steels and Ni-base alloys). Also, the effect of Cr and Mo depletion on localized

corrosion can be calculated. This effect can be examined using the repassivation potential, which provides a threshold potential for the stabilization of localized corrosion (Anderko et al., 2009).

For other alloys from the Fe-Ni-Cr-Mo-W-N-C family, the repassivation potential can be calculated if the alloy composition is known. This also includes experimental alloys and separate phases that may be formed as a result of various forms of heat treatment (Sridhar et al., 2009).

Calculation types

Thermal aging is an additional phenomenon that can be simulated within the framework of corrosion kinetics. All calculation types and, in particular, survey types, that are supported for corrosion kinetics are also supported in conjunction with the study of thermal aging.

If it is desired to make calculations on a thermally aged sample, the thermal aging temperature and time need to be specified in the **Calc Parameters** section in the **Definition** tab. The default values are 399 °C for the thermal aging temperature and 0.0 hours for the thermal aging time. If either of these default values is used, no thermal aging effects will be predicted. Thus, by default, Corrosion Analyzer performs calculations on samples that have not been thermally aged.

Thermal Aging Temperature Survey

This calculation makes it possible to vary the thermal aging temperature within a certain range. A fixed value of thermal aging time is assumed as specified by the user. Typically, the temperatures for which thermal aging effects can be observed range from ~500 °C to ~900 °C, with the effects being most pronounced in the middle of this range.

Thermal Aging Time Survey

This calculation can be used to examine the effect of aging time at a fixed thermal aging temperature.

Output Specific to Thermal Aging

The following output can be generated:

- Chromium and molybdenum depletion profiles, i.e., the variation of Cr and Mo concentration within the grain as a function of grain boundary.
- The depletion parameter, which provides compact information on the extent to which the depletion process reduces the grain boundary concentration below a certain critical value of, which can be defined by well-known criteria for maintaining passivity (e.g. $x_{Cr}^* = 0.11$ or 0.12). This parameter can be calculated as the area of the depletion profile below the threshold concentration x_{Cr}^* , divided by bulk Cr concentration, x_{Cr}^0 :

$$\delta(x_{Cr}^*) = \frac{1}{x_{Cr}^0} \int_0^{z^*} (x_{Cr}^* - x_{Cr}(z)) dz$$

where z^* is the distance from the grain boundary that corresponds to the threshold concentration x_{Cr}^* .

- The repassivation potential, which is a key parameter for determining whether localized corrosion can occur, may be affected by thermal aging in a rather complex way.

9.2. Thermal Aging and Variations in Alloy Composition

We will show examples of simulating the effects of thermal aging on Fe-Ni-Cr-Mo-W-C-N alloys (i.e., stainless steels and nickel-base alloys). Specifically, we will show how to predict:

1. Chromium and molybdenum depletion profiles in the vicinity of grain boundaries, which result from heat treatment of austenitic alloys;
2. Depletion parameters for sensitized austenitic alloys, which provide an indicator of whether the alloy is susceptible to intergranular corrosion.
3. Effect of thermal aging on the repassivation potential of austenitic alloys, which provides a threshold condition for localized corrosion (pitting or crevice corrosion).
4. The repassivation potential of alloys with compositional variations that may or may not result from thermal aging. This facility can also be used for bulk alloys that are not in the database or to hypothetical or experimental alloys as long as they belong to the Fe-Ni-Cr-Mo-W-C-N family. An example will be given for a duplex alloy, either annealed or thermally treated.

Example 53: Thermal aging of alloy 600

We will be studying the behavior of thermally aged alloy 600 in a dilute aqueous solution of sodium chloride, and will simulate how the time of thermal aging affects alloy 600 at a fixed thermal aging temperature of 700°C.

Starting the Simulation

Thermal Aging Calculation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Thermal Aging Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Thermal Aging	Stream Amount	Calculated
Calculation Type	Corrosion Rates	Temperature	60 °C
Survey by	Thermal Aging Time	Pressure	1 atm
Name Style	Display Name	H2O	Default – 55.5082 moles
Unit Set	Metric, Batch, Moles	NaCl	0.04 moles
Framework	AQ		

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Thermal Aging*
3. Select the AQ thermodynamic Framework (selected by default)
4. **Click** on the **Units Manager** Icon and select Metric, Batch, Moles
5. **Click** on the **Names Manager** Icon and select *Display Name*

6. **Enter** the stream composition and conditions specified in the table above
7. **Go** to the **Add Calculation** button and select **Corrosion Rates**
Note: Even though the thermal aging simulation facilities do not predict corrosion rates per se, they belong to the category of corrosion kinetics and, therefore, they are included in the Corrosion Rates section of the Corrosion Analyzer.
8. **Select** the Survey by **Thermal Aging Time**
9. **Change** the name from **Rates** to **Alloy 600** using the <F2> key or by **right-mouse click** on the object and select rename
10. Select **Alloy 600** from the **Contact Surface** grid
11. In the **Calculation Parameters** grid, change the default value for the **Thermal Aging Temperature** to 700°C.
 Note that the default value for the **Thermal Aging Temperature** is 399 °C, which is a low value so that, in the default case, no effects of thermal aging are being calculated.

Your screen should look like the image below.

The screenshot shows the OLI Studio interface for a corrosion simulation. The main window is titled "Alloy 600" and contains a table of variables and values. The table is organized into sections: Stream Parameters, Calculation Parameters, Inflows (mol), and Contact Surface. The "Thermal Aging Temperature" is highlighted in red and set to 700.000 °C. The "Contact Surface" is also highlighted in red and set to Alloy 600. The "Survey by" dropdown is set to Thermal Aging Time, and the "Specs..." button is highlighted in red. The "Summary" panel on the right shows the simulation parameters and results.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5482
Temperature (°C)	60.0000
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Static
Thermal Aging Temperature (°C)	700.000
Thermal Aging Time (hr)	
Inflows (mol)	
Water	55.5082
Sodium chloride	0.0400000
Nickel	0.0
Contact Surface	
Alloy 600	

Summary:

Unit Set: Metric (moles)

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Corrosion (AQ)
 Aqueous (H+ ion)
 Redox selected
 Using K-fit Polynomials
 T-span: 25.0 - 225.0
 P-span: 1.0 - 1500.0

Isothermal Calculation
 60.0000 °C 1.00000 atm
 Calculation not done

Thermal Aging Time survey:
 Range 0.0 to 10.0 hr
 Step size 2.0 hr
 No. steps 5

12. Now we need to specify the Thermal Aging Time range. **Click** on the **Specs** button. This will open a new window.

13. Under the **Survey Range** tab, change the range for Thermal Aging Time from 0 to 22 hours with an increment of 4.4 hours (of 5 steps).

The screenshot shows the 'Rates Calculation' dialog box with the 'Survey Range' tab selected. The 'Thermal Aging Time Range' is set to 'hr'. The 'Selected Range' is '0.0 to 22.0 in 5 steps of 4.4'. The 'End Points' are Start: 0.0, End: 22.0000. The 'Step Size' is Increment: 4.40000, Number Steps: 5. Radio buttons for 'Linear', 'Log', and 'Point List' are present, with 'Linear' selected.

14. Under the **Category** section, select the **Thermal Aging** option.

The screenshot shows the 'Rates Calculation' dialog box with the 'Thermal Aging' tab selected. The 'Category' list on the left has 'Thermal Aging' selected. The 'Thermal Aging' tab contains fields for 'Erp Directly from Correlation' (No), 'Alloy Composition wt%' (Fe: 8.534, Cr: 16.408, Ni: 75.032, Mo+W: 0, C: 0.026, N: 0), 'Carbide Stoichiometry' (Fe: 0, Cr: 7, Ni: 0, Mo+W: 0, C: 3), 'Carbide Thermochemistry' (A: -405190, B: -25.765), 'Cr Diffusion Coefficient' (D0: 4.4016e-006, Q: -243000), 'Mo, W Diffusion Coefficient' (D0: 0, Q: 0), and 'Cr Sensitization Threshold wt%' (11) and 'Grain Size' (123). A 'Revert to Default' button is also present.

In this **Thermal Aging** Category, you can change all parameters that are necessary for calculating chromium and (if applicable) molybdenum depletion profiles. You can change:

- The alloy composition (for example, to analyze the effect of a different carbon content);
- The stoichiometry of the carbide phase that may form at the grain boundary; the typical carbide stoichiometry is M_7C_3 or $M_{23}C_6$ (where $M = Cr, Mo$) but can be adjusted
- The parameters that define the equilibrium constant for the formation of the carbide
- The diffusion coefficient of Cr and, if applicable, Mo
- The threshold concentration of Cr for sensitization. This threshold concentration is used for calculating the depletion parameter.
- The average grain size, which affects the process of healing of chromium depletion as a function of time

Also, you can indicate whether the repassivation potential (E_{rp}) should be calculated directly from the correlation developed by Anderko et al. (2008), which expresses E_{rp} as a function of alloy composition or not. If it is not calculated directly, then the repassivation potential is calculated first using the alloy-specific parameters for the alloy of interest and only the decrement of E_{rp} (i.e., $E_{rp, \text{thermally aged}} - E_{rp, \text{bulk alloy}}$) is obtained from the correlation. This decrement is then added to the alloy-specific E_{rp} value. This option is set by default to “No” because this maximizes the accuracy of calculations for alloys that are already in the database.

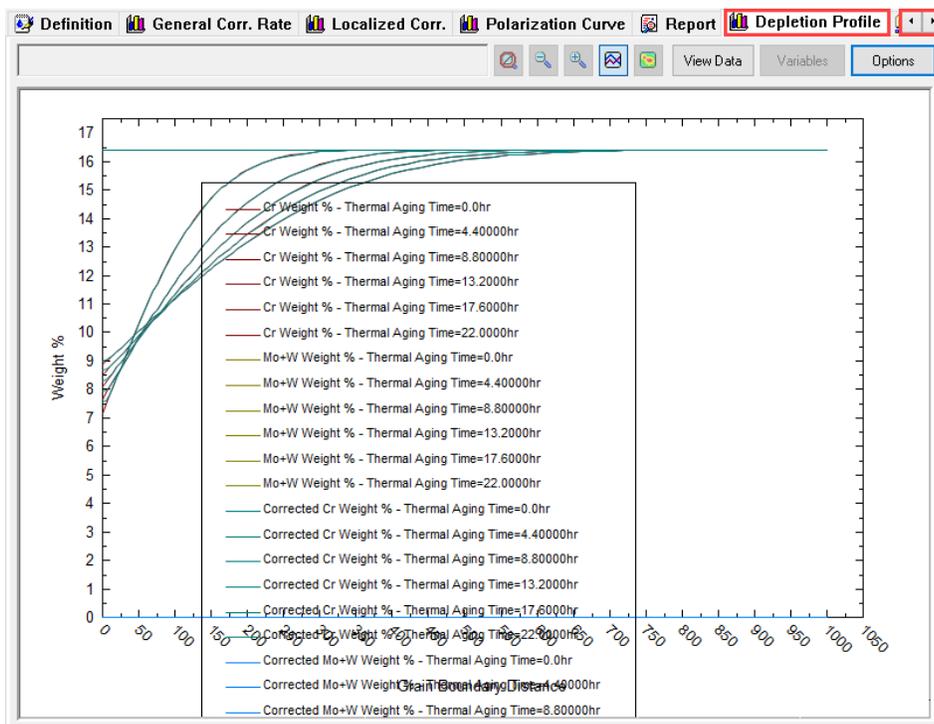
15. For now, we will accept the default settings. Click **OK**.

16. Now, we are ready to perform the calculation. Click on the **Calculate** button or press the **<F9>** key

17. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous section named *Corrosion Rates*.

Analyzing the Results

1. Click on the **Depletion Profile** tab ( **Depletion Profile**). If you don't see it in your screen, use the **◀▶** buttons to move the tabs.



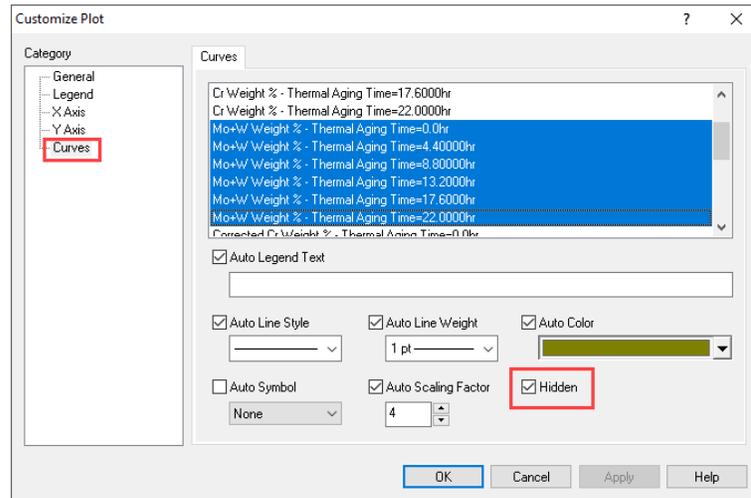
Note: Since alloy 600 does not contain any molybdenum, the molybdenum curves will always be equal to zero.

This plot will show the concentrations of chromium and molybdenum within a grain as a function of the distance from the grain boundary (in μm). You will see that, for each condition, there are four lines:

- **Cr weight %:** concentration of Cr in weight %
- **Mo+W weight %:** sum of the concentrations of molybdenum and tungsten in weight %
- **Corrected Cr weight %:** concentration of Cr corrected for beam scattering and related effects so that it can be directly compared with experimental results. The procedure for calculating the correction is described by Anderko et al. (2009).
- **Corrected Mo+W weight %:** sum of the concentrations of Mo and W corrected in the same way as those for Cr.

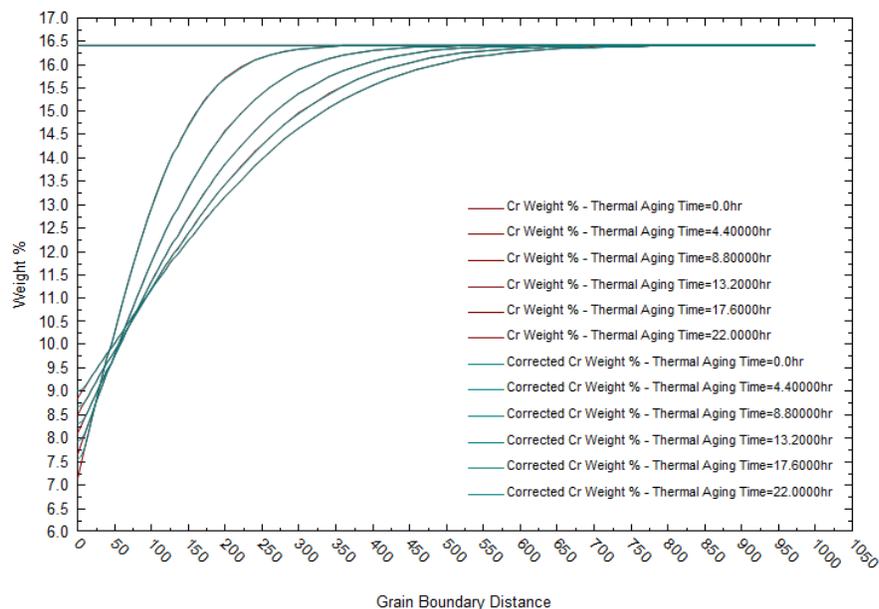
Let's customize the plot

2. Click on the **Options** button. This will open a new window.
3. Since alloy 600 does not contain Mo or W, eliminate the Mo+W curves. To do this, go to the **Category** section and select the **Curves** option
4. Highlight the Mo+W weight % curves by pressing the Shift key and the down key (**Shift + ↓**). After highlighting these curves, check the **Hidden** button.



5. After hiding the Mo+W weight % curves, do the same for the Corrected Mo+W weight % curves. Then click **OK**.

The plot should look like the image below.



The legend of this plot was modified for clarity. The border style of the legend was modified by double clicking on the legend, and selecting *None* as the Border Style

Differences between Uncorrected and Corrected Depletion Profiles

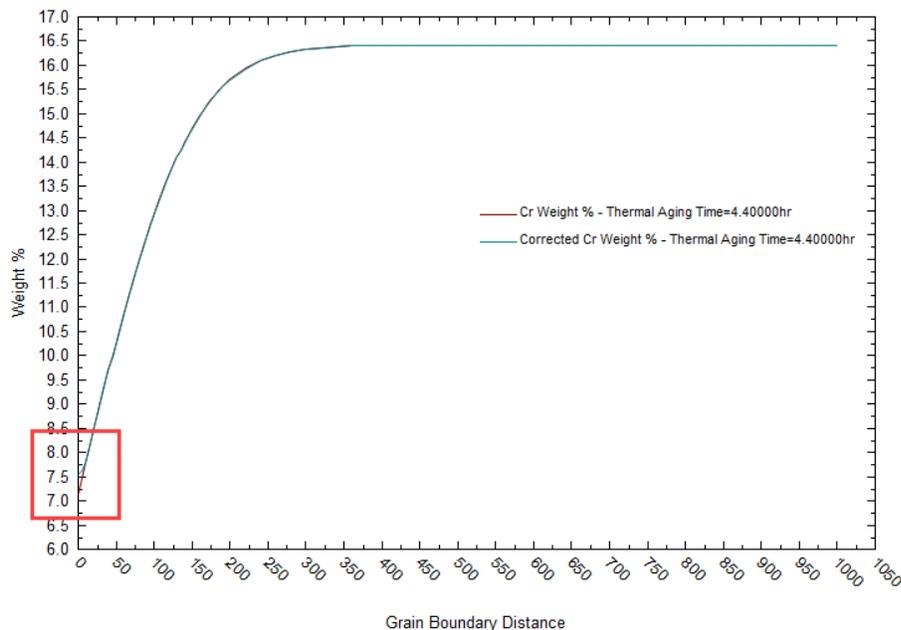
Now, let's focus on the differences between the uncorrected and corrected depletion profiles. To have a clear picture of the difference between them, we will analyze the depletion profiles results obtained at 4.4 hours of thermal aging.

6. Click on the **Options** button, and select the **Curves** category
7. Highlight all curves except the ones labeled as:

Cr Weight % - Thermal Aging Time = 4.40000 hr, and
Corrected Cr Weight % - Thermal Aging Time = 4.40000 hr

Check the Hidden box, then click **OK**.

Your plot should look that the image below.



In the obtained plot, you can see the difference between the two curves for small distances from the grain boundary (roughly below 30 μm). The corrected concentration is much more rounded in the vicinity of the minimum because instrumental measurement effects. At larger distances from the grain boundary, there is no difference between the two curves.

Effect of Cr depletion on corrosion

After analyzing the depletion profiles, let's focus on the effects of Cr depletion on corrosion. We will do it by analyzing two parameters – the depletion parameter and the repassivation potential.

To have more meaningful results, let's expand the range of thermal aging time and reduce the interval for calculations.

1. **Copy** the Alloy 600 corrosion calculation, and then **paste** it under the **Thermal Aging Stream**
2. **Rename** the new calculation as **Alloy 600 – Cr depletion**
3. Go back to the **Definition** tab and click the **Specs** button
4. In the **Var.1 Thermal Aging Time** category, change the Survey Range as follows: **Start=0** hours, **End= 60** hours with an **Increment= 1** hour. Then click **OK**.

Your screen should look like the image below

The screenshot shows the OLI Studio interface with the 'Alloy 600-Cr depletion' calculation selected. The 'Specs' tab is active, displaying a table of parameters and a summary of the survey settings.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5482
Temperature (°C)	60.0000
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Static
Thermal Aging Temperature (°C)	700.000
Thermal Aging Time (hr)	
Inflows (mol)	
Water	55.5082
Sodium chloride	0.0400000
Contact Surface	
Alloy 600	

Survey by: Thermal Aging Time

Then by (optional): None

Vary: Independently Together

Calculate

Summary

Unit Set: Metric (moles)

Automatic Chemistry Model

- Aqueous (H+ ion) Databanks:
- Corrosion (H+ AQ)
- Aqueous (H+ ion)
- Redox selected
- Using K-fit Polynomials
- T-span: 25.0 - 225.0
- P-span: 1.0 - 1500.0

Isothermal Calculation

60.0000 °C 1.00000 atm

Calculation not done

Thermal Aging Time survey:

- Range: 0.0 to 60.0 hr
- Step size: 1.0 hr
- No. steps: 60

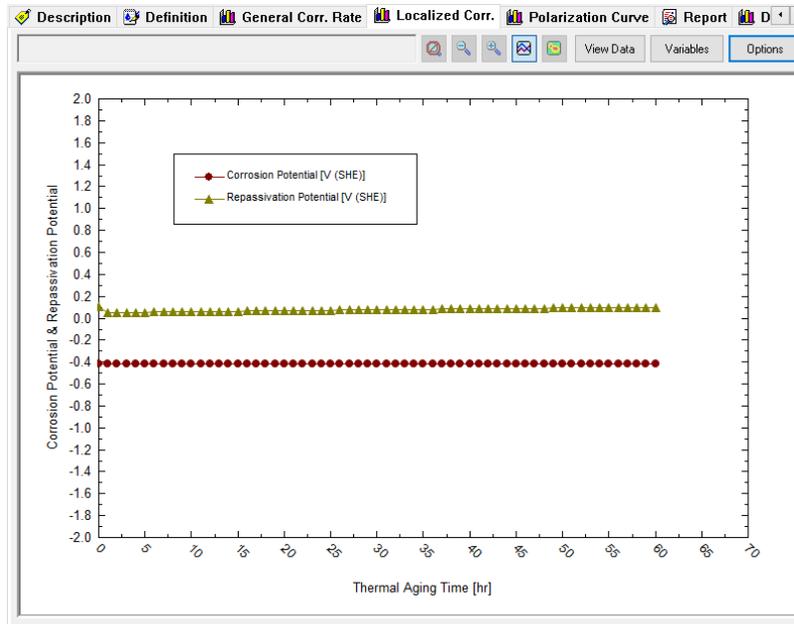
No secondary survey selected

Thermal Aging Temperature: 700.000 °C

5. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
6. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous section named *Corrosion Rates*.

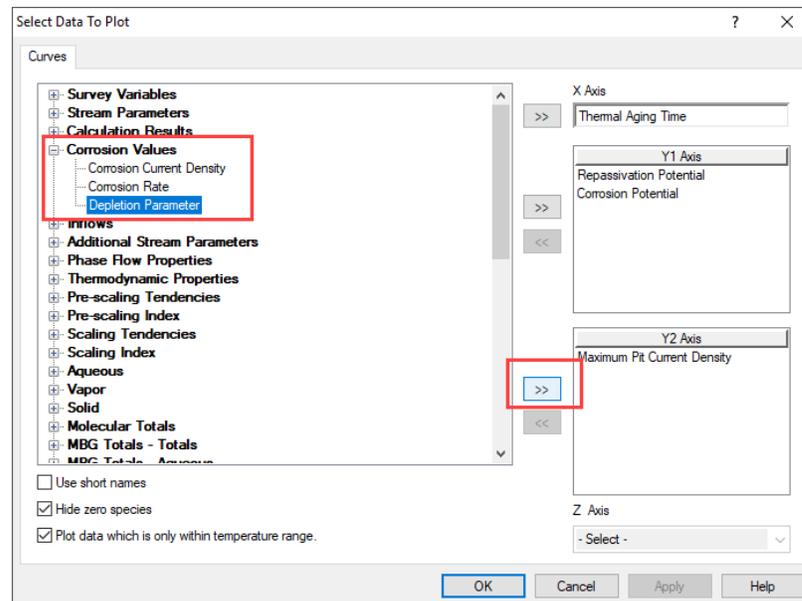
Analyzing the Results

1. Click on the **Localized Corr.** tab ( Localized Corr.). By default, this tab will show a plot of the corrosion potential and repassivation potential.

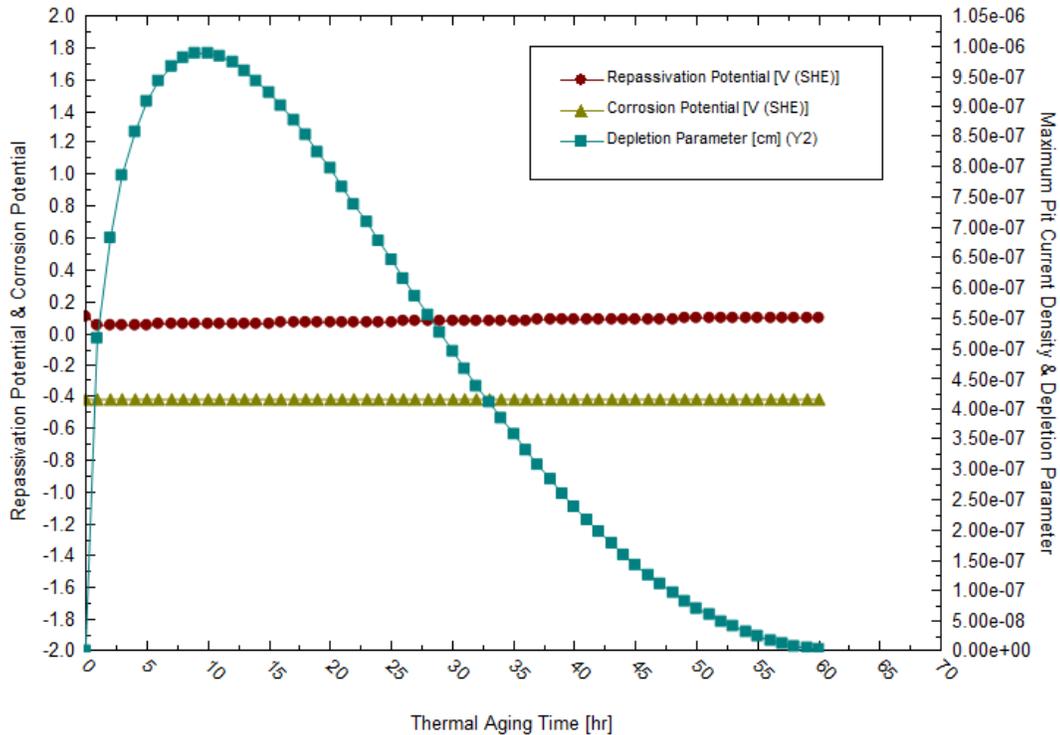


Let's add a new parameter to the plot: The **Depletion Parameter**.

2. Click on the **Variables** button. This will open a new window.
3. Look for the **Corrosion Values** section, click on the '+' icon, and select the **Depletion Parameter** option. Click on the >> button that belongs to the **Y2 Axis**. This action will place the new variable under the Y2 Axis. Then click **OK**.



The plot should look like the image below.



It is clear that the depletion parameter reaches a maximum for aging time of about 10 hours. Since the depletion parameter is a measure of the susceptibility of an alloy to intergranular corrosion, we can expect that the alloy will be most susceptible to intergranular corrosion at intermediate aging times. When the depletion parameter is zero, intergranular corrosion or intergranular stress corrosion cracking are unlikely. The decrease of the depletion parameter as a function of time is a manifestation of the phenomenon of healing of Cr depletion.

The repassivation potential shows a minimum as a function of aging time (see the option **View Data**). This indicates that the tendency of the alloy to undergo localized corrosion is enhanced as a result of thermal aging. However, the effect of thermal aging on the repassivation potential of alloy 600 is small (cf. Tormoen et al., 2009, Anderko et al., 2009). The repassivation potential shows a minimum at low aging times (ca. 1-2 hours). Therefore, the susceptibility to localized corrosion is enhanced the most for these aging times. It is noteworthy that the maximum in the depletion parameter does not coincide with the minimum in the repassivation potential. This is due to the fact that intergranular corrosion (which is related to the depletion parameter) and localized corrosion (which is controlled by the repassivation potential) are subject to different mechanisms. A general discussion of these differences is given by Tormoen et al. (2008).

In general, the alloy will be susceptible to localized corrosion if the corrosion potential exceeds the repassivation potential. In the above example, the corrosion potential is low because we have no oxidizing agents in the system. Therefore, the alloy will not undergo localized corrosion at the conditions of this example. However, a rise in the corrosion potential due to the presence of oxidizing agents may cause localized corrosion.

Example 54: Thermal aging of alloy 825

Alloy 825 is appreciably different from alloy 600 because it contains molybdenum and, also, substantially more chromium in addition to other alloying elements.

In this example, we will simulate how the temperature of thermal aging affects alloy 825 at a fixed thermal aging time of 15 hours.

Starting the Simulation

Thermal Aging Calculation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Thermal Aging Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Thermal Aging	Stream Amount	Calculated
Calculation Type	Corrosion Rates	Temperature	95 °C
Survey by	Thermal Aging Temperature	Pressure	1 atm
Name Style	Display Name	H2O	Default – 55.5082 moles
Unit Set	Metric, Batch, Moles	NaCl	2.846e-3 moles
Framework	AQ		

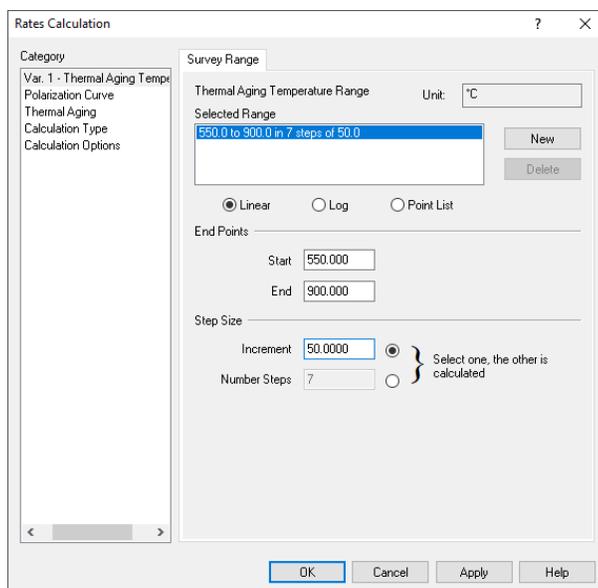
1. Under the Thermal Aging stream add a new calculation rate. Go to the **Add Calculation** button and select **Corrosion Rates** or select the **Add Corrosion Rates** icon in the **Actions** panel
2. **Change** the name from **Rates** to **Alloy 825** using the <F2> key or by **right-mouse click** on the object and select rename
3. **Select** the Survey by **Thermal Aging Temperature** option
4. **Change** the stream composition and conditions to the specified values in the table above
5. Select **Alloy 825** from the **Contact Surface** grid
6. In the **Calculation Parameters** grid, change the default value for the **Thermal Aging Time** to 15 hours

Note that the default value for the **Thermal Aging Temperature** is 0 hours, which means that no thermal aging is considered by default.

Your screen should look like the image below

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5111
Temperature (°C)	95.0000
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Static
Thermal Aging Temperature (°C)	
Thermal Aging Time (hr)	15.0000
Inflows (mol)	
Water	55.5082
Sodium chloride	2.84600e-3
Nickel	0.0
Contact Surface	
Alloy 825	

18. Now we need to specify the Thermal Aging Temperature range. **Click** on the **Specs** button. This will open a new window.
19. Under the **Survey Range** tab, change the range for **Thermal Aging Temperature** from 550 to 900 °C with increments of 50 °C. We will keep the other parameters at their default values. **Click OK**.

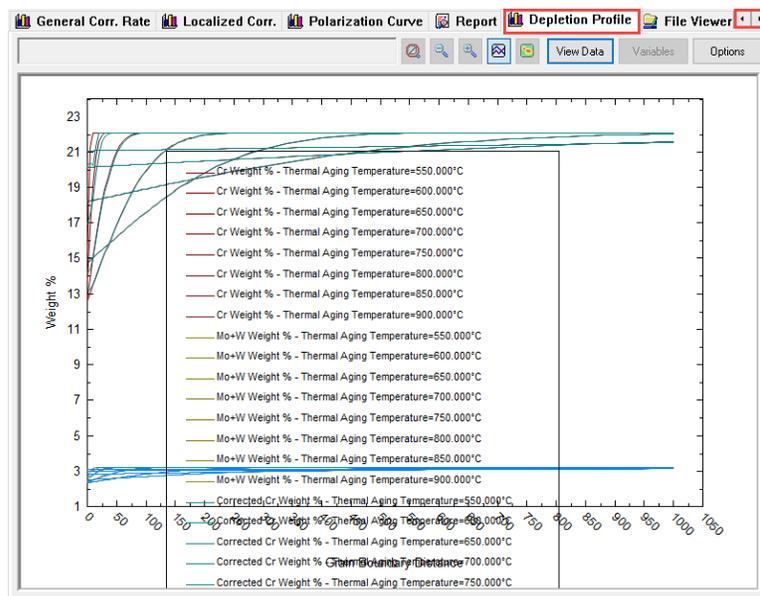


20. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
21. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous section named *Corrosion Rates*.

Analyzing the results

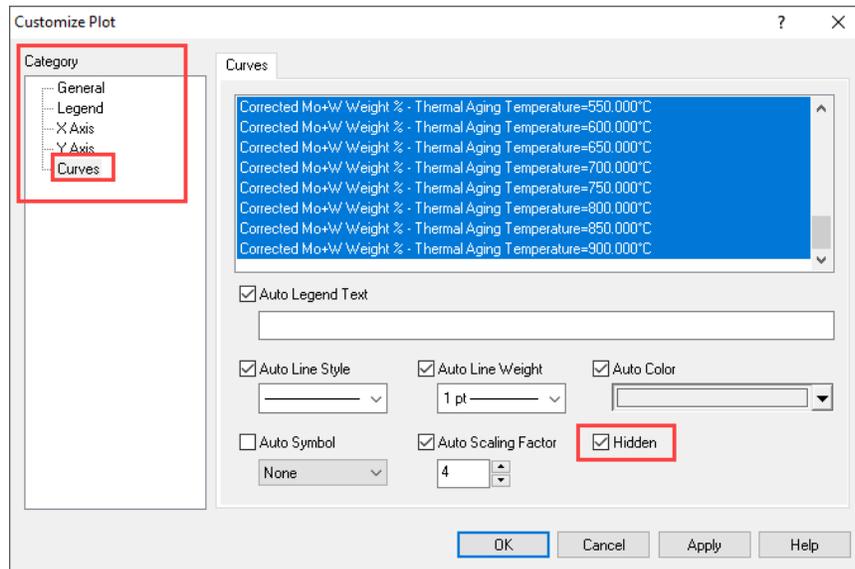
1. Click on the **Depletion Profile** tab (**Depletion Profile**). If you don't see it in your screen, use the **◀▶** buttons to move the tabs.

Since alloy 825 contains Mo in addition to Cr, you will see the depletion profiles for both Cr and Mo.

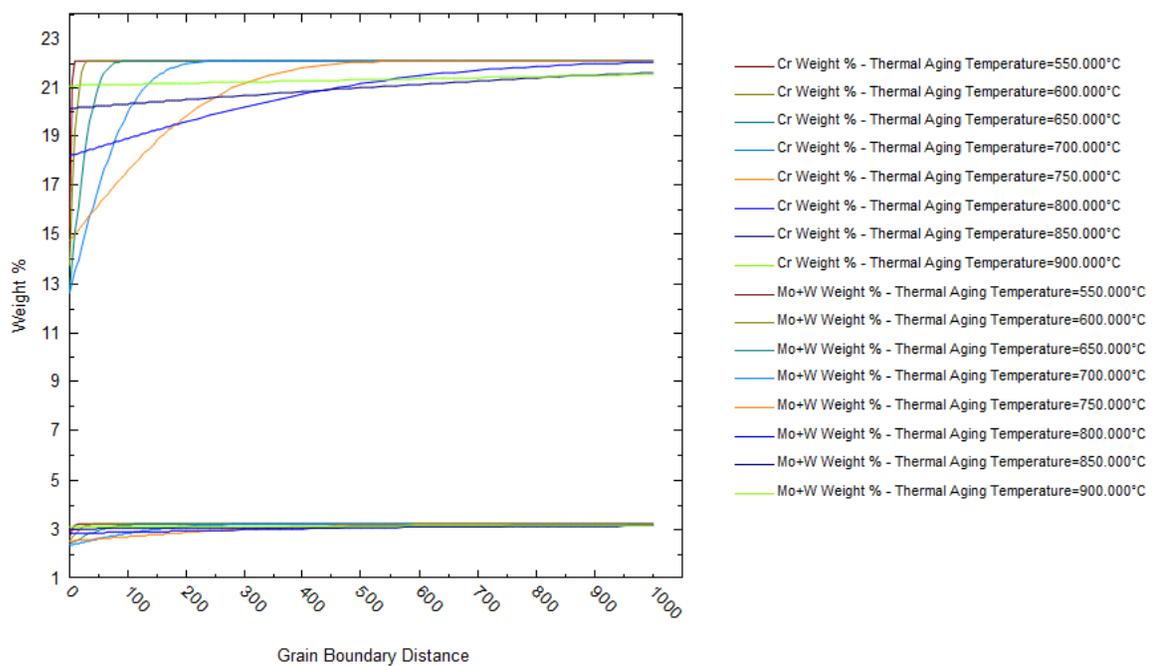


For clarity, let's customize the plot by removing the corrected depletion profiles and leaving only the uncorrected (or directly calculated) ones.

- Click on the **Options** button, and select the **Curves** category, highlight the Corrected curves and check the hidden box. Then click **OK**.



Your plot should look like the image below



The plot was modified by right clicking on it and selecting the option *Allow Layout Changes*. This option allows to move and rearrange the plot and legend. Additionally, the color of the lines was changed for each temperature in order to distinguish the temperature effect.

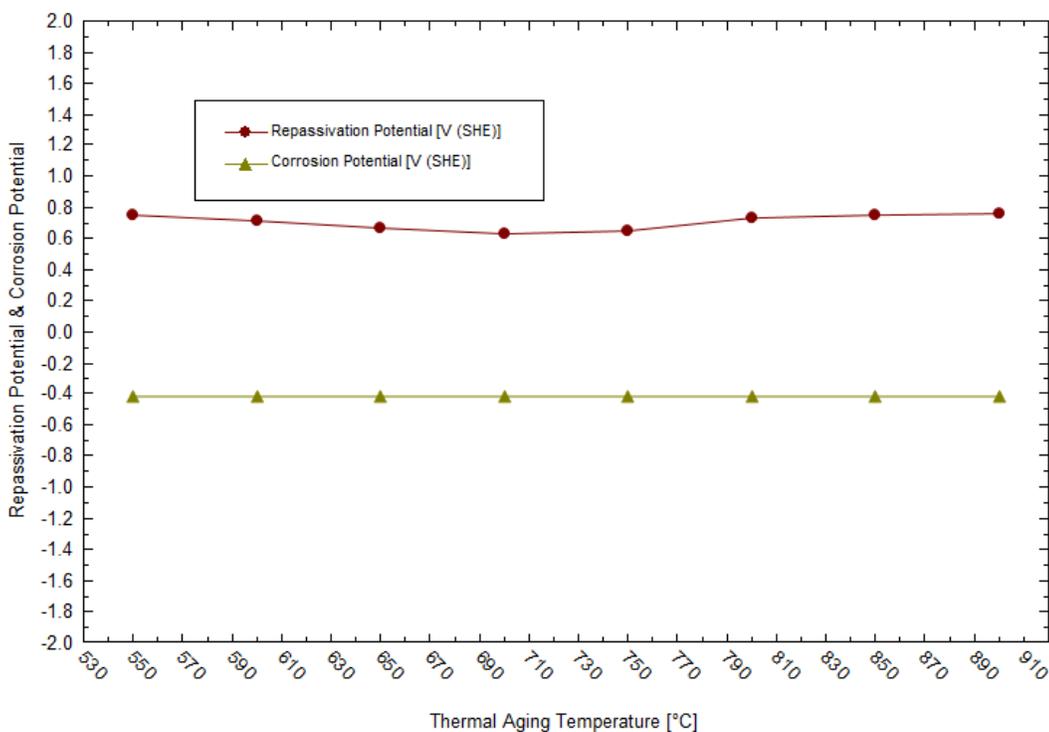
As shown in the plot above, the depletion profile is very narrow at the lowest temperature, i.e., 550 °C. On the other hand, it becomes flat at high temperatures and it has a high minimum. The high minimum value is particularly important because it indicates that the local depletion of Cr and Mo is much less severe at high temperatures (due to much faster diffusion of substitutional elements and subsequent healing).

It should be noted that the Mo profile qualitatively parallels the Cr profile but has somewhat different slopes because of differences in diffusion coefficients of Cr and Mo.

Effect of Cr and Mo depletion on corrosion

To look at the effect of Cr and Mo depletion on corrosion

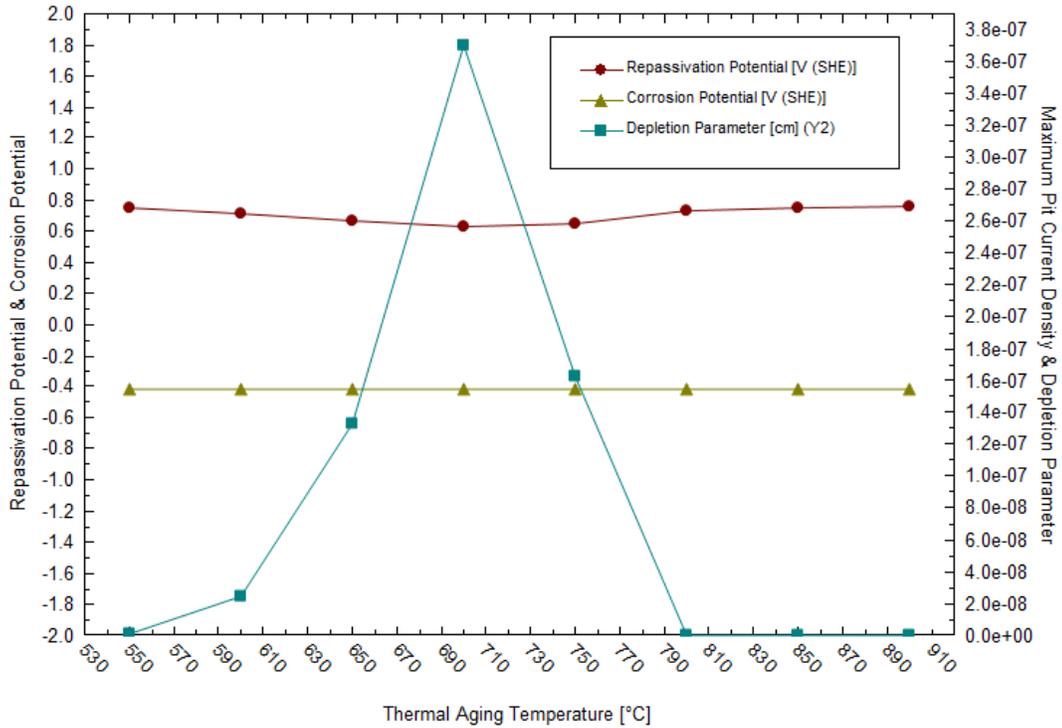
3. Click on the **Localized Corr.** tab ( Localized Corr.). By default, this tab will show a plot of the corrosion potential and repassivation potential.



Let's add a new parameter to the plot: The **Depletion Parameter**.

4. Click on the **Variables** button. This will open a new window.

Look for the **Corrosion Values** section, click on the '+' icon, and select the **Depletion Parameter** option. Click on the >> button that belongs the **Y2 Axis**. This action will place the new variable under the Y2 Axis. Then click **OK**.



It is evident that both the depletion parameter and repassivation potential show their extreme values at intermediate temperatures of thermal aging. In the case of the depletion parameter, it is a maximum and, in the case of the repassivation potential, it is a minimum. This is in agreement with experimental data (Anderko et al., 2009). Non-zero values of the depletion parameter indicate the possibility of intergranular corrosion. A depression in the repassivation potential indicates an increased tendency for localized corrosion.

9.3. Thermal Aging and Localized Corrosion of Annealed and Thermally Aged Duplex Alloy 2324

In the previous examples, we used the Corrosion Analyzer's capabilities to predict the Cr and Mo depletion profiles for austenitic stainless steels and nickel-base alloys. However, we are not limited to such calculations.

We can also use the Corrosion Analyzer to predict the localized corrosion behavior of other alloys and other phases, including those that are not stored in the database. This facility is based on a generalized correlation for predicting the repassivation potential of Fe-Ni-Cr-Mo-W-N alloys as a function of alloy composition (Anderko et al., 2008). This correlation can be applied to both bulk alloys that are not in the database and to phases that may result from thermal aging.

In this section, we will go through two simulations:

- First, we will predict the tendency for localized corrosion for the duplex alloy 2324 in an aerated chloride solution. Alloy 2324 (a.k.a. AISI 329) is not in the database, so the repassivation potential will be calculated from the generalized correlation (Anderko et al., 2008). The corrosion potential will be calculated for a similar alloy because the corrosion potential does not differ much for many Fe-Cr-Ni-Mo alloys in the passive state in neutral solutions.
- Second, we will predict the localized corrosion tendency for alloy 2324 after thermal aging. Thermal aging of duplex steels in the temperature range of 900°C to 600°C leads to the formation of various phases - χ , σ , $M_{23}C_6$ -type carbide, and secondary austenite (γ_2). The secondary austenite phase is primarily responsible for the increased tendency of the alloy for localized corrosion. This is due to a very significant depletion of chromium in the secondary austenite over relatively wide spatial areas (Sridhar et al., 2009). Since the composition of the secondary austenite cannot be predicted at present, we will use experimental microstructural data (Sridhar et al., 2009) in conjunction with the generalized correlation for the repassivation potential.

Example 55: Prediction of Localized Corrosion for Alloy 2324 Before Thermal Aging in an Aerated NaCl Solution

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Thermal Aging Calculation			
Calculation Settings		Stream Composition and Conditions	
Stream Name	Thermal Aging – Alloy 2324	Stream Amount	Calculated
Calculation Type	Corrosion Rates	Temperature	60 °C
Survey by	Composition	Pressure	1 atm
Name Style	Display Name	H2O	Default – 55.5082 moles
Unit Set	Metric, Batch, Moles	NaCl	0 moles
Framework	AQ	O2	0.02 moles
		N2	0.08 moles

Note: The oxygen and nitrogen have been added to simulate the presence of air

1. Add a new **Stream**
2. **Click** on the new Stream and press **<F2>** to change the name to *Thermal Aging – Alloy 2324*
3. Select the AQ thermodynamic Framework (selected by default)
4. **Click** on the **Units Manager** Icon and select Metric, Batch, Moles
5. **Click** on the **Names Manager** Icon and select *Display Name*
6. **Enter** the stream composition and conditions specified in the table above
7. **Go** to the **Add Calculation** button and select **Corrosion Rates**
8. **Select** the Survey by **Composition**
9. **Change** the name from *Rates* to *Alloy 2324 – before aging* using the **<F2>** key or by **right-mouse click** on the object and select rename

Since alloy 2324 is not available in the database, we will select stainless steel 316 as the contact surface. This will ensure that the predicted corrosion potential is very similar to that for alloy 2324.

10. Select **Stainless Steel 316** from the **Contact Surface** grid

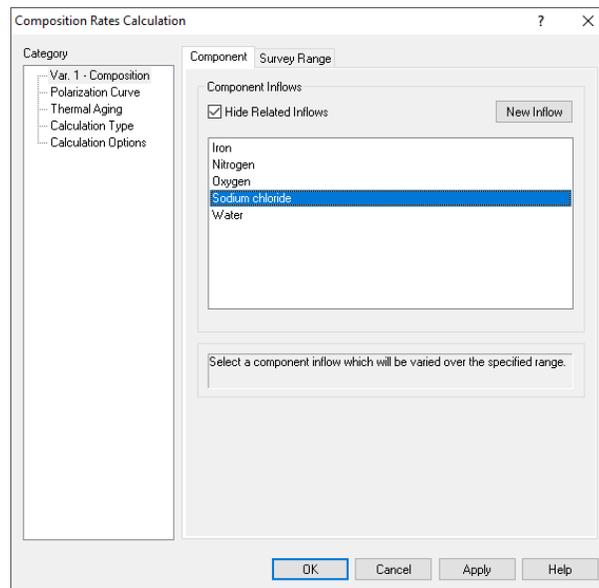
Unlike in the previous examples, do not make any changes in the **Calc Parameters** section. We will not make Cr depletion calculations; rather, we will be specifying the **compositions of the phases**.

Your screen should look like the image below.

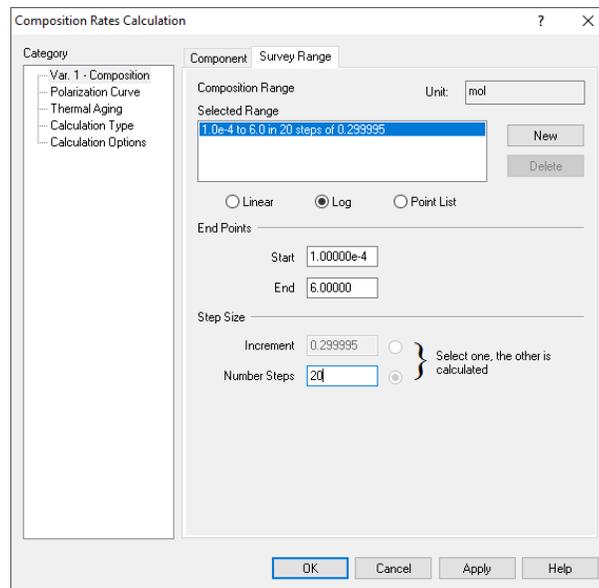
Variable	Value
Stream Parameters	
Stream Amount (mol)	55.6082
Temperature (°C)	60.0000
Pressure (atm)	1.00000
Calculation Parameters	
Flow Type	Static
Thermal Aging Temperature (°C)	399.000
Thermal Aging Time (hr)	0.0
Inflows (mol)	
Water	55.5082
Sodium chloride	0.0
Oxygen	0.0200000
Nitrogen	0.0800000
Iron	0.0
Contact Surface	
Stainless steel 316	

We will be running a composition survey to see how the concentration of NaCl affects the propensity for localized corrosion.

11. We need to specify the NaCl concentration range. **Click** on the **Specs** button. This will open a new window.
12. Under the **Component** tab select **Sodium Chloride**



13. Click on the **Survey Range** tab and change the concentration range as follows: Start=0.001 moles, End=6 moles, and number of steps=20. Then, click on the Log radio button.



14. Under the **Category** section, select the **Thermal Aging** option. The screen will be populated with default parameters for type 316 stainless steel.

In the following steps we are going to enter the alloy 2324 composition and use the repassivation potential (E_{rp}) correlation (embedded in the software) to calculate the E_{rp} of the alloy. This is necessary because no

parameters for alloy 2324 are stored in the databank and we have to rely exclusively on the correlation to predict the repassivation potential.

15. First, click on the **Yes** button next to “*Erp directly from correlation:*”

16. Then, enter the composition of alloy 2324 by replacing the default values for alloy 316.

Enter the following composition of alloy 2324:

Element	Composition (wt%)
Fe	67.245*
Cr	25.4
Ni	5.75
Mo+W	1.5
C	0.025
N	0.08

*which is the balance that includes many minor elements

The remaining parameters in the Thermal Aging screen can remain the same because we will not be using them in this example (i.e., we will not be calculating any depletion profiles). After entering the values, the screen should look as follows:

Composition Rates Calculation

Category

- Var. 1 - Composition
- Polarization Curve
- Thermal Aging
- Calculation Type
- Calculation Options

Thermal Aging

Erp Directly from Correlation: No Yes

Alloy Composition wt%:

Fe	67.245	Cr	25.4	Ni	5.75
Mo+W	1.5	C	0.025	N	0.08

Carbide Stoichiometry:

Fe	0	Cr	19.74	Ni	0
Mo+W	3.26	C	6	N	0

Carbide Thermochemistry:

A	41221	B	-966
---	-------	---	------

Cr Diffusion Coefficient: D0 0.00016818 Q -289000

Mo, W Diffusion Coefficient: D0 7.93e-005 Q -274000

Cr Sensitization Threshold wt%: 12 Grain Size: 100

Revert to Default

OK Cancel Apply Help

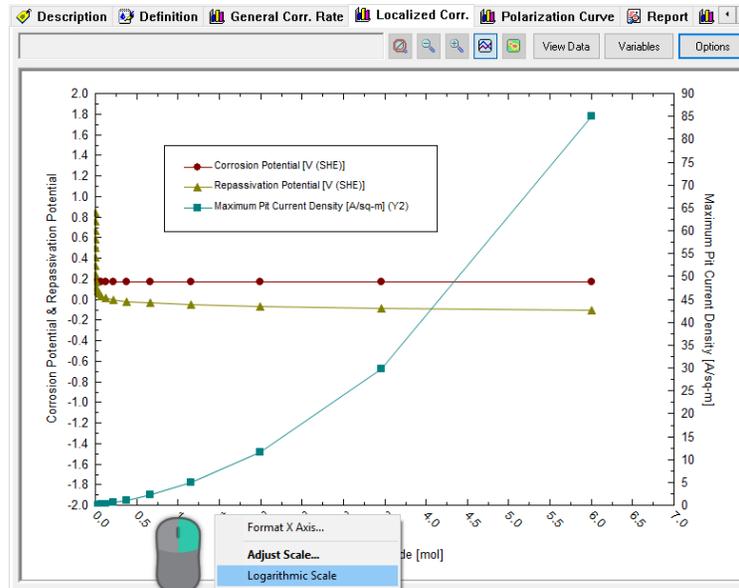
17. Click **OK** to accept the changes

18. We are now ready to perform the calculation. Click on the **Calculate** button or press the **<F9>** key

19. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under the same file created in the previous section named *Corrosion Rates*.

Analyzing the results

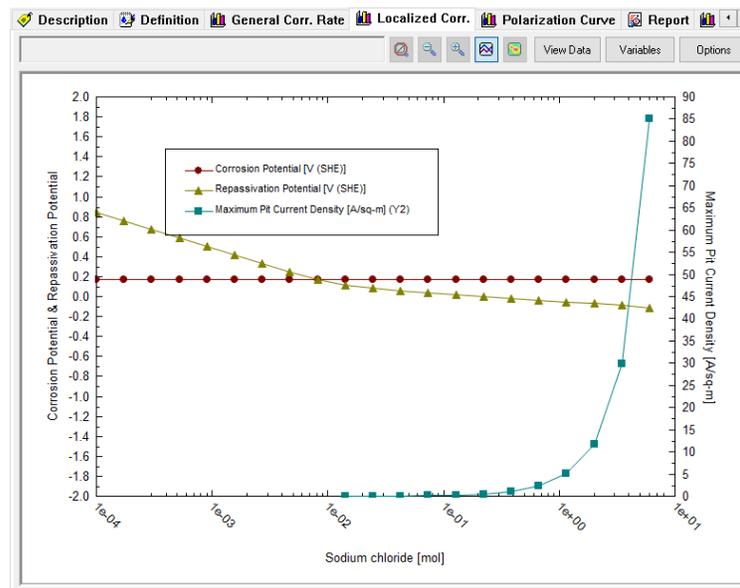
1. Click on the **Localized Corr.** tab (Localized Corr.). By default, this tab will show a plot of the corrosion and repassivation potentials as a function of NaCl concentration. In the Y2 axis the Maximum Pit Current Density is also plotted.



To visualize the results better, change the horizontal axis to a logarithmic scale.

2. **Right-mouse click** on the X Axis and select **Logarithmic Scale**

The plot should look like the image below.



These results indicate that alloy 2324 is susceptible to localized corrosion in aerated solutions when the chloride concentration exceeds ~0.3 molal. Above this concentration, the repassivation potential drops below the corrosion potential and, therefore, localized corrosion can be stabilized at these conditions.

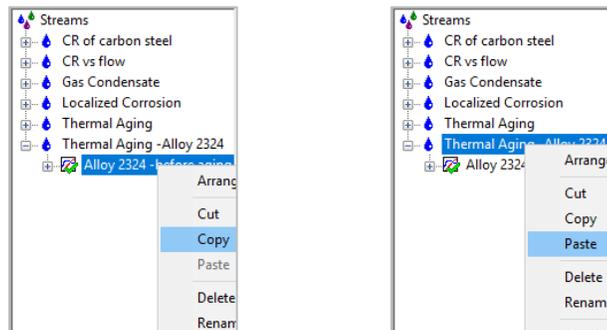
Example 56: Prediction of Localized Corrosion for Alloy 2324 After Thermal Aging

Now, we will perform the same prediction of localized corrosion calculations for thermally aged alloy 2324. We will run the same concentration survey as in the previous case so that we can compare the results for bulk alloy 2324 with those for a heat-treated sample.

Sridhar et al. (2009) found that after aging alloy 2205 at 700 °C for 24 hours, the formation of a chromium-depleted secondary austenite phase is responsible for a much-increase tendency for localized corrosion. We will use this experimental data to approximate the localized corrosion tendency of alloy 2324.

Starting the Simulation

1. **Copy** the *Alloy 2324-before aging* calculation and **paste** it under the *Thermal Aging – Alloy 2324* stream



2. **Rename** the calculation as *Alloy 2324 – after aging* by using the <F2> key or by **right-mouse click** on the object and select rename
3. Click on the **Specs** button. This will open a new window.
4. Under the **Category** section, select the **Thermal Aging** option. The screen will be populated with default parameters for type 316 stainless steel.
5. Click on the **Yes** button next to “*Erp directly from correlation.*” – because we will be running calculations for a completely new phase
6. Then, enter the composition of the secondary austenite phase by replacing the default values for alloy 316.

Note: we are using experimental data obtained for alloy 2205 for illustration purposes). For more details how these compositions were determined, see the paper of Sridhar et al. (2009).

Enter the following composition:

Element	Composition (wt%)
Fe	80.774*
Cr	12.512
Ni	5.134
Mo+W	1.399
C	0.017
N	0.164

*which is the balance that includes many minor elements

The remaining parameters in the Thermal Aging screen can remain the same because we will not be using them in this example (i.e., we will not be calculating any depletion profiles). After entering the values, the screen should look like the image below.

Composition Rates Calculation

Category: Thermal Aging

Etp Directly from Correlation: No Yes

Alloy Composition wt%:

Fe	80.774	Cr	12.512	Ni	5.314
Mo+W	1.399	C	0.017	N	0.164

Carbide Stoichiometry:

Fe	0	Cr	19.74	Ni	0
Mo+W	3.26	C	6	N	0

Carbide Thermochemistry:

A	41221	B	-966
---	-------	---	------

Cr Diffusion Coefficient: D0 0.00016818 Q -289000

Mo, W Diffusion Coefficient: D0 7.93e-005 Q -274000

Cr Sensitization Threshold wt%: 12 Grain Size: 100

Revert to Default

OK Cancel Apply Help

7. Click **OK** to accept the changes
8. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
9. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. You can save it under

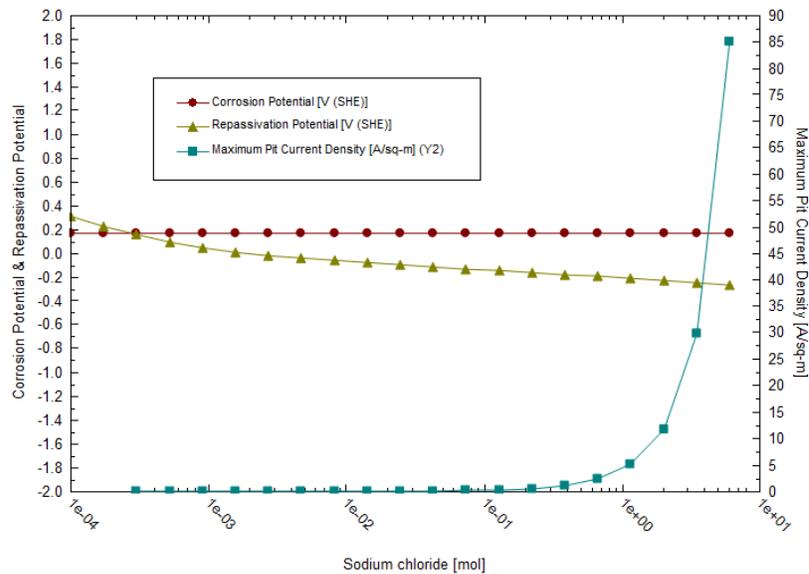
Analyzing the results

1. Click on the **Localized Corr.** tab ( Localized Corr.). By default, this tab will show a plot of the corrosion and repassivation potentials as a function of NaCl concentration. In the Y2 axis the Maximum Pit Current Density is also plotted.

To visualize the results better, change the horizontal axis to a logarithmic scale.

2. **Right-mouse click** on the X Axis and select **Logarithmic Scale**

The plot should look like the image below.



The obtained plot shows that the repassivation potential is much lower than that for bulk alloy 2324. Because of the strong depression of the repassivation potential, the corrosion potential exceeds the repassivation potential at chloride concentrations of ~ 0.0007 m. Thus, localized corrosion is predicted to be possible at concentrations above 0.0007 m. This indicates a very strong increase in the propensity for localized corrosion compared with bulk alloy 2324, for which the predicted threshold is ~ 0.3 m.

In general, you can use this facility to predict the repassivation potential for any alloys, including unknown and experimental ones, as long as they belong to the Fe-Ni-Cr-Mo-W-N-C family.

Section 10. Extreme Value Statistics (EVS)

10.1. Overview and Theoretical Foundation

Engineering systems may have a large number of pits and corroded areas of varying degree of severity. The first perforation, whose time and location will be a matter of probability, may cause the failure of the construction. Accordingly, the probability of such failure must be known as accurately as possible.

Extreme value statistics (EVS) is one of the most powerful statistical techniques that have been used extensively to extrapolate damage (maximum pit depth) from small samples in the laboratory to larger area samples in the field (see, for example, Eldridge G. 1957, Shibata T. et al. 1988, Kowaka et al. 1994). Thus, it was shown (Shibata T. et al. 1988) that probability of failure of a construction, P_f , i.e. the probability that at least one pit reaches the critical dimension, d , (for example wall thickness) in the system with area S is described by the equation:

$$P_f = 1 - \exp\left\{-\frac{\exp[-d-(u+\alpha \ln \frac{S}{s})]}{\alpha}\right\} \quad (1)$$

where location parameter, u , and scale parameter, α , are measured by using small samples with constant area, s . Equation (1) is to extrapolate corrosion damage from a small reference area, such as a coupon to a larger operation area, S . This is the classical use of Extreme Value Statistics.

Experimental studies demonstrate that both the shape and location parameters are time dependent. However, those dependencies must be established empirically and since no theory contained within classical EVS is available for the functional forms of $u(t)$ and $\alpha(t)$, it is necessary to know answer (prediction) in advance for predicting the damage at long times. This has proven to be a severe constrains of the applicability of classical EVS.

This problem can be overcome by applying damage function analysis (DFA) method that considers propagation of corrosion damage by drawing an analogy between the growth of a pit and the movement of a particle (Engelhardt and Macdonald, 2004). In many cases DFA yields an analytical expression for u and α in terms of time of the hyperbolic form:

$$u = \frac{a_1 t}{1+a_2 t} \text{ and } \alpha = a_3 t \quad (2)$$

where a_1 , a_2 , and a_3 are readily determined by calibration from short term data in order to predict damage over the longer time. Namely, equations (2) are used now by OLI software for predicting damage in corroding systems. It must be noted that a different (power) form of such dependencies has been used by Laycock et al. 1990.

Input and Output Specific to EVS

For applying this technique the user has to provide a set of experimental data (x_i, t_i, s_i) , $i = 1, 2, \dots, N$, where x_i is the depth of the deepest pit over area s_i , of a metal exposed to corrosion attack. The separate area, s_i , could be distinct coupons from a designed experiment or random samples at various times from different locations in the system. Experiments must be performed for at least two different times.

The output of the code yields the probability of failure as a function of time for a large system with area S . The code also allows the user to answers on several engineering questions, for example, what service life, t , will have the pipe with the width, d , and length L in order to ensure acceptable performance (probability of failure, P_f).

Advantages and Disadvantages of EVS

The advantage of this approach is self-evident. The prediction of corrosion damage for long times will be done by using experimental data for short times without requiring the explicit determination of any information about the kinetic parameters of the system. However, such approach has evident disadvantages, as follows:

1. The results of the analysis cannot be transferred for predicting corrosion damage to other systems (for example pipelines) due to the different technological and environmental conditions that generally exist. The results cannot be used for predicting damage in the same system if technological and environmental conditions change.
2. We can expect that when the depth of the pit increases some critical value, the nucleation of cracks can occur. It is clear that a purely statistical method cannot predict such a transition. This method also cannot predict any catastrophic event.
3. This method cannot be used for design of new constriction, because it relies upon calibration upon a pre-existing system.

10.2. Extreme Value Statistics for Predicting Pitting Damage

We will show examples of applications of Extreme Value Statistics for predicting pitting damage. Specifically, we will show how to predict:

1. The depth of the deepest pit in the engineering structure or laboratory systems as a function of time and the surface area of the system
2. Probability of failure for a given penetration depth and the area of the system as a function of observation time
3. Probability of failure for a given observation time and the area of the system as a function of penetration depth
4. Probability of failure for a given penetration depth and observation time as a function of the area of the system

Foundations of Extreme Value Statistics can be found in the following references: (Aziz, 1956, Kowaka et al. 1994, Laycock et al. 1990, Engelhardt and Macdonald, 2004).

Example 57: Corrosion of Aluminum Alloy in Tap Water

In this example, we will consider the classical data for pitting corrosion (Aziz, 1956). In this paper, we can find particularly the experimental data for the maximum pit depths developed on Alcan 2S-O coupons with area $\approx 129 \text{ cm}^2$ immersed in Kingston tap water at 25°C . The experimental data is summarized in the table below.

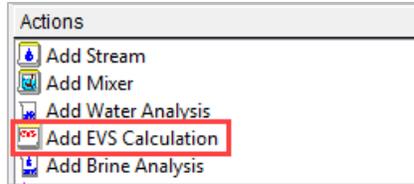
Maximum pit depth (in μm) developed on Alcan 2S-O coupons with immersed in Kingston tap water for different observation times. Area of all coupons is $\approx 129 \text{ cm}^2$

Coupon #	One Week 7 days	One Month 30 days	Three Months 90 days	Six Month 180 days	One Year 365 days
1	180	460	480	620	640
2	266	500	578	620	680
3	290	510	610	620	700
4	306	580	610	680	760
5	334	580	610	680	800
6	340	640	660	720	810
7	340	654	690	740	820
8	410	680	718	740	840
9	410	692	760	760	840
10	545	692	798	760	900

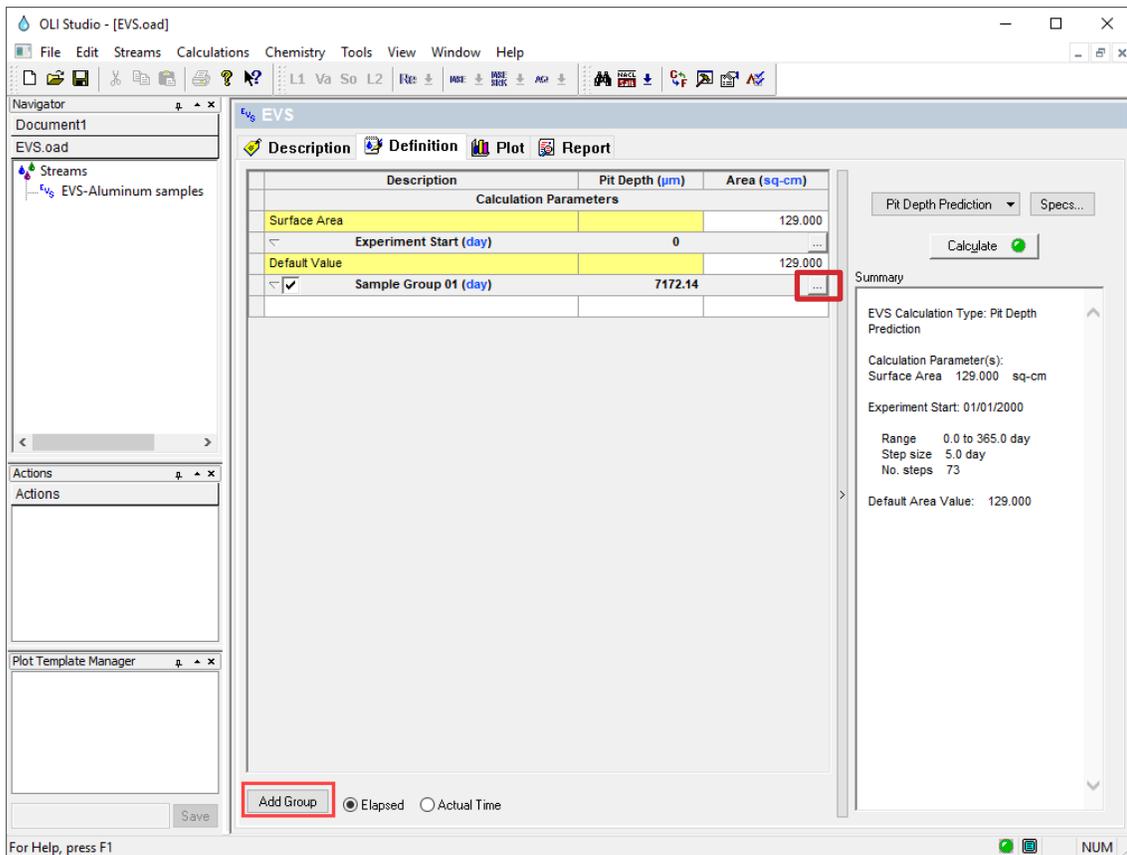
Calculating the Depth of the Deepest Pit

Starting the Simulation

1. Add a new **EVS** calculation. Select the **Add EVS Calculation** icon in the Actions Pane



2. **Click** on the new EVS calculation and press **<F2>** to change the name to *EVS-Aluminum samples*. Notice that the default calculation is the *Pit Depth Prediction*.
3. All samples have a constant area $s = 129 \text{ cm}^2$. Under the **Calculation Parameters** grid, enter 129 cm^2 for the **Surface Area** and **Default Value** cells.



There are experimental data sets for 5 different periods of time. This means that we need to enter 5 different sample groups.

4. By default, **Sample group 01** is created. Click on the  button to edit this field. This will open a new window.
5. **Change** the title to **One Week**, enter the number **7** for the number of **elapsed days**, and **check** the box **'Include for Calculation'**. Then click **OK**.

EVS Sample Group Info Editor

Title:
One Week

Elapsed: (day)
7

Included for Calculation

OK Cancel

- Enter the **Pit Depth** data (second column) obtained for 1 week

Description	Pit Depth (μm)	Area (sq-cm)
Calculation Parameters		
Surface Area		129.000
Experiment Start (day)	0	...
Default Value		129.000
<input checked="" type="checkbox"/> One Week (day)	7.0	...
1	180.000	129.000
2	266.000	129.000
3	290.000	129.000
4	306.000	129.000
5	334.000	129.000
6	340.000	129.000
7	340.000	129.000
8	410.000	129.000
9	410.000	129.000
10	545.000	129.000

Now we need to add 4 more groups.

- Click on the **Add Group** button (located at the bottom of the window). This will open a new window.
- Change** the title to **One Month**, enter the number 30 for the number of **elapsed days**, and **check** the box **'Include for Calculation'**. Then click **OK**.
- Enter the **Pit Depth** data (second column) obtained for 1 month.
- Click on the **Add Group** button, and repeat the same procedure for one month, three months, six months and one year.

The information for this group is entered, but by un-checking the box, the information is not considered for the calculation

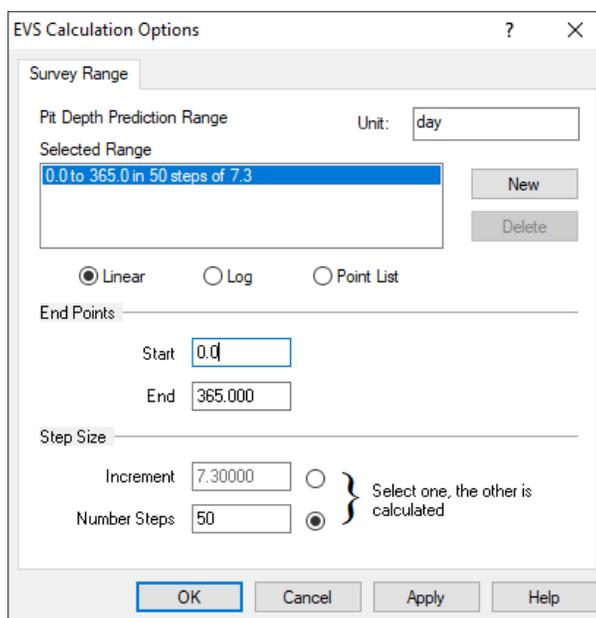
Description			Pit Depth (µm)	Area (sq-cm)
<input checked="" type="checkbox"/> One Month (day)			30.0	...
1			460.000	129.000
2			500.000	129.000
3			510.000	129.000
4			580.000	129.000
5			580.000	129.000
6			640.000	129.000
7			654.000	129.000
8			680.000	129.000
9			692.000	129.000
10			692.000	129.000
<input type="checkbox"/> Three Months (day)			89.9999	...
1			480.000	129.000
2			578.000	129.000
3			610.000	129.000
4			610.000	129.000
5			610.000	129.000
6			660.000	129.000
7			690.000	129.000
8			718.000	129.000
9			760.000	129.000
10			798.000	129.000
<input type="checkbox"/> Six Months (day)			180.0	...
1			620.000	129.000
2			620.000	129.000
3			620.000	129.000
4			680.000	129.000
5			680.000	129.000
6			720.000	129.000
7			740.000	129.000
8			740.000	129.000
9			760.000	129.000
10			760.000	129.000
<input type="checkbox"/> One Year (day)			365.0	...
1			640.000	129.000
2			680.000	129.000
3			700.000	129.000
4			760.000	129.000
5			800.000	129.000

Note the following:

- Here, for the description of different experiments we simply used the number of the corresponding row in Table 1. However, this description can be done in an arbitrary form.
- For each group, the order of samples relative depth can be arbitrary (not necessary in ascending order as in Table 1)
- If coupons have different areas each area must be specified in the column **Area**
- Radio button **Elapsed** means the time after corrosion attack is used in calculations and namely this time is used usually in scientific publication. However, it is possible to use also **Actual Time** of the experiments.

At this point, the experimental data has been entered. Now we need define the period of time for which we want to do the prediction of failure due to pitting.

11. **Click** on the **Specs** button. This will open a new window.
12. Under the **Survey Range** tab, enter the range for **Pit Depth Prediction** as follows: Start=0 days, End=365 days, and number of steps=50. Then click **OK**



Before running the calculation, we are going to study two different cases:

- I. The first case will include the experimental data for 1 week and 1 month – short term experiments
- II. The second case will include all the experimental data – long term experiments

Predicting the Worst Pit Depth for 1 year of service life using short term experiments (Experimental Data for 1 week and 1 month)

13. **Check** the boxes for 1 week and 1 month only to include them into the calculations

Description			
Description	Pit Depth (µm)	Area (sq-cm)	
Calculation Parameters			
Surface Area		129.000	
Experiment Start (day)	0	...	
Default Value		129.000	
<input checked="" type="checkbox"/> One Week (day)	7.0	...	
1	180.000	129.000	
2	266.000	129.000	
3	290.000	129.000	
4	306.000	129.000	
5	334.000	129.000	
6	340.000	129.000	
7	340.000	129.000	
8	410.000	129.000	
9	410.000	129.000	
10	545.000	129.000	
<input checked="" type="checkbox"/> One Month (day)	30.0	...	
1	460.000	129.000	
2	500.000	129.000	
3	510.000	129.000	
4	580.000	129.000	
5	580.000	129.000	
6	640.000	129.000	
7	654.000	129.000	
8	680.000	129.000	
9	692.000	129.000	
10	692.000	129.000	
<input type="checkbox"/> Three Months (day)	89.9999	...	
1	480.000	129.000	
2	578.000	129.000	
3	610.000	129.000	
4	610.000	129.000	
5	610.000	129.000	
6	660.000	129.000	
7	690.000	129.000	
8	718.000	129.000	
9	760.000	129.000	
10	798.000	129.000	
<input type="checkbox"/> Six Months (day)	180.0	...	
1	620.000	129.000	

Add Group Elapsed Actual Time

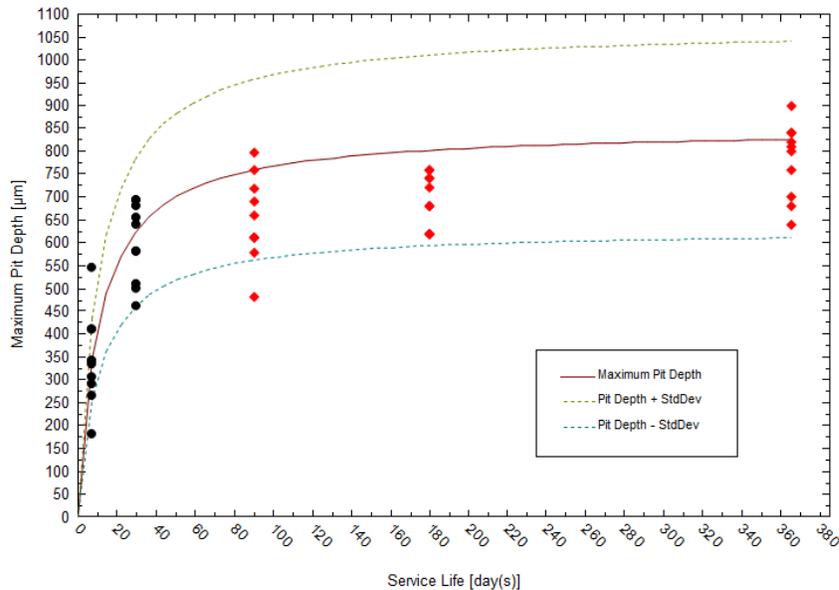
14. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

15. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. Save this new file as *EVS calculations*.

Analyzing the results

- Click on the **Plot** tab ( **Plot**). You will see a plot of the predicted mean value of the depth of the deepest pit, x_m and the plots of values $x_m - \sigma$ and $x_m + \sigma$, where σ is the standard deviation of x_m .

It is important to note that only data for short term experiments (for 1 week and 1 month) are shown as black circles in the plot. The additional data are shown as red diamonds, only for demonstrating the accuracy of prediction.



- Click on the **Report** tab, and to the **Calculation Results** table.

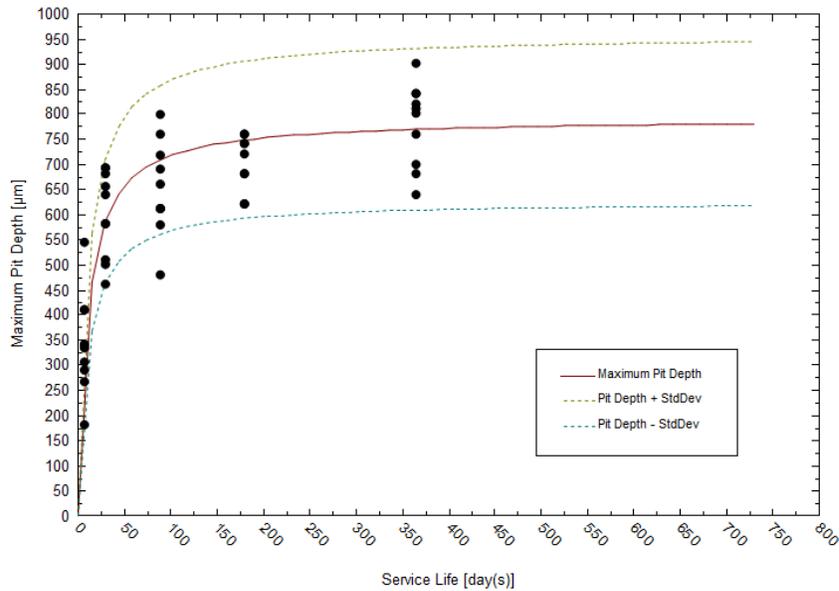
The predicted depth of the deepest pit at 365 days is $610.43\mu\text{m} \leq 825.373\mu\text{m} \leq 1040.31\mu\text{m}$ (based on the short-term experimental data).

Predicting the Worst Pit Depth for 2 years of service life using long term experiments (all data sets)

- The accuracy of prediction increases when additional group of experiments are included into consideration. For this case we are going to add the experimental data for 3 months, 6 months and 1 year.
- Go back to the **Definition** tab
- Include** (check) the experimental data for 3 months, 6 months and 1 year
- Click** on the **Specs** button. This will open a new window
- Under the **Survey Range** tab, enter the range for **Pit Depth Prediction** as follows: Start=0 days, End=730 days, and number of steps=50. Then click **OK**
- Then **Click** on the **Calculate** button or press the **<F9>** key

Analyzing the results

24. Click on the **Plot** tab ( Plot).



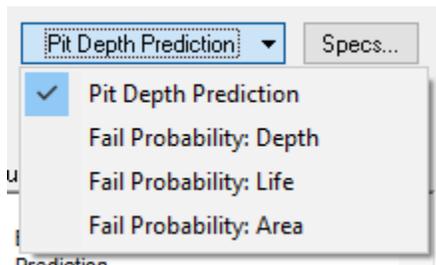
25. Click on the **Report** tab, and to the **Calculation Results** table.

The predicted depth of the deepest pit at 730 days (1 year) is $617.57 \mu\text{m} \leq 780.873 \mu\text{m} \leq 944.18 \mu\text{m}$.

Calculating Fail Probabilities

When doing engineering design, information regarding the probability of failure is of importance to consider. The next set of calculations will involve calculating the Probability of Failure for a given:

- Penetration depth
- Observation time (life)
- Area of the system



Fail Probability: Depth

Let's start with the calculation of Probability of Failure for a given penetration depth and the area of the system as a function of observation time.

We are going to answer the following question:

- Which thickness, d , does an aluminum pipe with the area of $S= 1 \text{ m}^2$ have to have in order to ensure acceptable performance (probability of failure $P_f < 5\%$ at design service life, $t_s = 5$ years)?

Starting the Simulation

1. Use the data enter in the example above. **Change** the Calculation Type to **Fail Probability: Depth**
2. Under the **Calculation Parameters** grid, enter 1 m^2 for the **Surface Area** and 5 years for the **Service Life**. Change units by clicking on the **blue** hyperlinks.
3. Make sure all data sets are selected (checked)

Your screen should look like the image below.

The screenshot shows the OLI Studio interface for the 'EVS-Fail Probability' simulation. The main window contains a table with the following data:

Description	Pit Depth (µm)	Area (sq-m)
Calculation Parameters		
Surface Area		1.00000
Service Life (yr)		5.00000
Experiment Start (yr)	0	
Default Value		0.0129000
<input checked="" type="checkbox"/> One Week (yr)	0.0191781	
1	180.000	0.0129000
2	266.000	0.0129000
3	290.000	0.0129000
4	306.000	0.0129000
5	334.000	0.0129000
6	340.000	0.0129000
7	340.000	0.0129000
8	410.000	0.0129000
9	410.000	0.0129000
10	545.000	0.0129000
<input checked="" type="checkbox"/> One Month (yr)	0.0821918	
1	460.000	0.0129000
2	500.000	0.0129000
3	510.000	0.0129000
4	580.000	0.0129000
5	580.000	0.0129000
6	640.000	0.0129000
7	654.000	0.0129000
8	680.000	0.0129000
9	692.000	0.0129000
10	692.000	0.0129000

The right sidebar shows a summary of the calculation parameters:

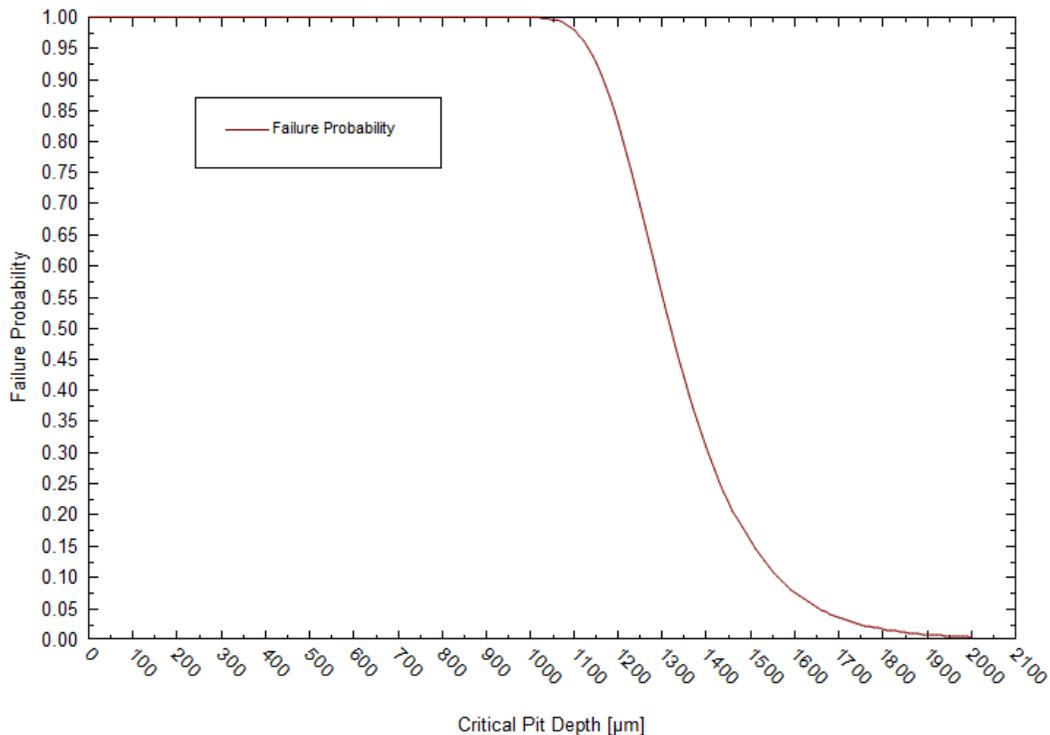
Fail Probability: Depth | Specs...
Calculate

Summary
EVS Calculation Type: Failure Probability - Critical Depth Based
Calculation Parameter(s):
Surface Area 1.00000 sq-m
Service Life 5.00000 yr
Experiment Start: 01/01/2000
Range 0.0 to 2000.0 µm
Step size 10.0 µm
No. steps 200
Default Area Value: 129.000

4. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
5. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the results

6. Click on the **Plot** tab ( **Plot**). You will see a plot of predicted probability of failure



7. Click on the **Report** tab, and to the **Calculation Results** table.

We can conclude that the acceptable pipe wall width is reached at $d > 1950 \mu\text{m}$.

Fail Probability: Life

Let's continue with the calculation of Probability of failure for a given service time (life) and the area of the system as a function of penetration depth.

We are going to answer the following question:

- What service life, t , will have the aluminum pipe with the width, $d=1850 \mu\text{m}$ with area $S=10 \text{ m}^2$ in order to ensure acceptable performance i.e. probability of failure, $P_f < 5 \%$?

Starting the Simulation

1. **Change** the Calculation Type to **Fail Probability: Life**
2. Under the **Calculation Parameters** grid, enter 10 m² for the **Surface Area** and 1850 μm for the **Critical Pit Depth**. Change units by clicking on the **blue** hyperlinks (If needed).

For this calculation we need to specify the period of time at which we want to bound the calculation.

3. Click on the **Specs** button. This will open a new window.
4. Change the **Service Life** range as follows: Start=0 years, End=3 years and Increments=0.2 years. Then click **OK**.

EVS Calculation Options

Survey Range

Failure Probability - Service Life Based Unit: [yr](#)

Selected Range

0.0 to 3.0 in 15 steps of 0.2

New

Delete

Linear Log Point List

End Points

Start 0.0

End 3.00000

Step Size

Increment 0.200000 } Select one, the other is calculated

Number Steps 15

OK Cancel Apply Help

Your screen should look like the image below.

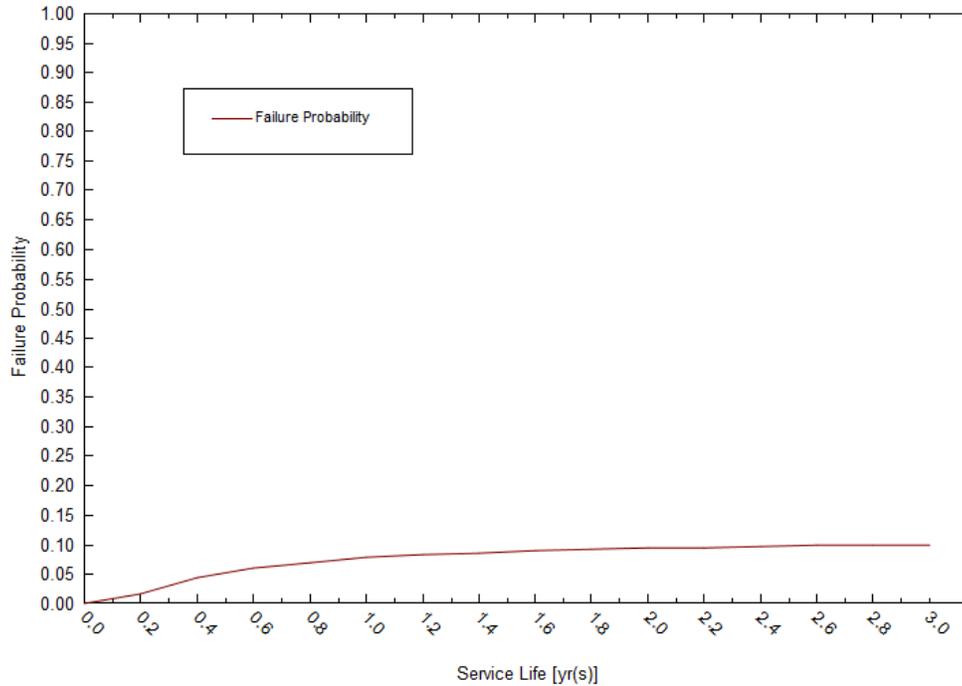
Description	Pit Depth (μm)	Area (sq-m)
Calculation Parameters		
Surface Area		10.0000
Critical Pit Depth	1850.00	
Experiment Start (yr)	0	
Default Value		0.0129000
<input checked="" type="checkbox"/> One Week (yr)	0.0191781	
1	180.000	0.0129000
2	266.000	0.0129000
3	290.000	0.0129000
4	306.000	0.0129000
5	334.000	0.0129000
6	340.000	0.0129000
7	340.000	0.0129000
8	410.000	0.0129000
9	410.000	0.0129000
10	545.000	0.0129000
<input checked="" type="checkbox"/> One Month (yr)	0.0821918	
1	460.000	0.0129000
2	500.000	0.0129000
3	510.000	0.0129000
4	580.000	0.0129000
5	580.000	0.0129000
6	640.000	0.0129000
7	654.000	0.0129000
8	680.000	0.0129000
9	692.000	0.0129000

Add Group Elapsed Actual Time

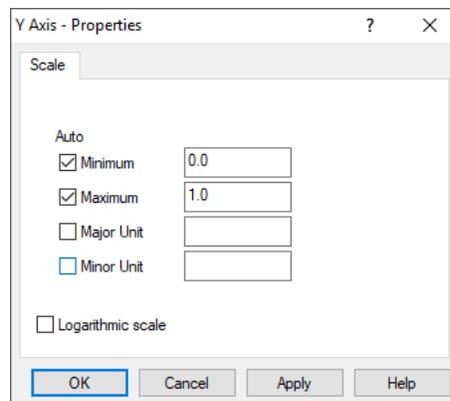
5. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
6. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the results

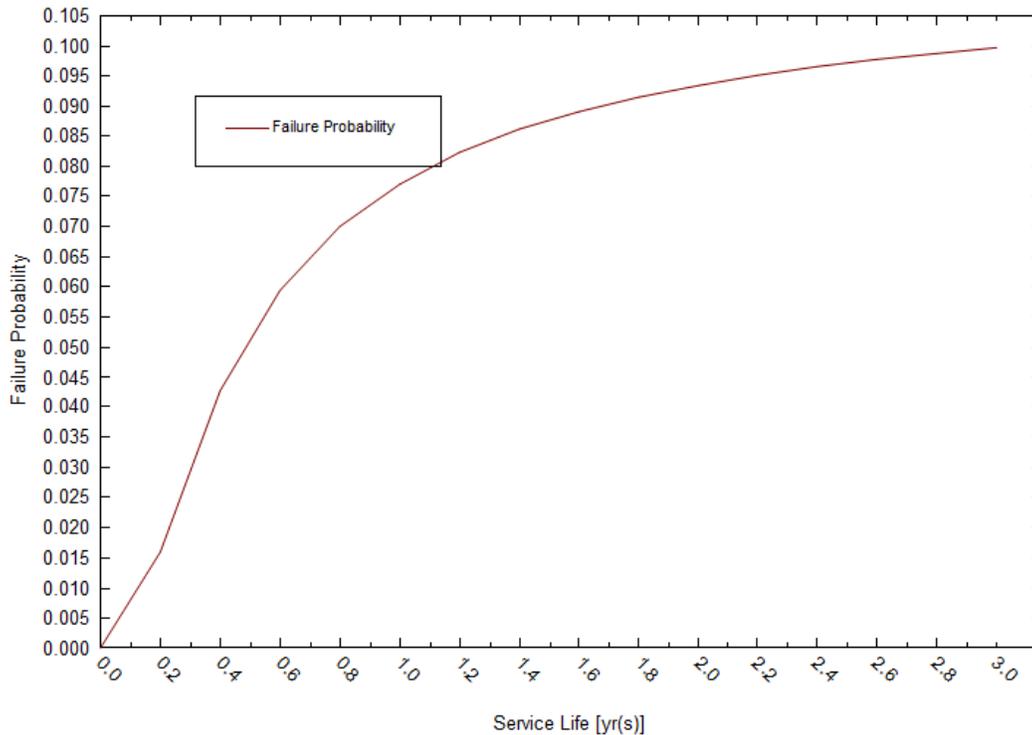
7. Click on the **Plot** tab ( **Plot**). You will see a plot of predicted probability of failure. We need to modify the plot to see the results in more detail.



8. **Double click** on the **Y axis**. This will open a new window.
9. **Check** the boxes Minimum and Maximum. Then click **OK**.



The plot should look like the image below



The maximum probability of failure seems to be at around 10%.

10. Click on the **Report** tab, and to the **Calculation Results** table.

We can conclude that the lifetime of this pipe before failing is <0.6 years.

Fail Probability: Area

Finally, let's do the calculation of Probability of failure for a given penetration depth and service time as a function of the area of the system.

We are going to answer the following question:

- What area, S , can have the aluminum pipe with the width, $d=2000 \mu\text{m}$ and service life $t=5$ years in order to ensure acceptable performance i.e. probability of failure, $P_f < 5 \%$?

Starting the Simulation

1. **Change** the Calculation Type to **Fail Probability: Area**
2. Under the **Calculation Parameters** grid, enter $2000 \mu\text{m}$ for **Critical Pit Depth** and 5 years for the **Service Life**. Change units by clicking on the **blue** hyperlinks (If needed).

For this calculation we need to specify the surface area range that we want to survey.

3. Click on the **Specs** button. This will open a new window.
4. Change the **Surface Area** range as follows: Start=0 sq-m, End=100 sq-m and Number of steps=50. Then click **OK**.

EVS Calculation Options

Survey Range

Failure Probability - Surface Area Based Unit: sq-m

Selected Range

0.0 to 100.0 in 50 steps of 2.0

New

Delete

Linear Log Point List

End Points

Start 0.0

End 100.000

Step Size

Increment 2.00000 } Select one, the other is calculated

Number Steps 50

OK Cancel Apply Help

Your screen should look like the image below.

Description Definition Plot Report

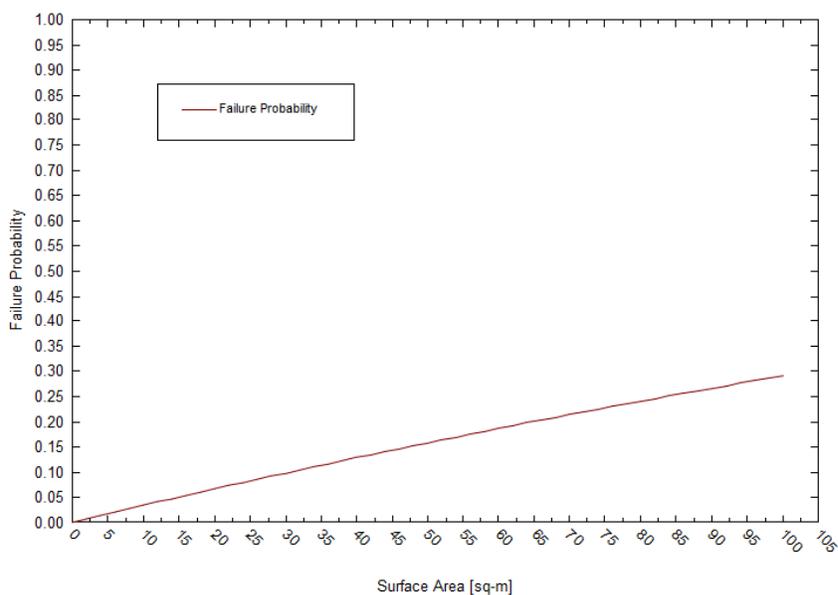
Description	Pit Depth (µm)	Area (sq-m)
Calculation Parameters		
Critical Pit Depth	2000.00	
Service Life (yr)		5.00000
Experiment Start (yr)	0	
Default Value		0.0129000
One Week (yr)	0.0191781	
1	180.000	0.0129000
2	266.000	0.0129000
3	290.000	0.0129000
4	306.000	0.0129000
5	334.000	0.0129000
6	340.000	0.0129000
7	340.000	0.0129000
8	410.000	0.0129000
9	410.000	0.0129000
10	545.000	0.0129000
One Month (yr)	0.0821918	
1	460.000	0.0129000
2	500.000	0.0129000
3	510.000	0.0129000
4	580.000	0.0129000
5	580.000	0.0129000
6	640.000	0.0129000
7	654.000	0.0129000
8	680.000	0.0129000
9	692.000	0.0129000

Add Group Elapsed Actual Time

5. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
6. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar.

Analyzing the results

7. Click on the **Plot** tab ( **Plot**). You will see a plot of predicted probability of failure. We need to modify the plot to see the results in more detail.



The maximum probability of failure seems to be at around 30%.

8. Click on the **Report** tab, and to the **Calculation Results** table.

We can conclude that acceptable performance is reached at <14 m².

Example 58: Failure Analysis due to Corrosion in Pipelines

In this example, we will show how in some cases reliable prediction of corrosion damage can be done by using a very limited number of experimental points.

In the table below, you can see the results of direct measurements of the depth of the deepest pits in the pipeline between Samara and Moscow [Zikerman, 1972].

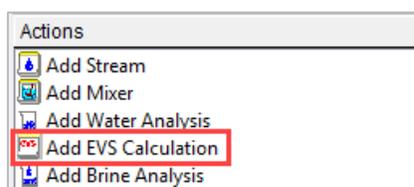
Pit depths (mm) for pipeline between Samara and Moscow

	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
Sample	1440 h	5040 h	5760 h	8959 h	12624 h	17688 h	28032 h	28272 h
1	0.1			1.4	1.7	1.9		2.1
2		0.49		1.95	2.1	2.08		2.25
3	0.3	1.6		1.8				
4	0.4			1.6	1.65	1.88		
5	0.9		1.57	2.1	2.21	2.4	2.4	
6	0.3		1.2	1.4	1.4	1.55	1.71	

Calculation the Depth of the Deepest Pit

Starting the Simulation

1. Add a new **EVS** calculation. Select the **Add EVS Calculation** icon in the Actions Pane

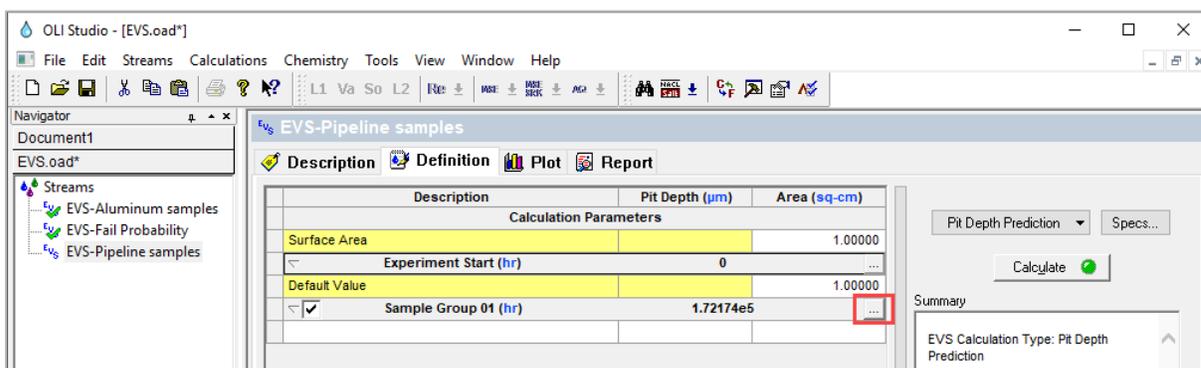


2. **Click** on the new EVS calculation and press **<F2>** to change the name to *EVS-Pipeline samples*. Notice that the default calculation is the *Pit Depth Prediction*.
3. Under the **Calculation Parameters** grid, enter 1 cm² for the **Surface Area** and **Default Value** cells.

Note: Because the area of the pipelines metal was not changed with time the information about this area is not needed for extrapolation of corrosion damage in time.

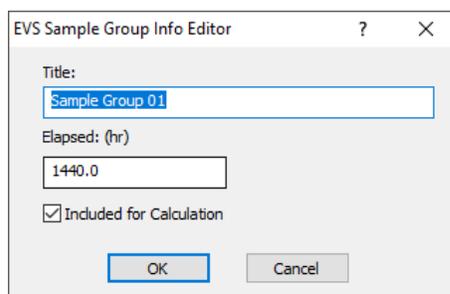
4. Since the data is in hours, click on the blue hyperlink **day** and change it to hours (**hr**) (for both: The **Experiment Start** and the **Sample Group**).

Your screen should look like the image below:

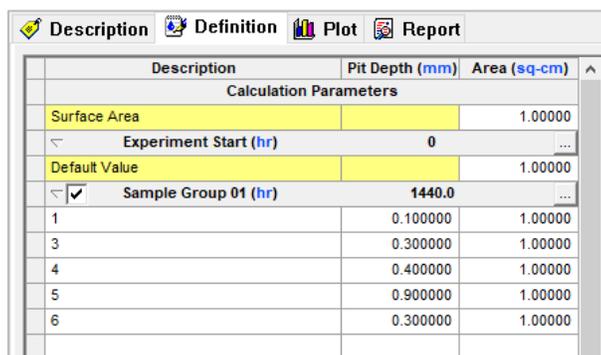


There are experimental data sets for 8 different periods of time. This means that we need to enter 8 different sample groups.

- By default, **Sample group 01** is created. Click on the button to edit this field. This will open a new window.
- Leave** the default name as **Sample Group 01**, enter the number **1440** for the number of **elapsed hours**, and **check** the box **'Include for Calculation'**



- Enter the **Pit Depth** data (second column) obtained for 1440 hours.

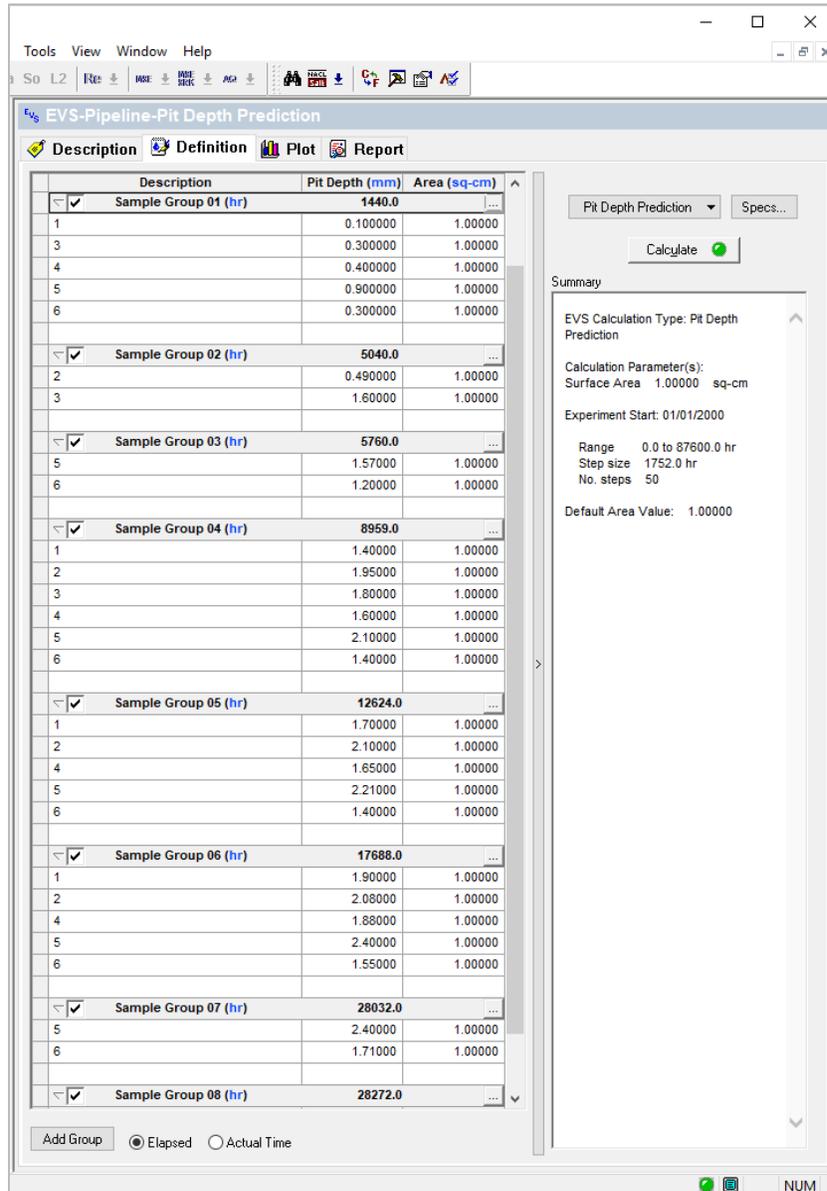


Now we need to add 7 more groups.

- Click on the **Add Group** button (located at the bottom of the window. This will open a new window.

9. Leave the default name as **Sample Group 02**, enter the number 5040 for the number of **elapsed hours**, and **check** the box '**Include for Calculation**'. Then click **OK**.
10. Enter the **Pit Depth** data (second column) obtained for 5040 hours.
11. Click on the **Add Group** button, and repeat the same procedure for 5760, 8959, 12624, 17688, 28032 and 28272 hours.

Once you have entered all the experimental data, your screen should look like the image below.



Make sure that all the groups are selected (checked) to be considered for the calculation.

At this point, the experimental data has been entered. Now we need define the period of time for which we want to do the prediction of failure due to pitting.

12. Click on the **Specs** button. This will open a new window.

- Under the **Survey Range** tab, enter the range for **Pit Depth Prediction** as follows: Start=0 hours, End=30000 hours, and Increment=2000 hours. Then click **OK**

The screenshot shows the 'EVS Calculation Options' dialog box with the 'Survey Range' tab active. The 'Pit Depth Prediction Range' is set to 'hr'. The 'Selected Range' is '0.0 to 30000.0 in 15 steps of 2000.0'. Below this, there are radio buttons for 'Linear' (selected), 'Log', and 'Point List'. The 'End Points' section shows 'Start' as 0.0 and 'End' as 30000.0. The 'Step Size' section shows 'Increment' as 2000.00 and 'Number Steps' as 15. A note indicates that either the increment or the number of steps can be selected, but only one should be calculated. At the bottom, there are buttons for 'OK', 'Cancel', 'Apply', and 'Help'.

Before running the calculation, we are going to study two different cases:

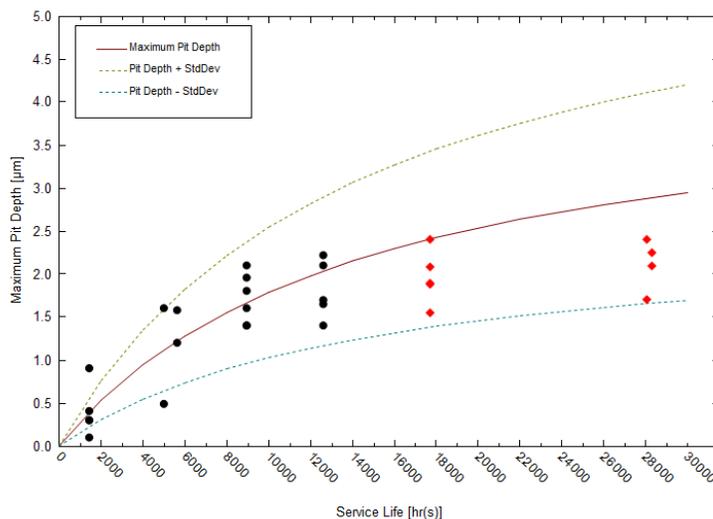
- The first case will include the experimental data from groups 01 to 05
- The second case will include all the experimental data from groups 01 to 08

Calculation including Groups 01 to 05

- Check** the boxes for Group 01 to 05
- We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. Save it under the same file that we previously created as *EVS calculations*.

Analyzing the results

- Click on the **Plot** tab (**Plot**). You will see a plot of the predicted mean value of the depth of the deepest pit, x_m and the plots of values $x_m - \sigma$ and $x_m + \sigma$, where σ is the standard deviation of x_m .



As previously noted, only the points in black mean that were used for predicting propagation of corrosion damage. The red diamonds mean that were not taken into account for the calculation and are shown only for demonstrating the accuracy of prediction.

Calculation including Groups 01 to 08

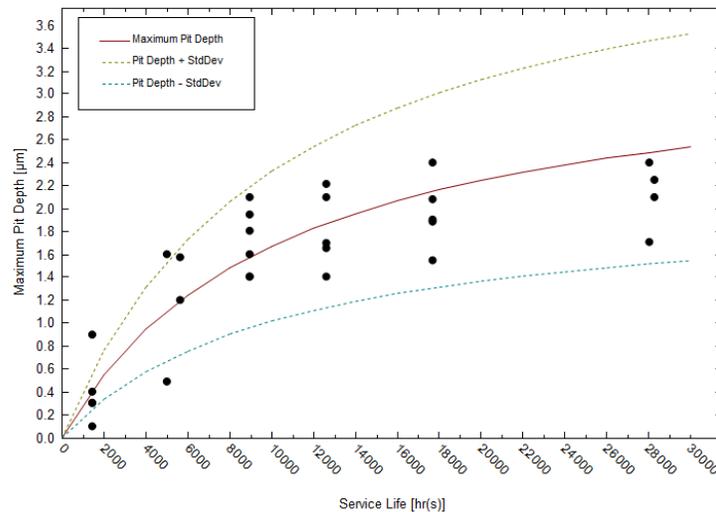
18. **Check** the boxes for Group 01 to 08

19. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

20. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. Save it under the same file that we previously created as *EVS calculations*.

Analyzing the results

21. Click on the **Plot** tab ( **Plot**).



The plot above show how the predicted results improved with increasing number of subsequent inspections.

Note: The predictions can be substantially improved if they were obtained on the same part of the pipe where conditions are approximately the same.

22. Click on the **Report** tab, and to the **Calculation Results** table.

You can see here that at 30,000 hours the maximum pit depth predicted is $1.55 \mu\text{m} \leq 2.54 \mu\text{m} \leq 3.53 \mu\text{m}$.

Example 59: Predicting the Pit Depth with Insufficient Data

In some cases, the data that provided by the user may be insufficient for reliable prediction of corrosion damage. The table below, shows experimental data (obtained from Laycock et al. 1990) for depths of the deepest pits that were measured on 316L coupons (2 x 2 x 1/2 in) in a 10% ferric chloride solution at 50 °C.

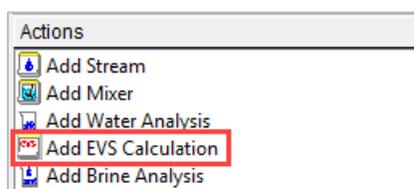
Pit Depth Data for an area of $s = 25.8 \text{ cm}^2$, depth in μm

Sample	Grp 1	Grp 2	Grp3	Grp 4	Grp 5	Grp 6	Grp 7	Grp 8	Grp 9
	40.5 h	144.17 h	215.33 h	292.5 h	331.0 h	378.5 h	453.25 h	477.0 h	528.0 h
1	775	1326	1036	912	1361	1613	2101	1722	1714
2		1176	1199	1173	1534	1641	2024	1798	1767
3								1496	1775

Calculation the Depth of the Deepest Pit

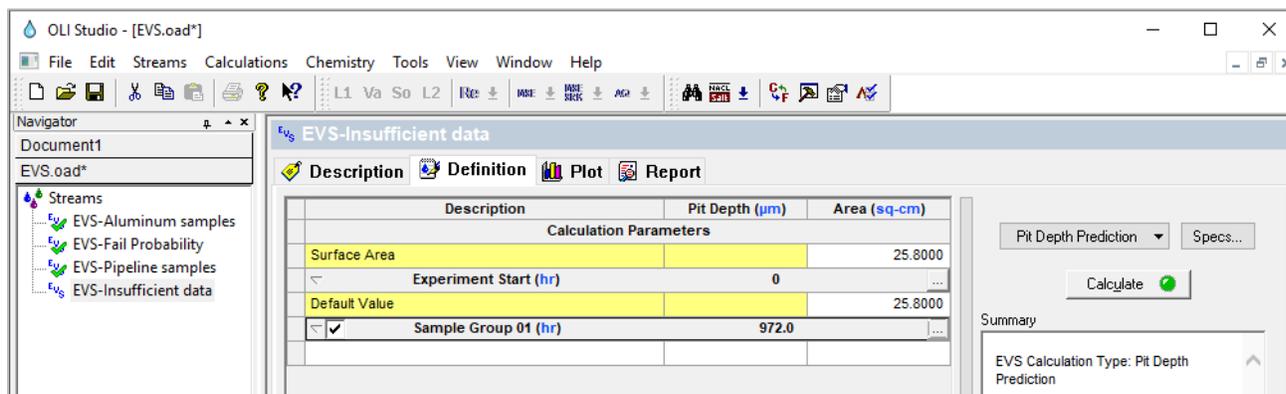
Starting the Simulation

1. Add a new **EVS** calculation. Select the **Add EVS Calculation** icon in the Actions Pane



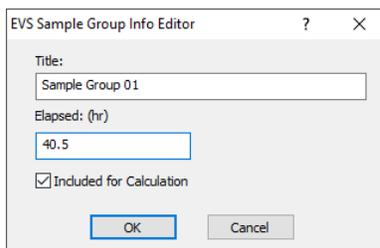
2. **Click** on the new EVS calculation and press **<F2>** to change the name to *EVS-Insufficient Data*. Notice that the default calculation is the *Pit Depth Prediction*.
3. Under the **Calculation Parameters** grid, enter 25.8 cm^2 for the **Surface Area** and **Default Value** cells.
4. Since the data is in hours, click on the blue hyperlink **day** and change it to hours (**hr**) (for both: The **Experiment Start** and the **Sample Group**).

Your screen should look like the image below:



There are experimental data sets for 9 different periods of time. This means that we need to enter 9 different sample groups.

- By default, **Sample group 01** is created. Click on the  button to edit this field. This will open a new window.
- Leave** the default name as **Sample Group 01**, enter the number **40.5** for the number of **elapsed hours**, and **check** the box **'Include for Calculation'**



- Enter the **Pit Depth** data (second column) obtained for 40.5 hours.

Now we need to add 8 more groups.

- Click on the **Add Group** button (located at the bottom of the window. This will open a new window.
- Leave** the default name as **Sample Group 02**, enter the number 144.17 for the number of **elapsed hours**, and **check** the box **'Include for Calculation'**. Then click **OK**.
- Enter the **Pit Depth** data (second column) obtained for 144.17 hours.
- Click on the **Add Group** button, and repeat the same procedure for the rest of the experimental data (groups)

Once you have entered all the experimental data, your screen should look like the image below.

Description	Pit Depth (µm)	Area (sq-cm)
Calculation Parameters		
Surface Area		25.8000
Experiment Start (hr)	0	
Default Value		25.8000
Sample Group 01 (hr)	40.5	
1	775.000	25.8000
2		
Sample Group 02 (hr)	144.17	
1	1326.00	25.8000
2	1176.00	25.8000
Sample Group 03 (hr)	215.33	
1	912.000	25.8000
2	1173.00	25.8000
Sample Group 04 (hr)	292.5	
1	912.000	25.8000
2	1173.00	25.8000
Sample Group 05 (hr)	331.0	
1	1361.00	25.8000
2	1534.00	25.8000
Sample Group 06 (hr)	378.5	
1	1613.00	25.8000
2	1641.00	25.8000
Sample Group 07 (hr)	453.25	
1	2101.00	25.8000
2	2024.00	25.8000
Sample Group 08 (hr)	477.0	
1	1722.00	25.8000
2	1786.00	25.8000
3	1496.00	25.8000
Sample Group 09 (hr)	528.0	
1	0.0	25.8000

At this point, the experimental data has been entered. Now we need define the period of time for which we want to do the prediction of failure due to pitting.

12. **Click** on the **Specs** button. This will open a new window.

13. Under the **Survey Range** tab, enter the range for **Pit Depth Prediction** as follows: Start=0 hours, End=580 hours, and number of steps=50 hours. Then click **OK**

The screenshot shows the 'EVS Calculation Options' dialog box with the 'Survey Range' tab selected. The 'Pit Depth Prediction Range' section has a 'Unit' dropdown set to 'hr'. Below it, the 'Selected Range' list contains one entry: '0.0 to 580.0 in 50 steps of 11.6'. To the right of this list are 'New' and 'Delete' buttons. Underneath, there are three radio buttons: 'Linear' (selected), 'Log', and 'Point List'. The 'End Points' section has 'Start' set to '0.0' and 'End' set to '580.000'. The 'Step Size' section has 'Increment' set to '11.6000' and 'Number Steps' set to '50'. A note next to these fields says 'Select one, the other is calculated'. At the bottom of the dialog are 'OK', 'Cancel', 'Apply', and 'Help' buttons.

Before running the calculation, we are going to study two different cases:

- I. The first case will include the experimental data from groups 01 to 03
- II. The second case will include all the experimental data from groups 01 to 09

Calculation including Groups 01 to 03

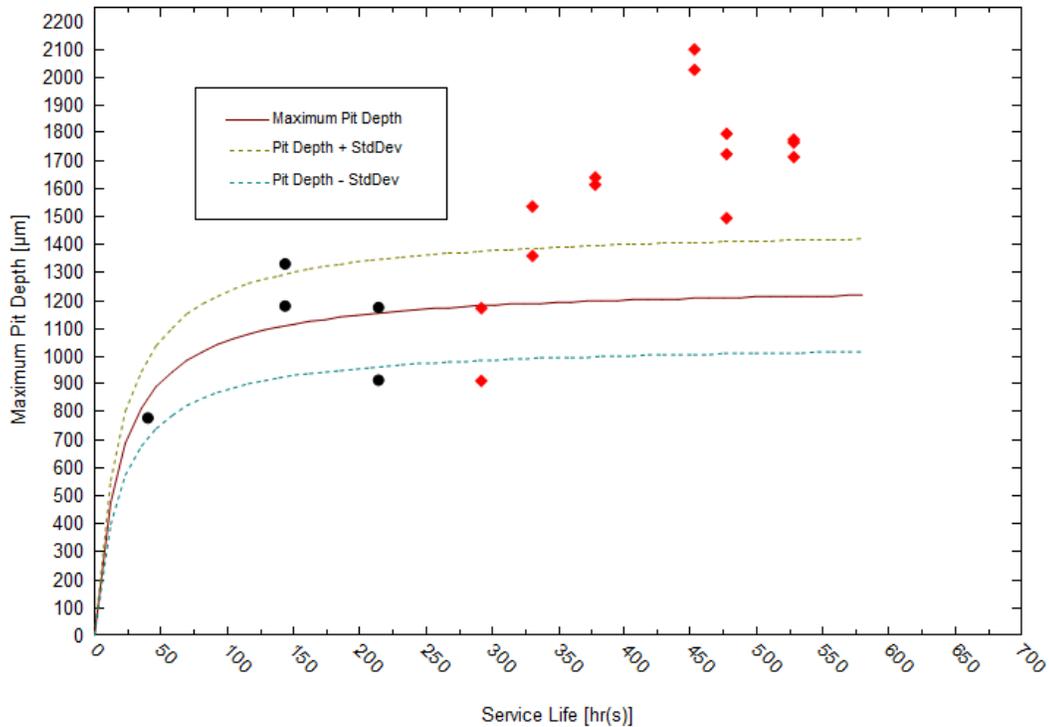
14. **Check** the boxes for Group 01 to 03

15. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

16. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. Save it under the same file that we previously created as *EVS calculations*.

Analyzing the results

17. Click on the **Plot** tab ( **Plot**).



We see that in this case the prediction cannot be considered satisfactory. The reason is that for the first, second, and third observation times the observed mean value of deepest pit decreases. Obviously, such behavior of maximum pit depth has no physical foundation. Generally speaking, such situation is the result of an insufficient numbers of experiments (used coupons) for given observation times. Accordingly, we can expect that after increasing the number of used coupons the situation can improve.

Calculation including Groups 01 to 09

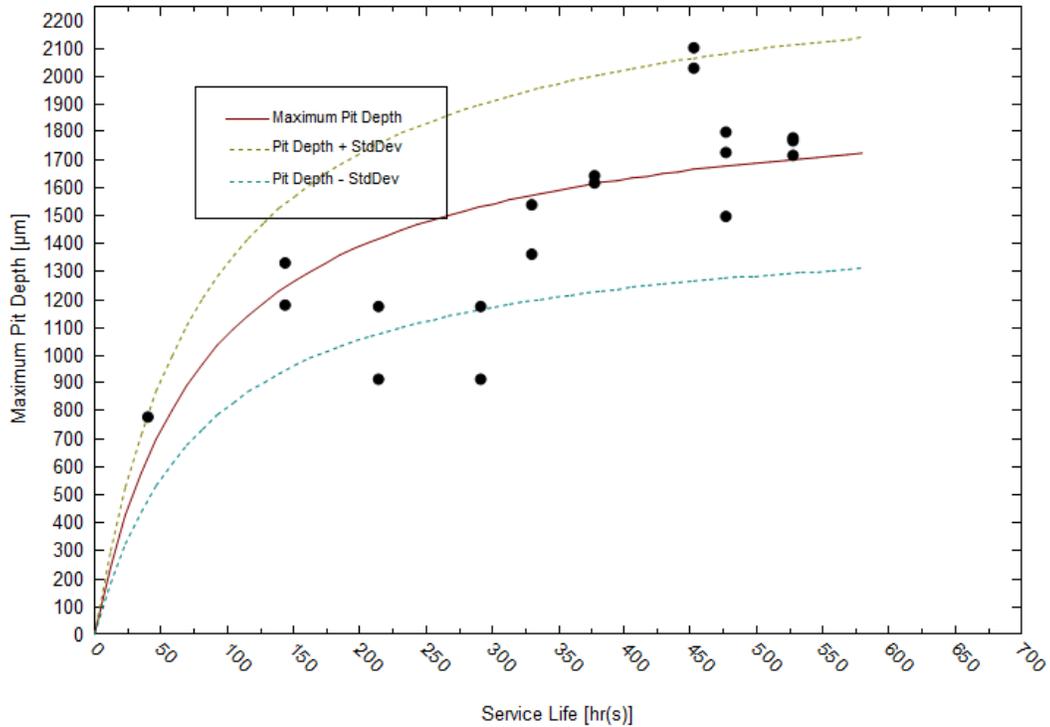
18. **Check** the boxes for Group 01 to 09

19. We are now ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

20. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. Save it under the same file that we previously created as *EVS calculations*.

Analyzing the results

21. Click on the **Plot** tab ( Plot).



The plot above show how the predicted results improved with increasing number of subsequent inspections.

The plot above also shows that the results of approximation of the full set of available experimental data from Laycock et al. 1990) can be reasonably approximated by using EVS approach.

Additionally, these results show that insufficient number of coupons (measurements at given observation times) can be compensated by increasing numbers of observation at different times.

22. Click on the **Report** tab, and to the **Calculation Results** table.

You can see here that at 580 hours the maximum pit depth predicted is $1309.93 \mu\text{m} \leq 1724.09 \mu\text{m} \leq 1724.09 \mu\text{m}$.

Chapter IV – OLI Studio: ScaleChem

ScaleChem is a module within the OLI Studio. A separate license enables this module.

Why Use OLI Studio: ScaleChem?

Scale problems arise when fluid, initially in equilibrium with its environment, is disturbed and becomes unstable. The unstable fluid results in H₂O, CO₂, and H₂S partitioning across the water, oil, and gas phases, corrosion of metal surfaces, and precipitation/dissolution of solids. OLI Studio: ScaleChem recognizes all three effects, which are all important to the oil and gas production professional.

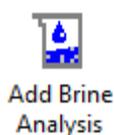
Precipitates form when mineral-forming elements increase the concentration of produced waters beyond supersaturation, or the saturation point. The primary causes of supersaturation are pressure, temperature, phase partitioning, and fluid mixing. OLI Studio: ScaleChem quantifies the effects on mineral scale potential while calculating the physical and chemical properties of fluid and gas phases. Industry professionals can use the software's calculations to help determine the best methods to deal with scaling situations.

OLI Studio: ScaleChem can be used to calculate scaling at one or more user specified temperatures and pressures. Other calculation options include the ability to mix waters at user specified ratios to find compatible waters, and the ability to saturate a water with respect to one or more solids to simulate reservoir conditions.

There are different types of inputs and calculations objects that can be used in OLI Studio: ScaleChem. A brief definition of each type of calculation is given below.

Input Objects

There are three different types of input objects, also referred to as analysis types, in the OLI Studio: ScaleChem software: Brine Analysis, Oil Analysis and Gas Analysis.



OLI Studio: ScaleChem refers to all waters and aqueous samples as brines. This option is added by double clicking on the **Add Brine Analysis**. A brine can be a surface water, an injection water, a formation water, a production water or any other type of aqueous fluid you can create. Brine compositions are entered in terms of ionic concentrations. In addition, the brine pH, total inorganic carbon and alkalinity can also be specified.



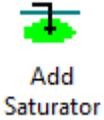
Add Oil Analysis allows you to enter an oil (non-aqueous phase). The oil sample may consist of pure component hydrocarbons (e.g., alkanes), distillation data, pseudocomponent or all three.



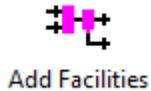
Add Gas Analysis allows you to enter any hydrocarbon mixture which may or may not contain water, carbon dioxide or hydrogen sulfide. The default hydrocarbon is methane (CH₄) but the hydrocarbon list may be expanded to include higher carbon numbers.

Calculation Objects

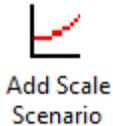
There are five different types of calculations that can be carried out in OLI Studio: Stream Analyzer: Single point, Survey (multiple point), Water Analysis, Mixer, and Chemical Diagram calculations. A brief definition of each type of calculation is given below.



Add Saturator object combines fluids at the specified temperature and pressure and saturates the combined phases with the selected minerals.



Add Facilities mixes and separates fluids. It is used to simulate production operations.



Add Scale Scenario object calculates the scaling of minerals from a fluid as temperature and pressure changes, e.g. at different production locations during production.



Add Scale Contour object calculates the scaling of minerals from a fluid over a matrix of temperature and pressure. It creates a 2D contour plot visual.



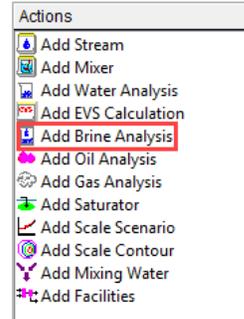
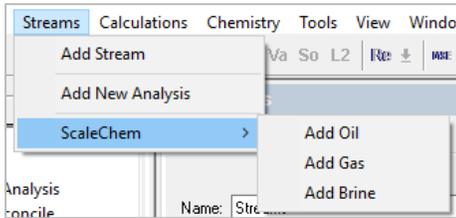
Add Mixing Water object mixes two potentially incompatible brines together to identify at what ratios the scale will form.

In these chapter we will model a hypothetical field and learn how to use and set up each one of the objects presented above.

Section 11. Entering a Brine Analysis in OLI Studio: ScaleChem

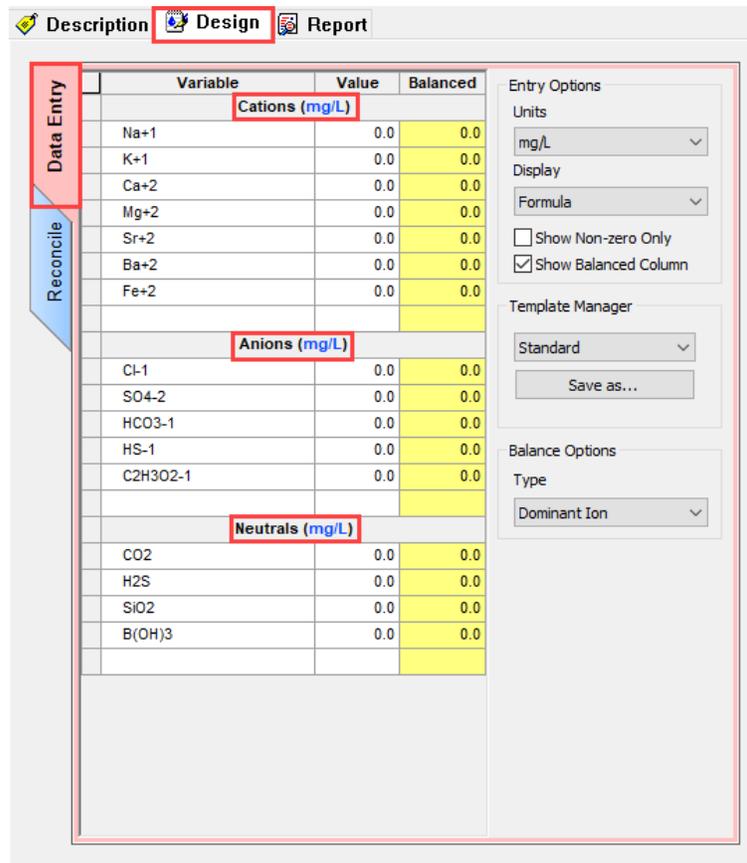
11.1. Entering Data for a Brine Analysis

To add a **Brine Analysis**, go to the toolbar menu and click on **Streams > ScaleChem > Add Brine**, or by selecting the **Add Brine Analysis** icon in the Actions Pane.



You will see three different tabs for this analysis. The **Description**, **Design** and **Report** tab.

The Brine Analysis open in the **Design**, which has 2 different sub-tabs: **Data Entry** and **Reconcile**, where we need to enter the laboratory analysis information.



The image shows a screenshot of the 'Design' tab in OLI Studio for a Brine Analysis. The 'Data Entry' sub-tab is active. The main area contains a table with columns 'Variable', 'Value', and 'Balanced'. The table is divided into three sections: 'Cations (mg/L)', 'Anions (mg/L)', and 'Neutrals (mg/L)'. The 'Cations' section lists Na+1, K+1, Ca+2, Mg+2, Sr+2, Ba+2, and Fe+2. The 'Anions' section lists Cl-1, SO4-2, HCO3-1, HS-1, and C2H3O2-1. The 'Neutrals' section lists CO2, H2S, SiO2, and B(OH)3. All values are 0.0 and all 'Balanced' cells are 0.0. On the right side, there are 'Entry Options' (Units: mg/L, Display: Formula, Show Non-zero Only: unchecked, Show Balanced Column: checked), 'Template Manager' (Standard, Save as...), and 'Balance Options' (Type: Dominant Ion).

Variable	Value	Balanced
Cations (mg/L)		
Na+1	0.0	0.0
K+1	0.0	0.0
Ca+2	0.0	0.0
Mg+2	0.0	0.0
Sr+2	0.0	0.0
Ba+2	0.0	0.0
Fe+2	0.0	0.0
Anions (mg/L)		
Cl-1	0.0	0.0
SO4-2	0.0	0.0
HCO3-1	0.0	0.0
HS-1	0.0	0.0
C2H3O2-1	0.0	0.0
Neutrals (mg/L)		
CO2	0.0	0.0
H2S	0.0	0.0
SiO2	0.0	0.0
B(OH)3	0.0	0.0

We will start in the **Data Entry** (red) sub-tab. Here you enter the concentration of Cations, Anions, and Neutrals. This sub-tab comes already prepopulated with some of the most common cations, anions, and neutrals species found in laboratory water/brine analyses (by default the units are in **mg/L**). If your species is not present in the prepopulated grid, simply click on the white grid and type the ion or neutral of interest. If it is a **cation**, type the element followed by a plus (+) sign and the corresponding oxidation state, e.g. Cu+2. If it is an **anion**, type the element followed by a minus (-) sign and the corresponding oxidation state, e.g. Br-1. If it is a **neutral**, simple type the species either using the formula name or its name, as has been shown in the previous sections.

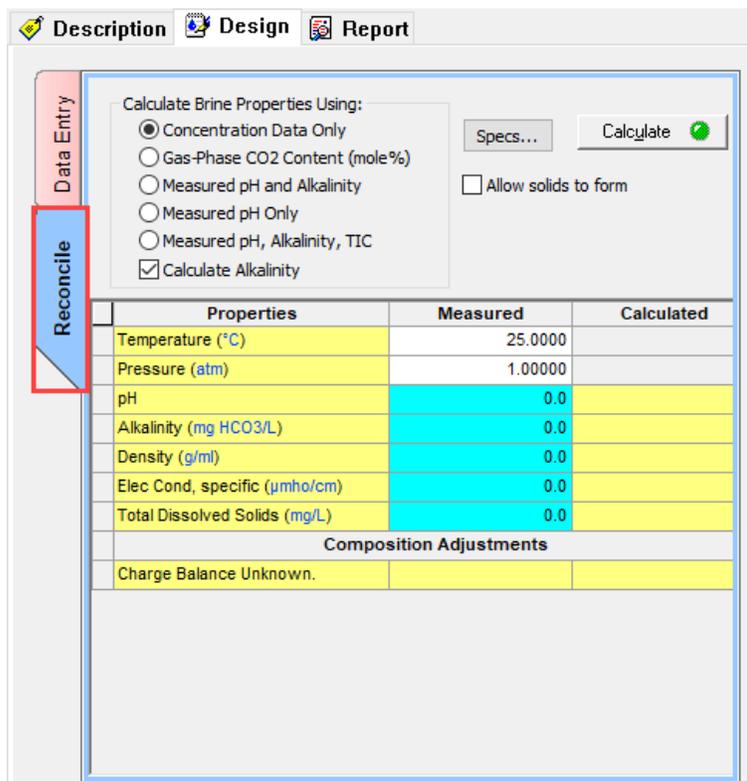
The Brine Analysis grid also contains search aids to find a specific cation, anion or neutral species. The first search aid is the drop list located in each the cation, anion, and neutral grid sections. The list is alphabetic and is activated using the drop-down arrow within the cell, after the first few letters of the ion is typed.

The screenshot shows the 'Data Entry' sub-tab with a table for 'Cations (mg/L)'. A search dropdown is open for the entry 'Cu', showing a list of suggestions. The suggestions include 'Cs+1', 'CSION', 'CUIION', 'Cu(+)', 'Cu(++)', 'Cu(+1)', and 'Cu(+2)'. The 'CUIION' entry is highlighted. To the right of the table, there are 'Entry Options' (Units: mg/L, Display: Formula, Show Non-zero Only: unchecked, Show Balanced Column: checked), 'Template Manager' (Standard, Save as...), and 'Balance Options' (Type: Dominant Ion).

If a name is misspelled or if the text is unrecognized, then a red 'X' appears to the left of the name. This name needs to be corrected or the row deleted before proceeding. To delete the row, simply select the wrong entry (which will turn black) and hit the key **<Delete>**.

The screenshot shows a portion of the 'Neutrals (mg/L)' grid. The entries are CO2, H2S, SiO2, B(OH)3, and 'oli'. The 'oli' entry has a red 'X' in the first column and a black background, indicating it is unrecognized or misspelled.

The **Reconcile** sub-tab is used to define the measured properties of the brine. In this **Reconcile** sub-tab, we will tell the software how to reconcile the brine.



The first step, however, is to enter the brine measured properties and conditions. To do this we need to start in the **Properties | Measured | Calculated** table.

Properties	Measured	Calculated
Temperature (°C)	25.0000	
Pressure (atm)	1.00000	
pH	0.0	
Alkalinity (mg HCO ₃ /L)	0.0	
Density (g/ml)	0.0	
Elec Cond, specific (µmho/cm)	0.0	
Total Dissolved Solids (mg/L)	0.0	
Composition Adjustments		
Charge Balance Unknown.		

By default, the values of temperature, and pressure are 25°C and 1 atm. The **aqua-blue** cells indicate the values that you need to enter if they were measured at the temperature and pressure specified, these are: Measured pH, Measured Alkalinity¹¹, Density, Specific Electrical Conductivity and Total Dissolved Solids (TDS).

You can always change the units of these properties by clicking on the units highlighted in **blue**. This action will open the Units Manager Window.

¹¹ This is generally a reliable value, unless solids have precipitated in the sample. Alkalinity is often but not always the same value as the bicarbonate ion (HCO₃⁻). OLI Studio: ScaleChem can reconcile on a measured alkalinity by adjusting the solution composition.

If you don't have a measured property value, let's say for example, the Specific Electrical Conductivity, just leave it blank.

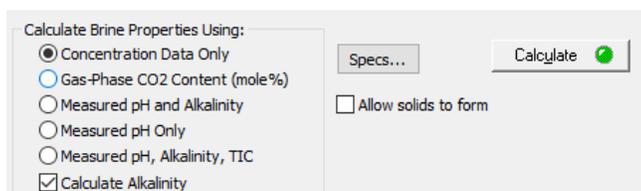
The yellow cells, under the **Calculated** column, will contain calculated values by the software and will be shown once the simulation is run.

When reviewing laboratory analysis of brine samples, it is quite common for the positive ions (cations) and the negatively charged ions (anions) in solution to not balance. This may be due to the precision limits of the various experimental procedures used to measure the ions - i.e. some ions may not have been analyzed. These solutions must have a neutral charge. OLI Studio: ScaleChem will adjust/modify inflows in order to balance the charges and make the solution neutral. This adjusting procedure is referred to as **Reconciliation**.

There are 5 different types of **Reconciliation Options**:

- a) Concentration Data Only
- b) Gas-phase CO₂ content (mole%)
- c) Measured pH and Alkalinity
- d) Measured pH Only
- e) Measured pH, Alkalinity, TIC

Additionally, there is the option to calculate the alkalinity value by checking the **Calculate Alkalinity** box.



When the Reconciliation Option is selected, the software will calculate the properties of the brine

A more detailed description of each reconciliation option is given in Section 11.3. Reconciliation Options in the Brine Analysis below.

11.2. Brine Analyses - Reporting Elements

Brine analysis data obtained from ICP measurements will contain concentrations for B, P, S, and Si. These elements do not exist in the water, rather they exist as dissolved ions. If they are part of your analysis, then you should convert them to the following before entering them into the Brine Analyses object.

Converting element concentration to species for Brine Analysis

ICP data	Aqueous Species	Formula to enter	Formula weight multiplier
B, boron	Boric Acid	H ₃ BO ₃	B (mg/l) × 5.72 = H ₃ BO ₃ (mg/l)
Si, Silicon	Silica	SiO ₂	Si (mg/l) × 2.14 = SiO ₂ (mg/l)
P, Phosphorus	Dihydrogen Phosphate	H ₂ PO ₄ -1	P (mg/l) × 3.13 = H ₂ PO ₄ (mg/l)
S, Sulfur	Sulfate or Sulfide	HS-1 or SO ₄ -2 (cannot tell from total S only)	S (mg/l) × 1.03 for HS-1 (mg/l) or S (mg/l) × 3.0 for SO ₄ -2 (mg/l)

11.3. Reconciliation Options in the Brine Analysis - Definitions

When reconciling a Brine Analysis, there are five options for reconciliation:

- 1. Concentration Data Only:** The software will run an electroneutrality reconciliation only, and then compute the water properties such as pH, density, etc., based on the entered concentration of neutral, cations, and anions species. In the **Concentration Data Only** option you may allow the program to pick the species to adjust for electroneutrality or you may manually choose the species to perform the adjustment. ([See electroneutrality options](#)).
- 2. Gas-phase CO₂ content (mole%):** Frequently it is simpler and more stable to measure the gas-phase CO₂ that is separated from the brine at the sampling point. When matched with another measured variable, usually alkalinity, the concentration of the carbonate species and the pH can be calculated. OLI Studio: ScaleChem performs a CO₂ gas fraction calculation by taking the P_{CO₂} and the calculated alkalinity (based on the water analysis data) to reconcile the system for pH and carbonate properties. The CO₂ is adjusted to match a saturated gas composition.
- 3. Measured pH Only:** Many brines analyses report a measured pH. This pH may or may not match the pH calculated by the software. The cause may be an incomplete and/or inaccurate brine description. The software will run both an electroneutrality and pH reconciliation. This type of reconciliation will match your recorded pH. Additionally, the software will compute the water properties such as, density, electrical conductivity, etc. The pH of the solution is automatically adjusted by the software by adding either HCl or NaOH, or you may select your preferred acids and bases to adjust the pH.
- 4. Measured pH and Alkalinity:** The purpose of the Measured pH and Alkalinity reconciliations is to match the computed pH and alkalinity values with those you measured (TIC is unknown). The software will run an electroneutrality, pH and alkalinity reconciliation. Additionally, the software will compute the water properties such as density, electrical conductivity, etc. The pH of the solution is automatically adjusted by the software by adding either HCl or NaOH or you may select your preferred acids and bases to adjust the pH. The Alkalinity is automatically calculated by the software, using CO₂ as the alkalinity titrant, H₂SO₄ as the alkalinity pH titrant and 4.5 as the alkalinity end point pH. You can also change a different alkalinity pH titrant if you prefer. However, you cannot change the CO₂ as the alkalinity titrant for the alkalinity adjustment.
- 5. Measured pH, Alkalinity, TIC:** The purpose of this reconciliation is to match the measured pH, alkalinity and Total Inorganic Carbon (TIC). The pH of the solution is automatically adjusted by the software by adding either HCl or NaOH or you may select your preferred acids and bases to adjust the pH. The TIC is automatically calculated by the software, using CO₂ as the alkalinity titrant, H₂SO₄ as the alkalinity pH titrant and 4.5 as the alkalinity end point pH. The (total) Alkalinity is adjusted by the software by adjusting the acetate concentration (organic acids) to match the target Alkalinity. The Alkalinity is adjusted by adding or removing Acetic Acid. In this calculation, you cannot change the CO₂ or Acetic Acid for the alkalinity adjustment, these are fixed by the software.

Additionally, there is the option to **Calculate Alkalinity**: Calculate Alkalinity . It is important to note, that this is only an alkalinity calculation based on the concentration entered, it is not an alkalinity reconciliation.

We will explore the different types of reconciliation and introduce the different specification options according to the reconciliation type.

11.4. A Basic Brine Analysis

A brief introduction to the brine analysis tool will be shown in the example below. As we go through the example, the basic definitions, functionalities and reporting for the *Brine Analysis object* will be shown.

Example 60: Basic Brine Analysis

In this example, we will input dissolved species concentrations and other measured properties into a **Brine Analysis** object to model a hypothetical water sample. Will calculate the **pH** and **scaling tendency** of a brine sample based upon its measured composition at 1 atm and 25 °C.

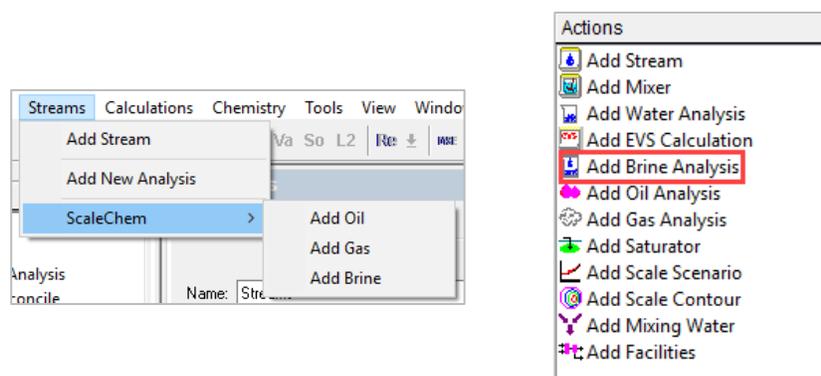
Starting the Simulation

Use the inputs and parameters from the table below to create the brine analysis. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Brine Analysis Composition							
Cations (mg/L)		Anions (mg/L)		Neutrals (mg/L)		Measured Properties	
Na+1	20400	Cl-1	37000	CO2	150	pH	7.1
K+1	400	SO4-2	2200	H2S	15	Alkalinity as HCO3-, mg/L	715
Ca+2	3800	HCO3-1	0				
Mg+2	830	HS-1	0				
Sr+2	15	C2H3O2-1	715				
Ba+2	0.7						
Fe+2	10						

Setting the Water Analysis

1. Add a **Brine Analysis**. Go to the toolbar menu and click on **Streams > ScaleChem > Add Brine**, or by selecting the **Add Brine Analysis** icon in the Actions Pane



2. **Click** on the new Brine and press **<F2>** to change the name to *Brine Analysis*
3. Select the **AQ** thermodynamic Framework (default)
4. **Click** on the **Names Manager** Icon and select the **Formula** option (default)
5. **Click** on the **Units Manager** Icon, and select Metric, Concentration (default)
6. Under the **Design** Tab, enter the **Cation**, **Anion**, and **Neutrals** composition given in the table above. Your screen should look like the image below:

Description Design Report

Data Entry

Variable	Value	Balanced
Cations (mg/L)		
Na+1	20400.0	20400.0
K+1	400.000	400.000
Ca+2	3800.00	3800.00
Mg+2	830.000	830.000
Sr+2	15.0000	15.0000
Ba+2	0.700000	0.700000
Fe+2	10.0000	10.0000
Anions (mg/L)		
Cl-1	37000.0	38949.0
SO4-2	2200.00	2200.00
HCO3-1	720.000	720.000
HS-1	0.0	0.0
C2H3O2-1	0.0	0.0
Neutrals (mg/L)		
CO2	150.000	150.000
H2S	15.0000	15.0000
SiO2	0.0	0.0
B(OH)3	0.0	0.0

Entry Options

Units: mg/L

Display: Formula

Show Non-zero Only

Show Balanced Column

Template Manager

Standard

Save as...

Balance Options

Type: Dominant Ion

- Dominant Ion
- Prorate Cation
- Prorate Anion
- Makeup Ion

Summary

Unit Set: Metric (mass concentration)

Automatic Chemistry Model

Aqueous (H+ ion) Databanks:

Aqueous (H+ ion)

No Solid phase(s)

Using K-fit Polynomials

T-span: 25.0 - 225.0

P-span: 1.0 - 1500.0

Stream Parameters:

Temperature (°C)	25.0000
Pressure (atm)	1.00000
Stream amount (L)	1.00000

Dominant Ion Charge Balance (eq/L):

Cation Charge	1.15621
Anion Charge	-1.10124
Imbalance	0.0549756

Ion(s) needed to balance (mg/L):

Cl-1	1949.049
------	----------

Concentration Data Only.

Note: It is highly unusual for the data to be electrically neutral. Therefore, the software reconciles the sample for **electroneutrality**. After entering each species concentrations, you will notice that the software shows a yellow column named **Balanced**. The software balances charges according to the selected option and displays this in the yellow column.

There are 4 different Balance Options:

- 1) **Dominant Ion:** This is the default method. The largest counter ion is used to adjust the electroneutrality. In our example, 1949.049 mg/L of Cl-1 are added since there is an excess of positive charge (see the above image).
- 2) **Prorate Cations:** All cations are adjusted up or down equally
- 3) **Prorate Anions:** All anions are adjusted up or down equally
- 4) **Make-up Ion:** This option allows for a single ion species to be adjusted. User selects an ion to increase or decrease.
- 5) Under the **Design** Tab, enter the **Cation, Anion, and Neutrals** composition given in the table above.
7. Select **Dominant Ion** as balance option
8. Click on the **Reconcile** (vertical blue tab)

Notice that there that five different types of reconciliation are available in in the upper left corner of the window (see image below). Also, you can see the **Calculate Alkalinity box** (Calculate Alkalinity) option, which allows you to compute the alkalinity, based on the concentration entered.

9. **Select the Concentration Data Only** option. This option means that the software will compute the water properties based on the current concentration of neutral, cations, and anions species. The calculation will not use the measured pH, or the measured alkalinity entered (if any).

10. Enter the **measured properties**: pH = 7.1 and Alkalinity = 715 as mg HCO₃/L

The screenshot shows the 'Reconcile' window with the following data:

Properties	Measured	Calculated
Temperature (°C)	25.0000	
Pressure (atm)	1.00000	
pH	7.10000	
Alkalinity (mg HCO ₃ /L)	715.000	
Density (g/ml)	0.0	
Elec Cond, specific (µmho/cm)	0.0	
Total Dissolved Solids (mg/L)	0.0	

Summary Panel:

Unit Set: Metric (mass concentration)

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 No Solid phase(s)
 Using K-fit Polynomials
 T-span: 25.0 - 225.0
 P-span: 1.0 - 1500.0

Stream Parameters:

Temperature (°C)	25.0000
Pressure (atm)	1.00000
Stream amount (L)	1.00000

Dominant Ion Charge Balance (eq/L):

Cation Charge	1.15621
Anion Charge	-1.10124
Imbalance	0.0549756

Ion(s) needed to balance (mg/L):

Cl-1	1949.049
------	----------

Concentration Data Only.

11. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

12. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. Create a new file and name it: *ScaleChem Analysis Calculations*.

Analyzing the Results

Once the calculation is done, the **Calculated** column displays the results obtained based on the concentrations entered in the **Data Entry** tab. Notice that the calculated results are pH=6.22 and Alkalinity=669 mg HCO₃-1/L vs the measured values of pH=7.1 and Alkalinity=715 mg HCO₃-1/L.

The screenshot shows a software interface with three tabs: Description, Design, and Report. The 'Data Entry' tab is active, displaying a 'Reconcile' section with a table and a 'Calculate' button. The table compares measured and calculated values for various properties. The 'Summary' box on the right provides detailed parameters and calculated results.

Properties	Measured	Calculated
Temperature (°C)	25.0000	
Pressure (atm)	1.00000	
pH	7.10000	6.22113
Alkalinity (mg HCO ₃ /L)	715.000	668.837
Density (g/ml)	0.0	1.04497
Elec Cond, specific (µmho/cm)	0.0	91767.6
Total Dissolved Solids (mg/L)	0.0	N/A
Composition Adjustments		
Add Charge Balance (mg/L Cl-1)		1949.05

Summary

Unit Set: Metric (mass concentration)

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
No Solid phase(s)
Using K-fit Polynomials
T-span: 25.0 - 225.0
P-span: 1.0 - 1500.0

Stream Parameters:

Temperature (°C)	25.0000
Pressure (atm)	1.00000
Stream amount (L)	1.00000

Dominant Ion Charge Balance (eq/L):

Cation Charge	1.15621
Anion Charge	-1.10124
Imbalance	0.0549756

Ion(s) needed to balance (mg/L):

Cl-1	1949.049
------	----------

Concentration Data Only.

Phase Amounts:

Aqueous (g)	1044.97
Vapor (g)	0.0

Aqueous Phase Properties:

pH	6.22113
Ionic Strength (mol/mol)	0.0226505
Density (g/ml)	1.04497

Calc. elapsed time: 5.687 sec.
Calculation complete

To the right you can see the results summarized in the **Summary Box**.

The top section contains the **Stream Parameters** information. In this example, the software performed the calculation at 25 °C, 1 atm, and a total Stream amount of 1 L.

The **Dominant Ion Charge Balance** section shows the type of balance that was used to reach electroneutrality, which cation/anion was deficient, and how much of it was added.

The **Phase amounts** section shows the distribution of species in the different phases. This analysis contains two phases: aqueous and vapor.

The **Aqueous Phase Properties** information shows the computed pH, ionic strength, and density of the solution. It is important to note here that the measured pH is 7.1 and the computed pH is 6.22. The density of this solution is 1.04497 g/ml. Remember, for this example the software used only the concentration of neutrals, cations and anions in solution to do a reconciliation.

1. Click on the **Report** tab, and scroll down to the **Pre and Post Scaling Tendencies** table.

Pre and Post Scaling Tendencies

Scale Mineral	Pre-scaling	Pre-index	Post-scaling	Post-index
BaSO ₄ (Barite)	9.44533	0.975217	9.44533	0.975217
CaCO ₃ (Calcite)	2.44082	0.387535	2.44082	0.387535
CaSO ₄ .2H ₂ O (Gypsum)	0.938902	-0.0273798	0.938902	-0.0273798
CaSO ₄ (Anhydrite)	0.740543	-0.130450	0.740543	-0.130450
FeCO ₃ (Siderite)	0.178450	-0.748484	0.178450	-0.748484
FeS (Pyrrhotite)	500.789	2.69966	500.789	2.69966
KCl (Sylvite)	6.72458e-4	-3.17233	6.72458e-4	-3.17233
FeS (Mackinawite)	8.54999	0.931965	8.54999	0.931965
NaCl (Halite)	0.0122161	-1.91307	0.0122161	-1.91307
SrCO ₃ (Strontianite)	0.0290888	-1.53627	0.0290888	-1.53627
SrSO ₄ (Celestine)	0.203964	-0.690447	0.203964	-0.690447

From this table, you can see that Barite, Calcite, Pyrrhotite and Mackinawite solids have been predicted to be supersaturated.

For more detailed information about scaling tendencies you can go to Scaling section in page 176.

2. Scroll down to the **Brine Composition** table

Brine Composition

Cations	Value (mg/L)	Anions	Value (mg/L)	Neutrals	Value (mg/L)
K(+1)	400.000	Cl(-1)	38949.0	CO ₂	158.990
Na(+1)	20400.0	HCO ₃ ⁻ (*)	707.535	H ₂ S	14.9948
Ba(+2)	0.700000	SO ₄ ⁻²	2203.08		
Ca(+2)	3800.00				
Fe(+2)	10.0000				
Mg(+2)	830.000				
Sr(+2)	15.0000				

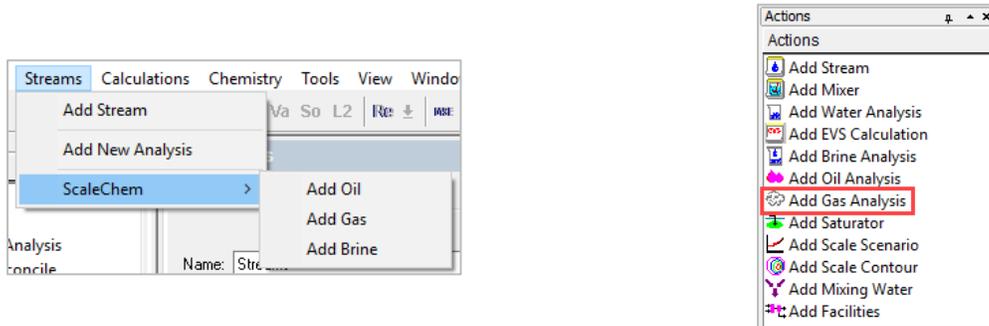
This table shows the composition of the brine after the reconciliation (calculation) has taken place.

Concentration Only, etc. reconciliation options

Section 12. Entering a Gas Analysis in OLI Studio: ScaleChem

12.1. Entering Data for a Gas Analysis

To add a **Gas Analysis**, go to the toolbar menu and click on **Streams > ScaleChem > Add Gas**, or by selecting the **Add Gas Analysis** icon in the Actions Pane.



You will see four different tabs for this analysis. The **Description, Design, Definition** and **Report** tab.

The gas analysis opens in the **Design** tab, which has 2 different sub-tabs: **Inflows** and **Reconcile**, where we need to enter the laboratory gas analysis information.

The image shows the OLI Studio interface with the 'Design' tab selected. The 'Inflows' sub-tab is active, showing a table of components and their values. The 'Reconcile' sub-tab is also visible. The table has columns for 'Component', 'Value', and 'Normalized'. The 'Value' column is labeled 'Subtotal: 0.0/100.000 (mole %)' and the 'Normalized' column is labeled 'Subtotal: 100.000/100.000 (mole %)'. The 'CH4' component is checked in the 'Reconcile' sub-tab. The 'Inflows' sub-tab shows a list of components with their values and normalized values. The 'Reconcile' sub-tab shows a list of components with their values and normalized values. The 'Inflows' sub-tab shows a list of components with their values and normalized values. The 'Reconcile' sub-tab shows a list of components with their values and normalized values.

Component	Value	Normalized
Subtotal: 0.0/100.000 (mole %)		
H2O	0.0	0.0
N2	0.0	0.0
CO2	0.0	0.0
H2S	0.0	0.0
CH4	0.0	100.000
C2H6	0.0	0.0
C3H8	0.0	0.0
i-C4H10	0.0	0.0
n-C4H10	0.0	0.0
i-C5H12	0.0	0.0
C5H12	0.0	0.0
C6H14	0.0	0.0
Subtotal: 100.000/100.000 (mole %)		

We will start in the **Data Entry** (red) sub-tab. Here you enter the concentration of a pure-component hydrocarbon gas, in **mole %** units. The standard list of component extents to C6 alkanes.

If there is a component that is not present in the prepopulated grid, simply click on the white grid and type the species of interest, using the formula name or its name, as has been shown in the previous sections. Let's say for example, you want to add Isooctane. Type isooctane or i-C8H18 in the white cell to add it to the list.

There is also the option of using the drop-down arrow, that allows you to search for the specific components you want to add.

The screenshot shows the 'Inflows' section of the software. A table lists components with columns for 'Component', 'Value', and 'Normalized'. A dropdown menu is open for the 'i-C8H18' entry, showing a list of suggestions including 'i-C4H10', 'i-C5H12', 'i-C8H18', 'I2', 'SYN|BA', 'OLI|IRFN7FNF', 'ISOBUTANE', 'IPENTAN', 'MEPNTAN224', 'IOD2EL', 'IBUTYLAMN', and 'IRFN7FNF'. The 'i-C8H18' option is highlighted in blue. To the right, there are control panels for 'Entry Options', 'Template Manager', 'Normalize Options', and 'Group Manager'.

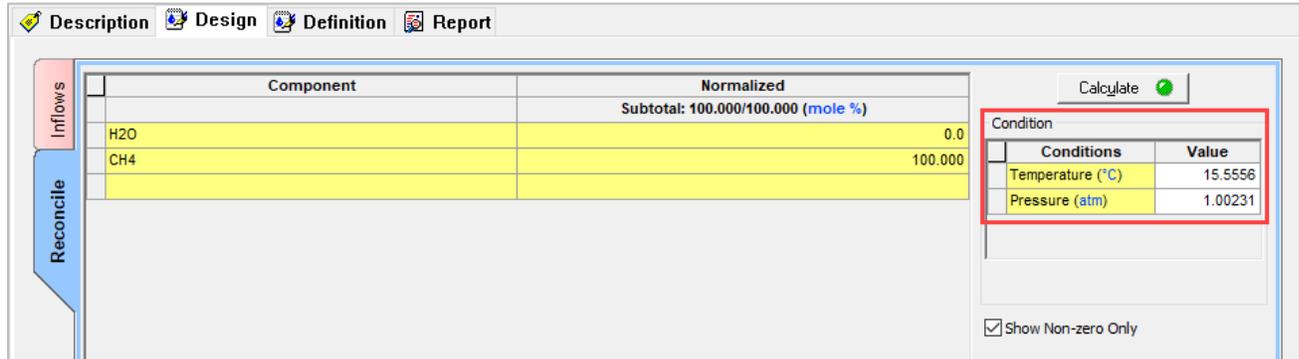
Component	Value	Normalized
Subtotal: 0.0/100.000 (mole %)		Subtotal: 100.000/100.000 (mole %)
H2O	0.0	0.0
CH4	0.0	100.000
N2	0.0	0.0
CO2	0.0	0.0
H2S	0.0	0.0
C2H6	0.0	0.0
C3H8	0.0	0.0
i-C4H10	0.0	0.0
n-C4H10	0.0	0.0
i-C5H12	0.0	0.0
C5H12	0.0	0.0
C6H14	0.0	0.0
i-C8H18	0.0	0.0

If a name is misspelled or if the text is unrecognized, then a red 'X' appears to the left of the name. This name needs to be corrected or the row deleted before proceeding. To delete the row, simply select the wrong entry (which will turn black) and hit the key <Delete>.

The screenshot shows the same software interface as above, but the 'OLI' entry in the component list is now highlighted in black and has a red 'X' icon to its left, indicating it is unrecognized or misspelled. The rest of the interface remains the same.

Component	Value	Normalized
Subtotal: 0.0/100.000 (mole %)		Subtotal: 100.000/100.000 (mole %)
H2O	0.0	0.0
CH4	0.0	100.000
N2	0.0	0.0
CO2	0.0	0.0
H2S	0.0	0.0
C2H6	0.0	0.0
C3H8	0.0	0.0
i-C4H10	0.0	0.0
n-C4H10	0.0	0.0
i-C5H12	0.0	0.0
C5H12	0.0	0.0
C6H14	0.0	0.0
i-C8H18	0.0	0.0
OLI	0.0	0.0

The **Reconcile** sub-tab is used to calculate the properties of the gas at the temperature and pressure conditions specified. By default, the values of temperature, and pressure are 60 °F (15.56°C) and 14.7 psia (1 atm).



12.2. A Basic Gas Analysis

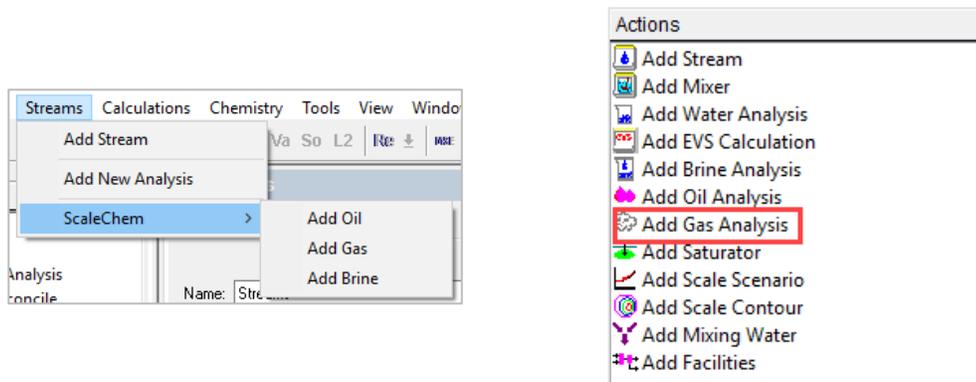
A brief introduction to the gas analysis tool will be shown in the example below. As we go through the example, the basic definitions, functionalities and reporting for the *Gas Analysis object* will be shown.

Example 61: Basic Gas Analysis

The Gas Analysis object provides a quick way to enter a pure-component hydrocarbon gas.

Setting the Gas Analysis

1. **Add a Gas Analysis.** Go to the toolbar menu and click on **Streams > ScaleChem > Add Gas**, or by selecting the **Add Brine Analysis** icon in the Actions Pane



2. **Click** on the new Gas and press **<F2>** to change the name to *Gas Analysis*
3. Select the **AQ** thermodynamic Framework (default)
4. **Click** on the **Names Manager** Icon and select the **Formula** option (default)
5. **Click** on the **Units Manager** Icon, and select Metric, Concentration (default)
6. Under the **Inflows** Tab, enter the gas composition given in the table below

Gas Analysis Composition		
Formula	Component Name	Mole %
H2O	Water	1.80
N2	Nitrogen	3.00
CO2	Carbon Dioxide	1.50
H2S	Hydrogen Sulfide	0.50
CH4	Methane	65.5
C2H6	Ethane	14.0
C3H8	Propane	8.00
i-C4H10	Isobutane	1.00
n-C4H10	n-Butane	3.00
i-C5H12	Isopentane	0.50
C5H12	n-Pentane	0.70
C6H14	n-Hexane	0.50

Your screen should look like the image below:

The screenshot shows a software interface with a menu bar (Description, Design, Definition, Report) and a main window. On the left, there are vertical tabs for 'Inflows' and 'Reconcile'. The main area contains a table with the following data:

Component	Value	Normalized
Subtotal: 100.000/100.000 (mole %)		Subtotal: 100.000/100.000 (mole %)
H2O	1.80000	1.80000
N2	3.00000	3.00000
CO2	1.50000	1.50000
H2S	0.500000	0.500000
CH4	65.5000	65.5000
C2H6	14.0000	14.0000
C3H8	8.00000	8.00000
i-C4H10	1.00000	1.00000
n-C4H10	3.00000	3.00000
i-C5H12	0.500000	0.500000
C5H12	0.700000	0.700000
C6H14	0.500000	0.500000

On the right side of the interface, there are several control panels:

- Entry Options:** Units (mole %), Display (Formula), Show Non-zero Only, Show Normalized Column.
- Template Manager:** Standard, Save as...
- Normalize Options:** Makeup.
- Group Manager:** Use Groups, Add.

Note: There are several options to the right of the data entered.

- 1) **Entry options:** Here you can select the prefer units, and display name. You also have the options to show the non-zero values only – sometimes the composition of species is zero – and show normalized (yellow) column – this option is useful when the values don't add up to 100 mole%.
 - 2) **Template manager:** Here you can select the standard (default) template or the extended template – which includes hydrocarbons with longer chains. You can also create and save your own template for future use.
 - 3) **Normalize options:** When your analysis does not add up 100 mole% you can select between two options: Make-up and Prorate. For the Make-up option, the default gas used is CH4.
7. Click on the **Reconcile** (vertical blue tab). The reconciliation calculation will be calculated at 15.556 C and 1.00231 atm (standard conditions).

Component	Normalized	Reconciled Gas
	Subtotal: 100.000/100.000 (mole %)	Subtotal: 100.000/100.000 (mole %)
H2O	1.80000	1.75645
N2	3.00000	3.00133
CO2	1.50000	1.50066
H2S	0.500000	0.500221
CH4	65.5000	65.5290
C2H6	14.0000	14.0062
C3H8	8.00000	8.00355
i-C4H10	1.00000	1.00044
n-C4H10	3.00000	3.00133
i-C5H12	0.500000	0.500222
C5H12	0.700000	0.700310
C6H14	0.500000	0.500222

Conditions	Value
Temperature (°C)	15.5556
Pressure (atm)	1.00231

- Now, we are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key
- It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. Create a new file and name it: *ScaleChem Analysis Calculations*.

Analyzing the Results

Once the calculation is done, the **Reconciled Gas** column displays the results at equilibrium conditions.

Component	Normalized	Reconciled Gas
	Subtotal: 100.000/100.000 (mole %)	Subtotal: 100.000/100.000 (mole %)
H2O	1.80000	1.75645
N2	3.00000	3.00133
CO2	1.50000	1.50066
H2S	0.500000	0.500221
CH4	65.5000	65.5290
C2H6	14.0000	14.0062
C3H8	8.00000	8.00355
i-C4H10	1.00000	1.00044
n-C4H10	3.00000	3.00133
i-C5H12	0.500000	0.500222
C5H12	0.700000	0.700310
C6H14	0.500000	0.500222

Conditions	Value
Temperature (°C)	15.5556
Pressure (atm)	1.00231

Summary

Unit Set: Metric (mole fraction)

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 Second Liquid phase
 Using K-fc Polynomials
 T-span: 25.0 - 225.0
 P-span: 1.0 - 1500.0

Stream Parameters:
 Temperature (°C) 15.5556
 Pressure (atm) 1.00231

Makeup Normalization: CH4.

Equilibrium Calculation.

Phase Amounts:
 Aqueous (mol) 0.0443282
 Vapor (mol) 99.9557
 Solid (mol) 0.0
 2nd Liquid (mol) 0.0

Aqueous Phase Properties:
 pH 4.75177
 Ionic Strength (mol/mol) 3.20592e-7
 Density (g/ml) 0.999257

Calc. elapsed time: 0.940 sec.
 Calculation complete

To the right you can see the results summarized in the **Summary Box**.

The top section contains the **Stream Parameters** information. In this example, the software performed an equilibrium calculation at 15.556°C and 1.00231 atm.

The **Phase amounts** section shows the distribution of species in the different phases. This analysis contains two phases: aqueous and vapor.

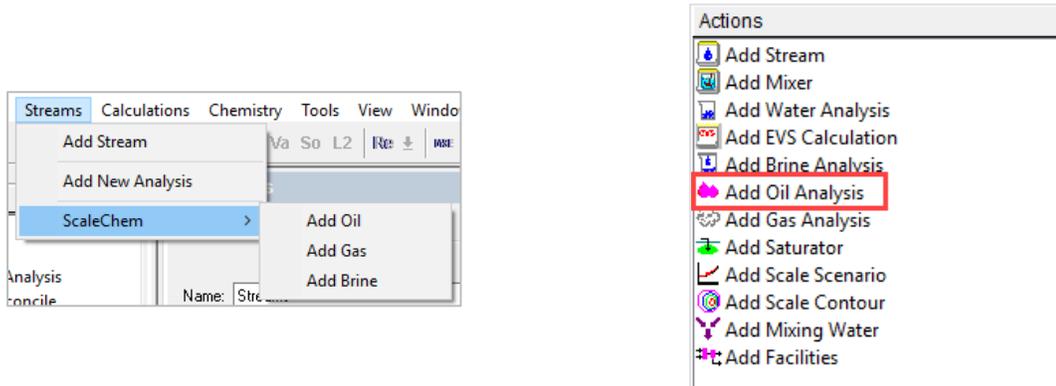
The **Aqueous Phase Properties** information shows the computed pH, ionic strength, and density of the solution.

- Click on the **Report** tab. Here you will see a more complete representation of the results at equilibrium.

Section 13. Entering an Oil Analysis in OLI Studio: ScaleChem

13.1. Entering Data for an Oil Analysis

To add an **Oil Analysis**, go to the toolbar menu and click on **Streams > ScaleChem > Add Oil**, or by selecting the **Add Oil Analysis** icon in the Actions Pane.



You will see four different tabs for this analysis. The **Description, Design, Definition** and **Report** tab.

The oil analysis opens in the **Design** tab, which has 4 different sub-tabs: **Combined, Pseudocomponents, Assay** and **Reconcile**.

In the **Combined** (red) sub-tab, pure components (organic and inorganic) are entered. If there is a component that is not present in the prepopulated grid, simply click on the white grid and type the species of interest, using the formula name or its name, as has been shown in the previous sections. Let's say for example, you want to add Isooctane. Type isooctane or i-C₈H₁₈ in the white cell to add it to the list.

Also, you can use the **show non-zero only** option to hide all the zero values – since they are not needed.

The image shows the OLI Studio Design tab with the 'Combined' sub-tab selected. The main area is a grid with columns for 'Component', 'Value', and 'Normalized'. The 'Value' and 'Normalized' columns are highlighted in yellow. The 'Component' column lists various hydrocarbons. On the right, the 'Entry Options' panel is visible, showing 'Units' set to 'mole %', 'Display' set to 'Formula', and the 'Show Non-zero Only' checkbox checked. The 'Template Manager' is set to 'Standard' and the 'Normalize Options' are set to 'Prorate'.

Component	Value	Normalized
n-C ₄ H ₁₀	0.0	0.0
i-C ₅ H ₁₂	0.0	0.0
C ₅ H ₁₂	0.0	0.0
C ₆ H ₁₄	0.0	0.0
C ₇ H ₁₆	0.0	0.0
i-C ₈ H ₁₈	0.0	0.0
n-C ₈ H ₁₈	0.0	0.0
C ₉ H ₂₀	0.0	0.0
C ₁₀ H ₂₂	0.0	0.0
C ₁₁ H ₂₄	0.0	0.0
C ₁₂ H ₂₆	0.0	0.0
C ₁₃ H ₂₈	0.0	0.0
C ₁₄ H ₃₀	0.0	0.0
C ₁₅ H ₃₂	0.0	0.0
C ₁₆ H ₃₄	0.0	0.0
C ₁₇ H ₃₆	0.0	0.0
C ₁₈ H ₃₈	0.0	0.0
C ₁₉ H ₄₀	0.0	0.0
C ₂₀ H ₄₂	0.0	0.0
C ₂₁ H ₄₄	0.0	0.0
C ₂₂ H ₄₆	0.0	0.0
C ₂₃ H ₄₈	0.0	0.0
C ₂₄ H ₅₀	0.0	0.0
C ₂₅ H ₅₂	0.0	0.0
C ₃₀ H ₆₂	0.0	0.0
C ₃₅ H ₇₂	0.0	0.0
C ₄₀ H ₈₂	0.0	0.0

In the **Pseudocomponents** (blue) sub-tab, you can enter pseudocomponents. Here you need to provide the molecular weight, NBP, SG, Thermodynamic Method and the mole% information.

Component	Molecular Weight	Nomal Boiling Point (°C)	Specific Gravity	Thermo Method	Value (mole %)
<Enter a name>					

In the **Assay** (red) sub-tab, distillation curves can be entered. The Assay screen contains three data entry grids: Component, Entry Options and Distillation Data.

Component	mole %
<Enter a name>	

Entry Options

Type: ASTM D86
 Thermo Method: API-8
 Density: 0.00
 Specific Gravity:
 No. of Cuts: 0

Distillation Data Grid

Volume%	Temperature (°C)

Assay Properties

Name	Mole %	Mol Wt.	NBP (°C)	Sp Gr	Cr Temp (°C)	Cr Pres (atm)	Cr Vol (L/mol)	Acentric Factor

Component Grid: In the component grid you can name your assay. No more than 5 letters are allowed for the name. The mole% instructs the software that the mole% entered represents the total hydrocarbon mass.

Entry Options Grid: In this grid there are four pieces of information that the user needs to fill out: The Assay Type, the Thermo Method, Density and No. of Cuts.

There are four Assay types. These are experimental methods used to create distillation curves.

Entry Options

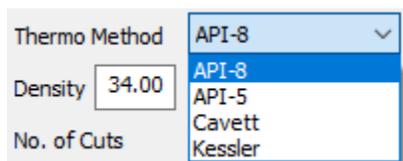
Type: **ASTM D86** (dropdown menu open showing: ASTM D86, ASTM D1160, ASTM D2887, TBP CURVE)

Thermo Method:
 Density: 34.00

- **ASTM D86** runs at atmospheric pressures and is used for all oil types
- **ASTM D1160** runs at vacuum pressure and is used for heavy oils
- **ASTM D2887** runs on a gas chromatograph and is used for light oils
- **TBP** is the true boiling point curve

There are also four methods for calculating thermodynamic properties, referred to as **Thermo Method** in the software, and these are: API-8, API-5, Cavett and Lee-Kessler.

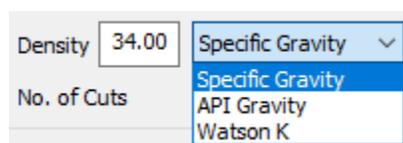
Thermo Method	API-8
Density	34.00
No. of Cuts	



- The **API-8** and **API-5** are methods that use specific gravity to determine critical parameters.
- **Cavett** is a method to determine critical parameters using the API gravity
- **Lee-Kessler** is a method to determine critical parameters by using the Watson K

There are three average bulk density options: Specific Gravity, API gravity and Watson K.

Density	34.00
No. of Cuts	



- **Specific Gravity (SG)** is the ratio of the material density to water. OLI Studio: ScaleChem requires specific gravity to be between 0.228 and 1.6.
- **API Gravity** is defined as $API\ Gravity = (141.5/SG) - 131.5$
- **Watson K** is a method that relates density to boiling point

A more detailed description of the different assay types, thermodynamic methods and density calculation methods is found in the Basic Definitions for the Oil Analysis Tool section on pages 381-384.

Distillation Data Grid: In this section the distillation data is entered.

And in the **Reconcile** tab, is where the equilibrium calculations are performed.

The **Reconcile** sub-tab is used to calculate the properties of the gas at the temperature and pressure conditions specified. By default, the values of temperature, and pressure are 60 °F (15.56°C) and 14.7 psia (1 atm).

The screenshot displays the software interface for the Reconcile tab. The top menu bar includes 'Description', 'Design', 'Definition', and 'Report'. The left sidebar shows 'Inflows' and 'Reconcile' tabs. The main content area features a table with the following data:

Component	Normalized
Subtotal: 100.000/100.000 (mole %)	
H2O	0.0
CH4	100.000

Below the table is a 'Calculate' button with a green checkmark. To the right, a 'Condition' table is highlighted with a red border:

Conditions	Value
Temperature (°C)	15.5556
Pressure (atm)	1.00231

At the bottom right, there is a checkbox labeled 'Show Non-zero Only' which is checked.

13.2. Basic Definitions for the Oil Analysis Tool

13.2.1. Hydrocarbon Petroleum Fractions

Frequently a hydrocarbon analysis is the only data available for entry into the software. This analysis is usually a distillation curve where the volume distilled as a function of temperature of a petroleum fraction has been analyzed. This information must be turned into a vapor, organic and aqueous component for use in the simulator.

ASTM D86

Used for light and medium petroleum products and is carried out at atmospheric pressure. The results are converted internally in the OLI model generator to a TBP (True Boiling Point Curve). This curve is then fit to a spline to smooth the curve. The cuts are taken from the spline.

ASTM D1160

Used for heavier petroleum products and is often carried out under vacuum. Sometimes as low as 1 mm Hg. The results are converted internally in the OLI model generator to a TBP (True Boiling Point Curve). This curve is then fit to a spline to smooth the curve. The cuts are taken from the spline.

ASTM D2887

Uses gas chromatography to produce the distillation curve and is applicable to a wide range of petroleum products. The results are always reported on a volume percent basis. The results are converted internally in the OLI model generator to a TBP (True Boiling Point Curve). This curve is then fit to a spline to smooth the curve. The cuts are taken from the spline

True Boiling Point (TBP)

These curves, in practice, are difficult to obtain. The other methods are usually used instead.

13.2.2. Thermodynamic Methods (pseudo-components and petroleum fractions)

The methods used within OLI to calculate the critical temperature and pressure are the API, Cavett and Lee-Kesler methods.

API Method

Uses the specific gravity to estimate the critical parameters. The specific gravity, if not entered, can be estimated from the API gravity or the Watson K. The boiling points are taken from the assay data. API version 5 (API-5) and API version 8 (API-8) are currently supported.

The API method is selected by the user. T_c , P_c , and V_c are calculated as follows:

$$T_c = 24.2787 \times T_b^{0.58848} \times SG^{0.3596}$$
$$\ln P_c = \frac{3.12281\rho + 9}{T_b^{2.3125}SG^{2.3201}} \text{ if } T_b < 1000 \text{ }^\circ\text{F}$$

Otherwise

$$\ln P_c = 8.3634 - \frac{0.566}{SG} - \left(0.24244 + \frac{2.2898}{SG}\right) + \left(\frac{0.11857}{SG^2}\right) \times 0.001 \times T_b$$

$$+ \left(1.4685 + \frac{3.648}{SG} + \frac{0.47127}{SG^2}\right) \times \left|\rho - 7 \times T_b^2 - \left(0.42019 + \frac{1.6977}{SG^2}\right)\right| \rho - 10 \times T_b^3$$

$$V_c = \frac{Z_c \times T_c \times 10.73}{P_c}$$

Where,

Tc = Critical temperature in Rankine

Pc = Critical pressure in psia

Zc = Critical compressibility factor

$$Z_c = \frac{1}{3.43 + 6.7\rho - 9 \times \Delta^2}$$

And

$$\Delta = \frac{8.75 + 1.978(\log T_b) \times T_b}{1.8} \text{ if } T_c < 536.67 \text{ R}$$

If $536.67 < T_c < 593 \text{ R}$, the above result for Δ is multiplied by f:

$$f = \left(T_c - \frac{536.67}{T_c - T_b}\right)^{0.38}$$

If $T_c > 593 \text{ R}$,

$$\Delta = \left(\frac{(0.98907 \times SG)(\Delta - 592.4439)}{MW}\right)^{0.5}$$

Cavett

This method uses the API gravity method to determine the critical properties. The API gravity, if not entered can be estimated from the actual specific gravity or the Watson K. The boiling points for the pseudo-components are taken from the assay.

If the Cavett method is chosen by the user, Tc, Pc and Vc are calculated as follows:

$$T_c = 768.0712 + 1.7133693 \times T_b - 0.0010834 \times T_b^2 - 0.008921258 \times T_b \times API + (3.8890584\rho - 7)$$

$$+ T_b^3 \times 5.309492\rho - 6 \times T_b^2 \times API + 3.27116\rho - 8 \times (T_b \times API)^2$$

$$\log P_c = 2.829046 + 0.0009412 \times T_b - 3.047475\rho - 5 \times T_b^2 - 2.087611\rho - 5 \times API \times T_b + 1.5184103\rho - 9 \times T_b^3$$

$$+ 1.1047809\rho - 8 \times API \times T_b^2 - 4.82716\rho - 8 \times API^2 \times T_b + 1.3949619\rho - 10 \times (API \times T_b)^2$$

$$V_c = \frac{Z_c \times T_c \times 10.73}{P_c}$$

Where,

T_c = Critical temperature in Rankine

P_c = Critical pressure in psia

Z_c = Critical compressibility factor

$$Z_c = \frac{1}{3.43 + 6.7\rho - 9 \times \Delta^2}$$

And

$$\Delta = \frac{8.75 + 1.978(\log T_b) \times T_b}{1.8} \text{ if } T_c < 536.67 \text{ R}$$

If 536.67 < T_c < 593 R, the above result for Δ is multiplied by f:

$$f = \left(T_c - \frac{536.67}{T_c - T_b} \right)^{0.38}$$

If T_c > 593 R,

$$\Delta = \left(\frac{(0.98907 \times SG)(\Delta - 592.4439)}{MW} \right)^{0.5}$$

Lee-Kesler

This method uses the Watson K and the specific gravity (which can be estimated via the Watson K) to determine the critical parameters.

If the Lee-Kesler method is selected by the user, T_c, P_c, and V_c are calculated as follows:

$$T_c = 341.7 + \frac{811}{SG} + (0.4244 + 0.1174 SG) \times T_b + (0.4669 - 3.2623 SG) + \frac{100,000}{T_b}$$

$$\ln P_c = 8.3634 - \frac{0.566}{SG} - \left(0.24244 + \frac{2.2898}{SG} + \frac{0.11857}{SG^2} \right) \times 0.001 \times T_b$$

$$+ \left(1.4685 + \frac{3.648}{SG} + \frac{0.47127}{SG^2} \right) \times \left| \rho - 7 \times T_b^2 - \left(0.42019 + \frac{1.6977}{SG^2} \right) \right| \rho - 10 \times T_b^3$$

$$V_c = \frac{Z_c \times T_c \times 10.73}{P_c}$$

Where,

T_c = Critical temperature in Rankine

P_c = Critical pressure in psia

Z_c = Critical compressibility factor

$$Z_c = \frac{1}{3.43 + 6.7\rho - 9 \times \Delta^2}$$

And

$$\Delta = \frac{8.75 + 1.978(\log T_b) \times T_b}{1.8} \text{ if } T_c < 536.67 \text{ R}$$

If $536.67 < T_c < 593 \text{ R}$, the above result for Δ is multiplied by f:

$$f = \left(T_c - \frac{536.67}{T_c - T_b} \right)^{0.38}$$

If $T_c > 593 \text{ R}$,

$$\Delta = \left(\frac{(0.98907 \times SG)(\Delta - 592.4439)}{MW} \right)^{0.5}$$

13.2.3. Average Bulk Density

Specific Gravity

Unitless, relative to pure water (H_2O) at $15 \text{ }^\circ\text{C}$ which has a density of 1.0 g/mL

API Gravity

Degrees API ($^\circ\text{API}$). This is calculated via the following equation:

$$\text{API}(60F) = \left(\frac{141.5}{s.g.(60F)} \right) - 131.5$$

where, SG is the specific gravity at $60 \text{ }^\circ\text{F}$.

Watson K

The Watson K has no units but is calculated via:

$$K = \left(\frac{NBP^{1/3}}{SG} \right)$$

where NBP is the normal Boiling point.

13.3. A Basic Gas Analysis

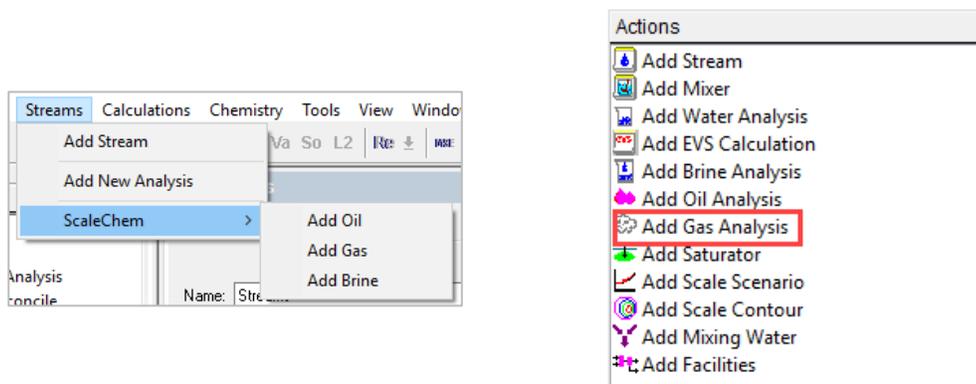
A brief introduction to the gas analysis tool will be shown in the example below. As we go through the example, the basic definitions, functionalities and reporting for the *Gas Analysis object* will be shown.

Example 62: Basic Gas Analysis

The Gas Analysis object provides a quick way to enter a pure-component hydrocarbon gas.

Setting the Gas Analysis

10. **Add a Gas Analysis.** Go to the toolbar menu and click on **Streams > ScaleChem > Add Gas**, or by selecting the **Add Brine Analysis** icon in the Actions Pane



11. **Click** on the new Gas and press **<F2>** to change the name to *Gas Analysis*
12. Select the **AQ** thermodynamic Framework (default)
13. **Click** on the **Names Manager** Icon and select the **Formula** option (default)
14. **Click** on the **Units Manager** Icon, and select Metric, Concentration (default)
15. Under the **Inflows** Tab, enter the gas composition given in the table below

Gas Analysis Composition		
Formula	Component Name	Mole %
H2O	Water	1.80
N2	Nitrogen	3.00

CO2	Carbon Dioxide	1.50
H2S	Hydrogen Sulfide	0.50
CH4	Methane	65.5
C2H6	Ethane	14.0
C3H8	Propane	8.00
i-C4H10	Isobutane	1.00
n-C4H10	n-Butane	3.00
i-C5H12	Isopentane	0.50
C5H12	n-Pentane	0.70
C6H14	n-Hexane	0.50

Your screen should look like the image below:

The screenshot shows a software interface with a menu bar (Description, Design, Definition, Report) and a main window. On the left, there is a sidebar with 'Inflows' and 'Reconcile' buttons. The main window contains a table with the following columns: Component, Value, and Normalized. The table data is as follows:

Component	Value	Normalized
	Subtotal: 100.000/100.000 (mole %)	Subtotal: 100.000/100.000 (mole %)
H2O	1.80000	1.80000
N2	3.00000	3.00000
CO2	1.50000	1.50000
H2S	0.500000	0.500000
CH4	65.5000	65.5000
C2H6	14.0000	14.0000
C3H8	8.00000	8.00000
i-C4H10	1.00000	1.00000
n-C4H10	3.00000	3.00000
i-C5H12	0.500000	0.500000
C5H12	0.700000	0.700000
C6H14	0.500000	0.500000

On the right side of the interface, there are several control panels:

- Entry Options:** Units (mole %), Display (Formula), Show Non-zero Only, Show Normalized Column.
- Template Manager:** Standard, Save as...
- Normalize Options:** Makeup.
- Group Manager:** Use Groups, Add.

Note: There are several options to the right of the data entered.

- 4) **Entry options:** Here you can select the prefer units, and display name. You also have the options to show the non-zero values only – sometimes the composition of species is zero – and show normalized (yellow) column – this option is useful when the values don't add up to 100 mole%.
 - 5) **Template manager:** Here you can select the standard (default) template or the extended template – which includes hydrocarbons with longer chains. You can also create and save your own template for future use.
 - 6) **Normalize options:** When your analysis does not add up 100 mole% you can select between two options: Make-up and Prorate. For the Make-up option, the default gas used is CH₄.
16. Click on the **Reconcile** (vertical blue tab). The reconciliation calculation will be calculated at 15.556 C and 1.00231 atm (standard conditions).

Component	Normalized	Reconciled Gas
	Subtotal: 100.000/100.000 (mole %)	Subtotal: 100.000/100.000 (mole %)
H2O	1.80000	1.75645
N2	3.00000	3.00133
CO2	1.50000	1.50066
H2S	0.500000	0.500221
CH4	65.5000	65.5290
C2H6	14.0000	14.0062
C3H8	8.00000	8.00355
i-C4H10	1.00000	1.00044
n-C4H10	3.00000	3.00133
i-C5H12	0.500000	0.500222
C5H12	0.700000	0.700310
C6H14	0.500000	0.500222

Conditions	Value
Temperature (°C)	15.5556
Pressure (atm)	1.00231

Show Non-zero Only

17. Now, we are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
18. It is time to **save** your file (**File >Save as...**) or using the **save** icon in the tool bar. Create a new file and name it: *ScaleChem Analysis Calculations*.

Analyzing the Results

Once the calculation is done, the **Reconciled Gas** column displays the results at equilibrium conditions.

Description Design Definition Report

Component	Normalized	Reconciled Gas
	Subtotal: 100.000/100.000 (mole %)	Subtotal: 100.000/100.000 (mole %)
H2O	1.80000	1.75645
N2	3.00000	3.00133
CO2	1.50000	1.50066
H2S	0.500000	0.500221
CH4	65.5000	65.5290
C2H6	14.0000	14.0062
C3H8	8.00000	8.00355
i-C4H10	1.00000	1.00044
n-C4H10	3.00000	3.00133
i-C5H12	0.500000	0.500222
CSH12	0.700000	0.700310
CSH14	0.500000	0.500222

Condition

Conditions	Value
Temperature (°C)	15.5556
Pressure (atm)	1.00231

Show Non-zero Only

Summary

Unit Set: Metric (mole fraction)

Automatic Chemistry Model
 Aqueous (H+ ion) Databanks:
 Aqueous (H+ ion)
 Second Liquid phase
 Using K-fc Polynomials
 T-span: 25.0 - 225.0
 P-span: 1.0 - 1500.0

Stream Parameters:

Temperature (°C)	15.5556
Pressure (atm)	1.00231

Makeup Normalization: CH4

Equilibrium Calculation.

Phase Amounts:

Aqueous (mol)	0.0443282
Vapor (mol)	99.9557
Solid (mol)	0.0
2nd Liquid (mol)	0.0

Aqueous Phase Properties:

pH	4.75177
Ionic Strength (mol/mol)	3.20592e-7
Density (g/ml)	0.999257

Calc. elapsed time: 0.940 sec.
 Calculation complete

To the right you can see the results summarized in the **Summary Box**.

The top section contains the **Stream Parameters** information. In this example, the software performed the

The **Phase amounts** section shows the distribution of species in the different phases. This analysis contains two phases: aqueous and vapor.

The **Aqueous Phase Properties** information shows the computed pH, ionic strength, and density of the solution.

4. Click on the **Report** tab.

Here you will see a more complete representation of the results at equilibrium.

Calculations Overview

OLI Studio: ScaleChem can be used to calculate scaling at one or more user specified temperatures and pressures. Other calculation options include the ability to mix waters at user specified ratios to find compatible waters, and the ability to saturate a water with respect to one or more solids to simulate reservoir conditions.

We have already reviewed a scaling calculation in the OLI Studio: ScaleChem Tour.

This chapter will cover the same calculation objects using fewer instructions and will introduce *Mixing* and *Facility* Calculations. Its purpose is to reinforce what was learned in the previous chapter and to promote the anticipating of next-steps when using the interface. This will be divided into different tasks.

Task 1 – Add a Brine

- Add a *Brine Analysis* from the Action Panel
- Rename the Brine in the **Description** Tab, and name it WTXWTR

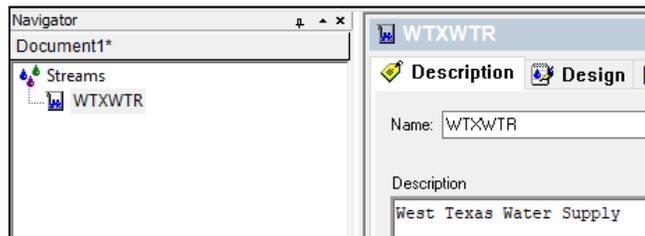


Figure 0-1 The default brine sample description

- Go to the **Design** Tab and enter the following composition in the **Data Entry** (vertical) tab:

Name	WTXWTR		
Type of water	Aquifer		Water
Comment:	West Texas Water Supply		
Species	Concentration		
Na ⁺	3074	mg/L	
Ca ⁺²	910	mg/L	
Mg ⁺²	249	mg/L	
Fe ⁺²	0.77	mg/L	
Cl ⁻¹	4474	mg/L	
SO ₄ ⁻²	2960	mg/L	
HCO ₃ ⁻	439	mg/L	
HS ⁻¹	146.2	mg/L	

- Check the *Show non-zero Only* box (under Entry Options)
- Go to the **Reconcile** (vertical) tab

- Select the measured pH and alkalinity Option
- Enter the following conditions (change units if necessary)
 - To change units just click on the hyperlink next to the variable that you want to change.



Temperature	77			F
Pressure		14.7		psia
pH	7.98			
Alkalinity end Point pH	439	mg/L	as	HCO ₃ ⁻
Titration pH	4.5			
Density	(will be estimated)			

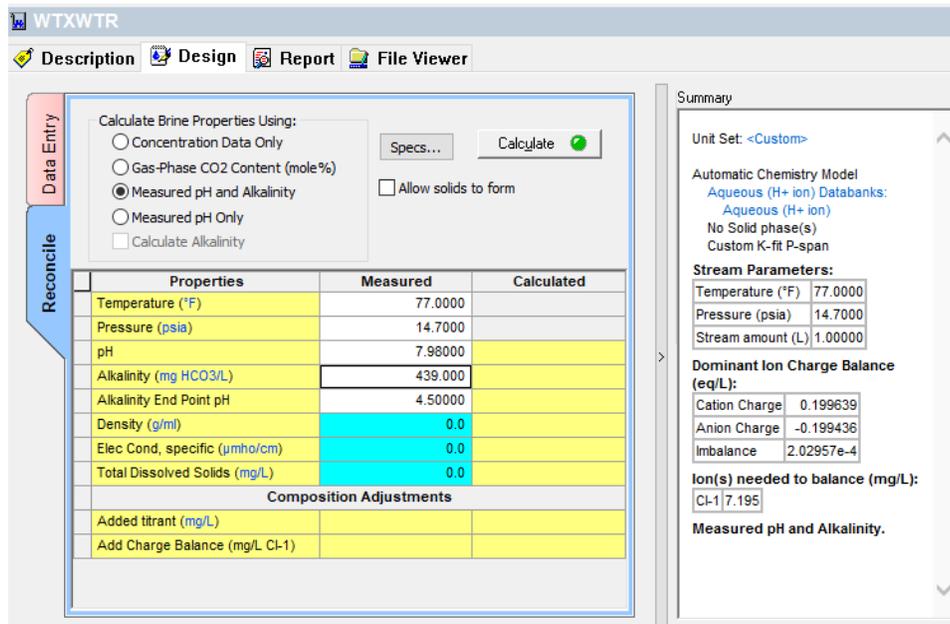


Figure 0-2 The calculated Brine WTXWTR

- Click the Calculate Button

Task 2 – Add a Second Brine

- Add a Brine Analysis
- Enter the composition given below in the **Data Entry** (vertical) Tab

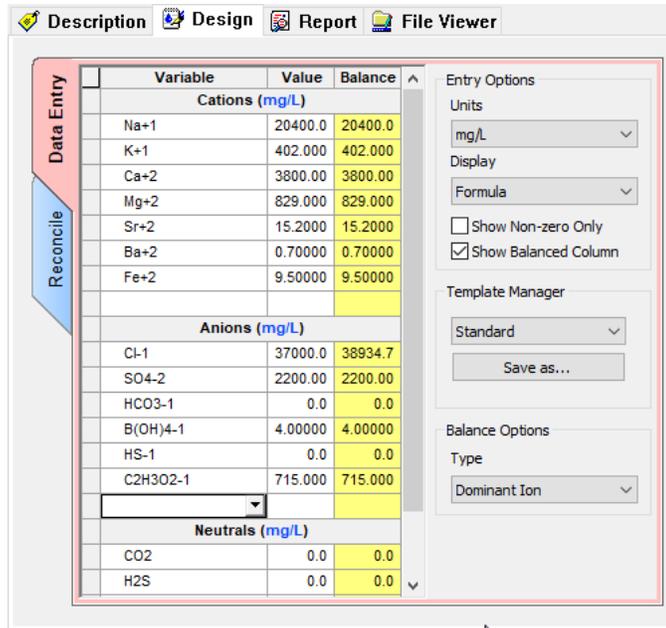


Figure 0-4 Brine data entry

- Go to **Reconcile** tab
- Select *pH and Alkalinity* calculation type, and enter the information provided in the figure below:

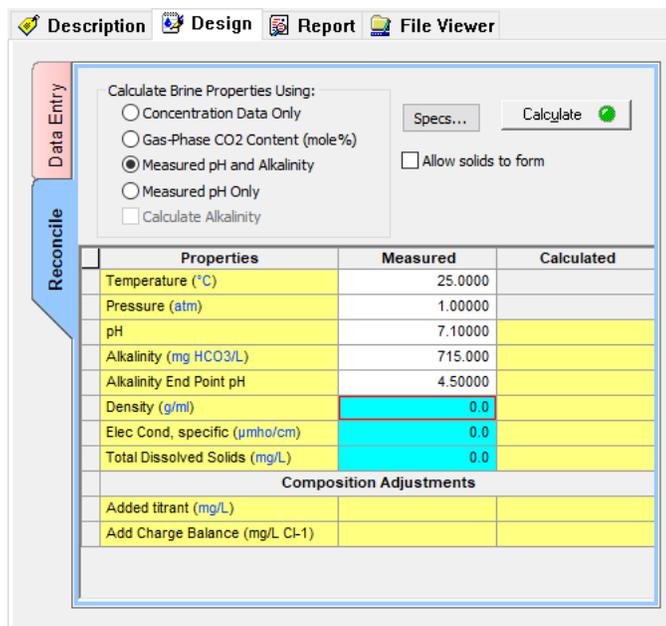


Figure 0-4 Reconcile data entry

- Click the Calculate button

Task 3 – Add a Gas

- From the Actions Panel click on *Add Gas Analysis*

- Input the name in the **Description** tab. Name it *LightHC*

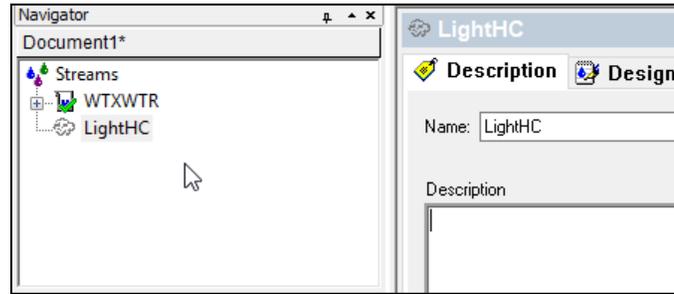


Figure 0-3 Entering a gas sample

- Go to the **Design** Tab and enter the following composition in the **Inflows** (vertical) tab,
- Enter the following composition:

Component	Composition		
Carbon dioxide (CO ₂)	10	mole	%
Water (H ₂ O)	15 mole %		

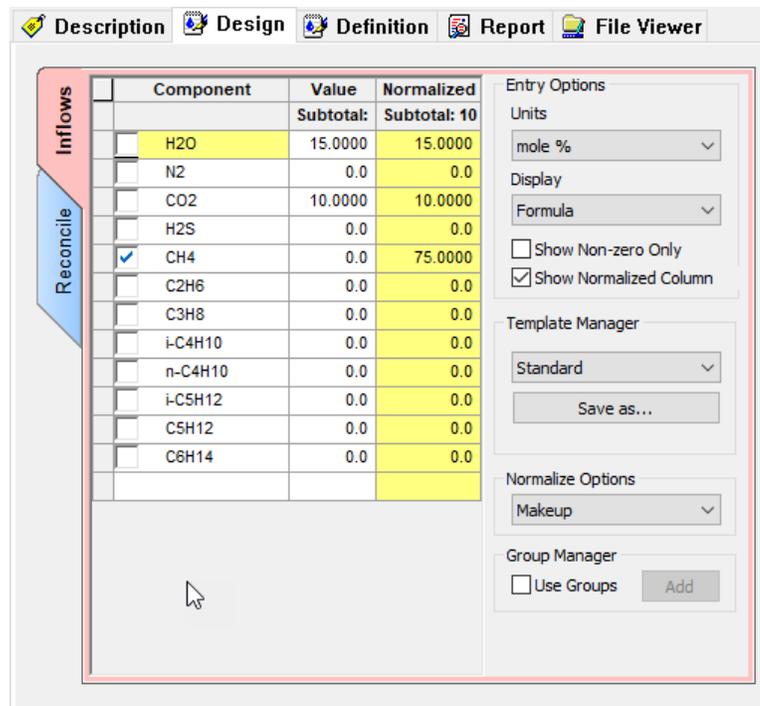


Figure 0-5 Entered gas.

OLI Studio: ScaleChem will assume that all of the hydrocarbon gas is methane (CH₄). So, in this case the software normalizes the gas adding 75 mole% of CH₄.

- Go to the **Reconcile** (vertical) Tab

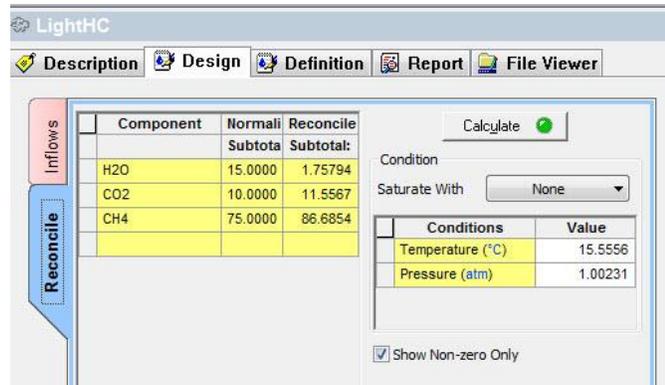


Figure 0-6 Reconcile tab

- Leave the default conditions for Temperature and Pressure
- Calculate

Task – Add an Oil

- From the Actions Panel click *Add Oil Analysis*.
- Enter the name in the **Description** Tab. Name it *OIL-1*

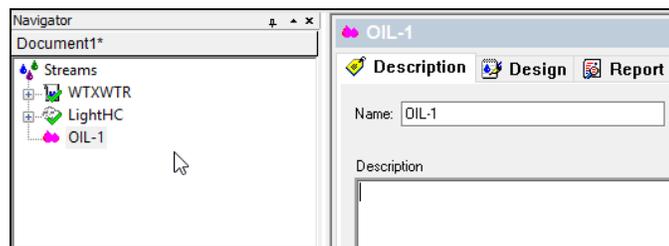


Figure 0-7 Input name for the Oil Analysis

- Go to the **Design** tab
 - This tab is divided into:
 - Combined Tab: Here pure components (organic and inorganic) are entered.
 - Pseudocomponent Tab
 - Assay Tab: Here distillation curves are entered.
 - Reconcile Tab

For this example, we will enter pure component and pseudocomponent data.

- Go to the **Combined** tab
- Enter the following composition:

Methane (CH4)	20.53mole %
Hexane (C6H14)	8.595mole %
CO2	6.09mole %

Note: You will have to scroll down to find the CO2 entry.

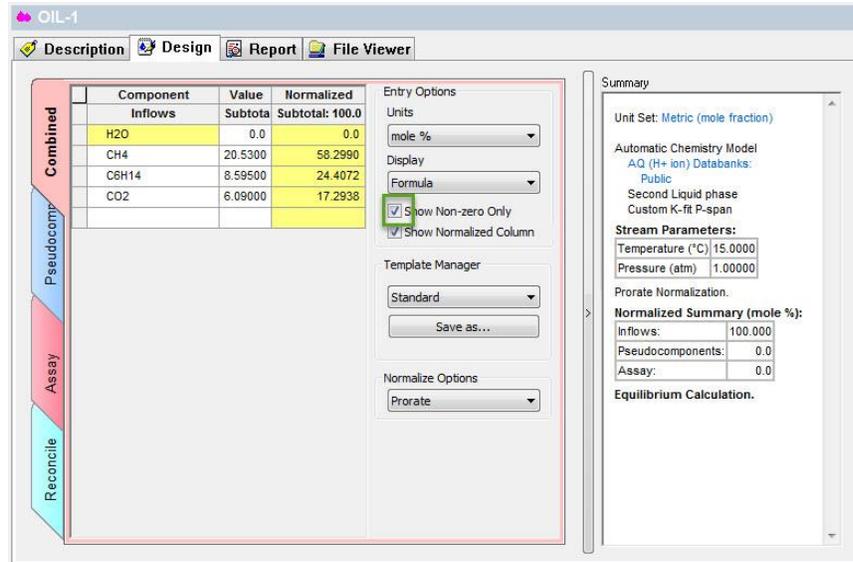


Figure 0-8 Starting to add compositions.

- Go to the **Pseudocomponent** tab

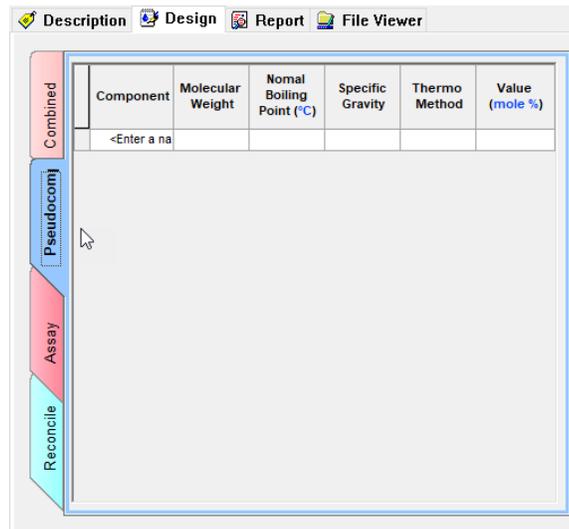


Figure 0-10 Entering pseudocomponents

- Add the following pseudocomponents:

Name	MW (g/mol)	nBP (F)	Thermo Method	Value mole %
PC1	98.43	100.21	API	27.57
PC2	170.34	216.32	API	29.35
PC3	282.55	343.78	API	7.19
PC4	506.0	645.00	API	0.68

The completed input looks like this:

Component	Molecular Weight	Normal Boiling Point (°F)	Specific Gravity	Thermo Method	Value (mole %)
PC1	98.4300	100.210		API-8	27.5700
PC2	170.340	216.320		API-8	29.3500
PC3	282.550	343.780		API-8	7.19000
PC4	506.000	645.000		API-8	0.680000
<Enter a na					

Figure 0-12 Completed input

- Go to the **Reconcile** (vertical) tab
Here you will see how well the pseudocomponent will predict the phase behavior of the hydrocarbon sample.
- In the Condition option (below calculate button) enter T=204 F and P=1 atm.
- Click on the *Add boiling point curve* (red square)

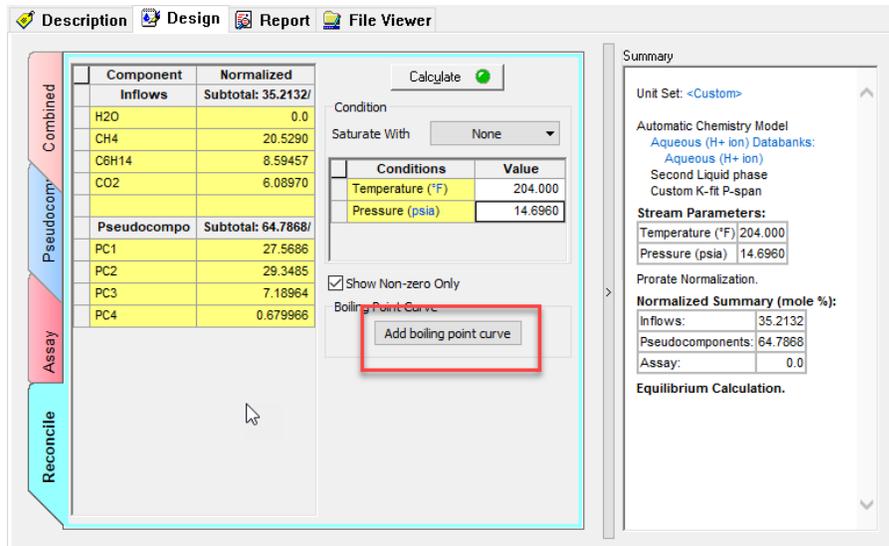


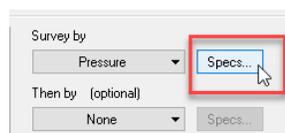
Figure 0-13 Reconciliation Tab

- A new calculation appears in the navigation panel below OIL1 Object.



Figure 0-14 Boiling Point calculation

- This is a survey by Pressure. Click on the specs button and specify the conditions below. Change pressure units if necessary.



- Enter a pressure range:

Start	200	psia
End	2000	psia
Decrement	100 psia	

- Click the Calculate button.
- Click on the plot tab, you will see the following graph: You could adjust the parameters by clicking on curves.

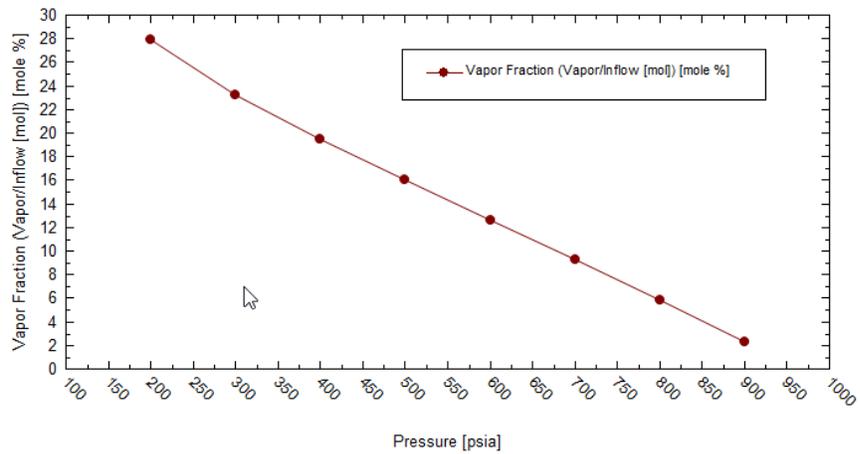


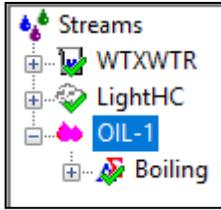
Figure 0-15 Boiling point curve

If the curve does not meet expectations, you will have to adjust the mole percentages or the pseudocomponent properties. This is a manual iterative approach. You can see the actual data by clicking the View data button.

	Pressure	Vapor Fraction (Vapor/Inflow [mol])
	psia	mole %
1	200.000	27.8711
2	300.000	23.1977
3	400.000	19.4660
4	500.000	16.0216
5	600.000	12.6532
6	700.000	9.26672
7	800.000	5.80919
8	900.000	2.24433
9	1000.00	
10	1100.00	
11	1200.00	
12	1300.00	
13	1400.00	
14	1500.00	
15	1600.00	
16	1700.00	
17	1800.00	
18	1900.00	
19	2000.00	

Frequently the hydrocarbon was saturated with water.

- Go back to OIL-1 in the Action panel



- Click on the **Design** tab
- Click on the Saturate with drop down. Select H2O

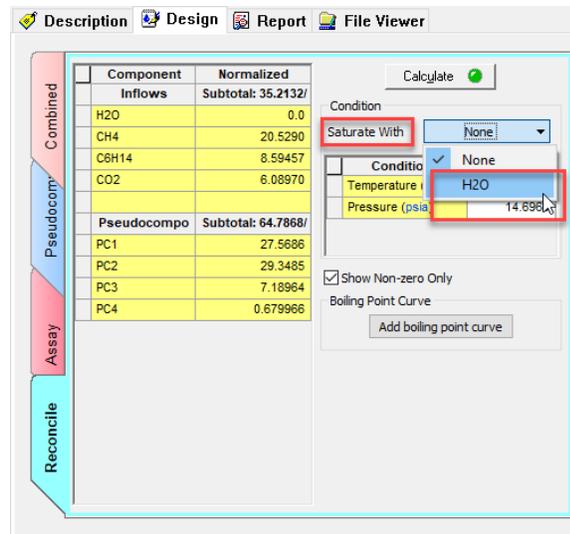


Figure 0-16 Saturate with H2O

- In the Conditions option use T= 77 F and 14.7 psia.

The software requires an initial "Guess" for the concentration of the water..

- Click on the Calculate button.

When done, the software will create a *Reconciled OIL-1* in the Navigator pane.

The Brine, Gas and Oil that we already calculated will be used for Mix, Saturator and Facilities Calculations.

You can download a worked example file for this tutorial from here:

Mix Calculation: Overview

The Mixer calculation determines if two waters (brines) can be mixed. Frequently the mixing of two waters will cause precipitates to form which were not present in original brines. This can lead to the plugging of a formation when an injection water is mixed with the natural fluids in the formation.

Mix Calculation: Set Up

- From the Actions Panel, click on the Add Mixing Water logo.



- After double clicking the logo, you will see the object in the Navigation Panel.

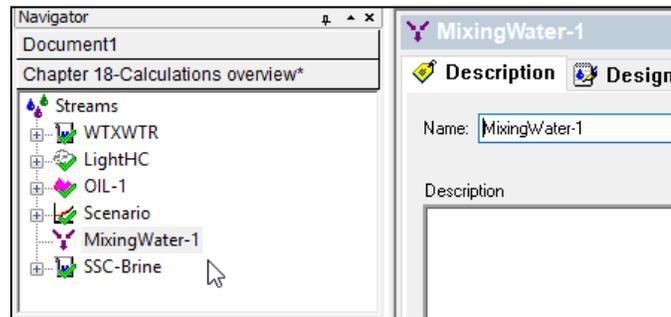


Figure 0-17 Input name for Mixing Water object

- Click on the **Design** tab to enter more information.
- Select your Brines, Gas and Oil s as shown in the figure below. Enter the indicated brine flow rate of 1000 bbl/day, gas flow of 230 stdMft3/day and oil flow of 7 bbl/day.

There are two ways to change the units.

Method 1 To change units on brine, oil and gas, click on the hyperlinked (blue) units inside of the bracket next to Inlets First Brine, Second Brine etc. This is under the column heading Type.



Figure 0-19 Changing units

This should pop the following window up. Click on Inlets tab and change the units.

Inlets tab looks like below. Changing units on Brine:

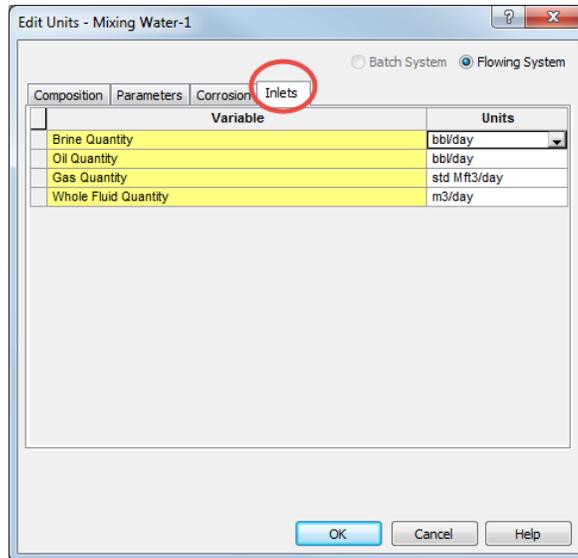


Figure 0-20 Units manager layering

Method 2 This can also be done in one other way, that is through the units manager button on the toolbar.

which looks like .

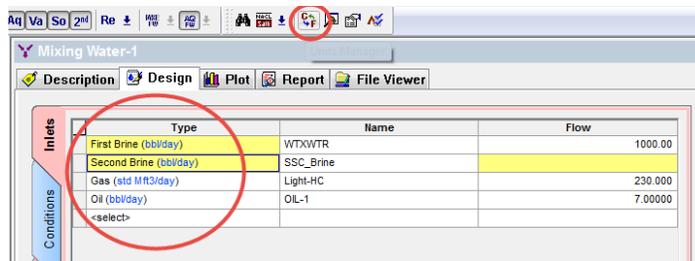


Figure 0-21 Units Manager accessibility

When you click on units manager, following windows pops up.

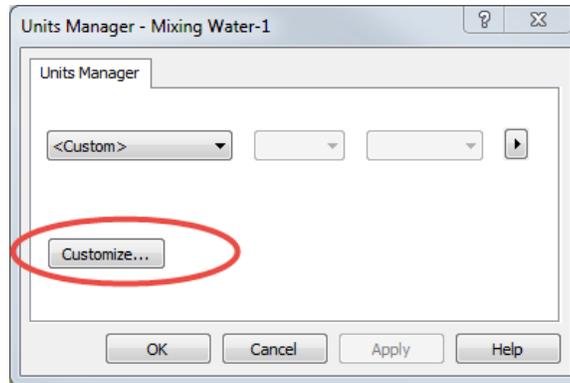


Figure 0-22 Units Manager first layer

Click on Customize. Change the individual parameters as shown below.

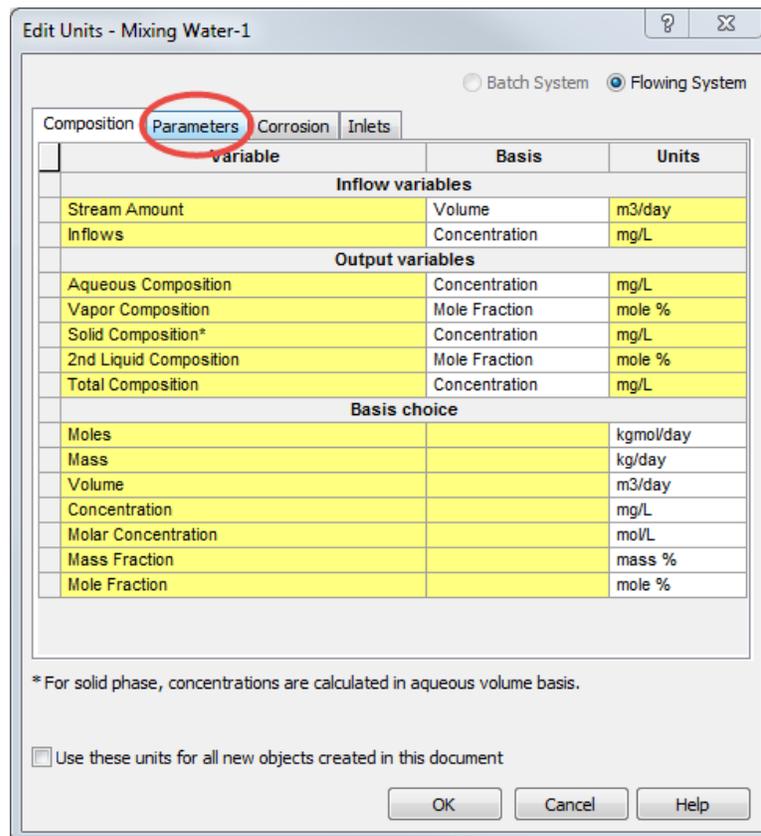


Figure 0-23 Changing units for parameters

The final Mixer with inflows entered should look like the image below:

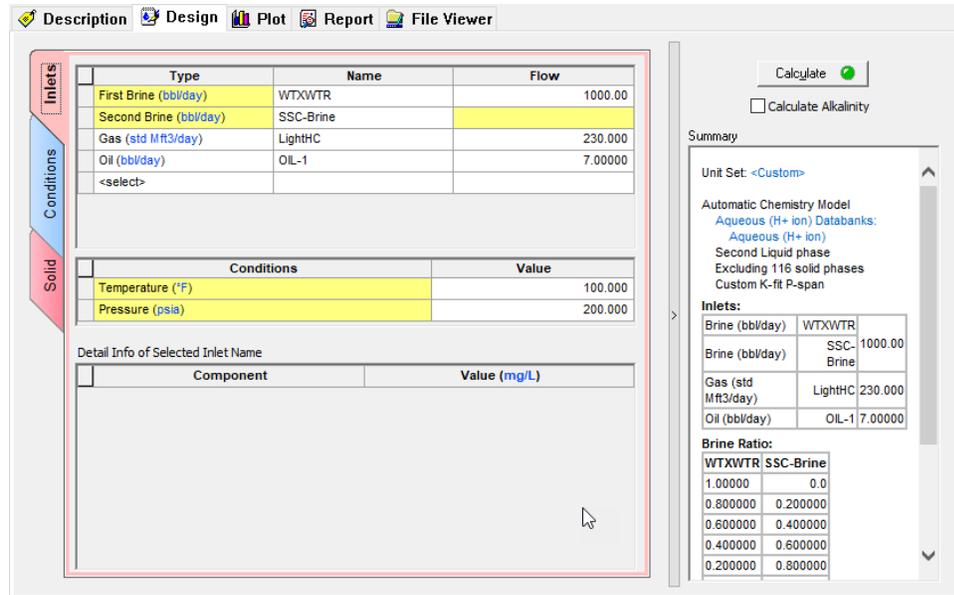


Figure 0-24 Mixer with inflows entered (Inlets Tab)

- Go to the **Conditions** tab

In this example, we are mixing the brines at 100 F and 200 psia. The first brine specified (WTXWTR) is the one we compare to when evaluating the ratios. In this case we start out with all brine WTXWTR and none of the SSC_Brine and end up with none of brine WTXWTR and all of the SSC_Brine.

- Leave the default values

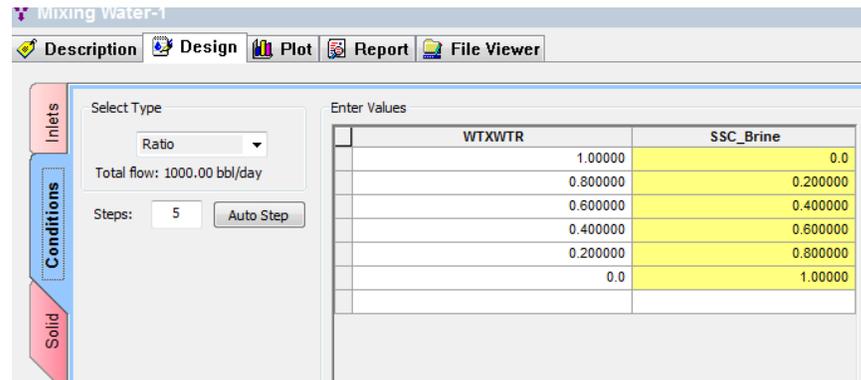


Figure 0-25 the mixing conditions (Conditions tab)

- Go to the **Solid** tab

For this calculation we are only selecting a few of the possible solids. Mark a check box next to desired solids (BaSO₄, CaCO₃, CaSO₄.2H₂O, NaCl).

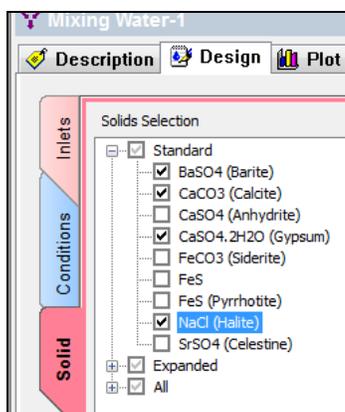


Figure 0-27 Selecting a few solids. (Solids tab)

- Click on the Calculate button.
- Click on the **Plot** tab.

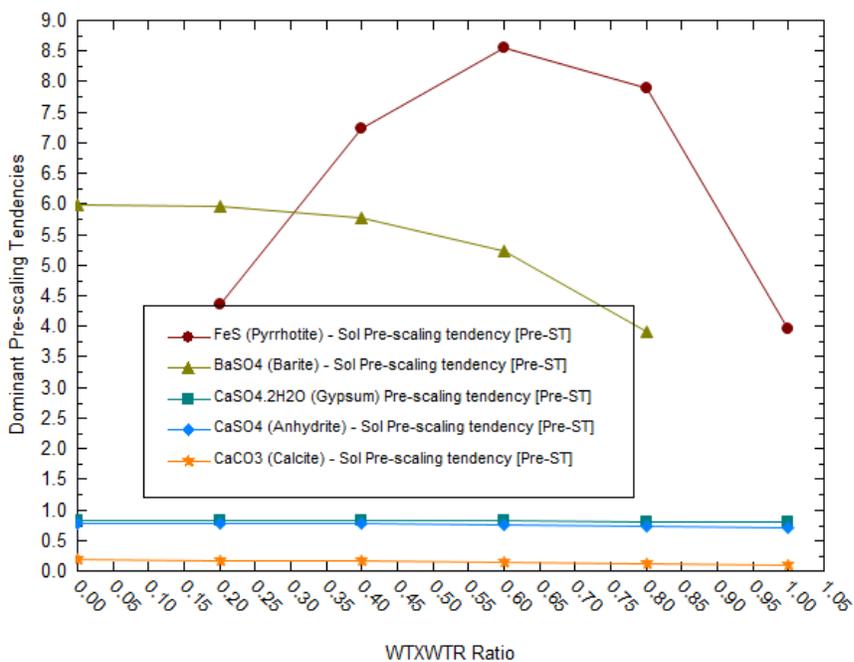


Figure 0-28 Default plot

To study the effects better go to the variables button and eliminate other solids precipitated by the << arrow. Keep only one solid (in this case BaSO₄). The ratio is relative to the first brine specified. This means at a ratio

of 0.0 (all the first brine and none of the second) we have no BaSO₄ scaling. As we add the second brine, the amount of BaSO₄ increases. These waters are perhaps incompatible.

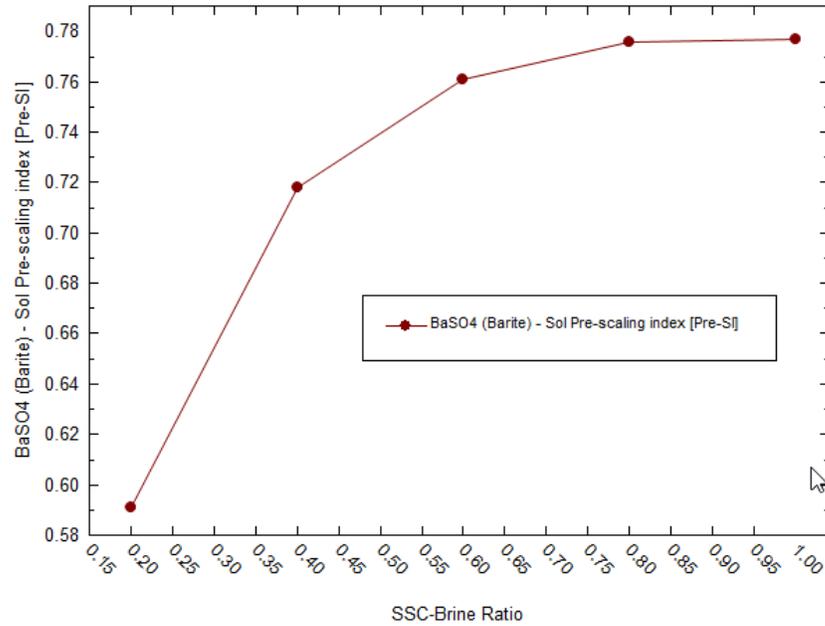


Figure 0-29 Mixing results

Saturate Calculations: Overview

Water and gas samples at the surface are not necessarily representative of conditions in the reservoir. The processing of the samples may involve significant changes in the chemistry.

The Saturate option (often referred to as "Saturate at reservoir conditions") allows the user to "Back-calculate" the conditions down hole.

- Select **Add Saturator** from the Actions Panel.



- Rename the object in the descriptions tab. Name it Saturator-1

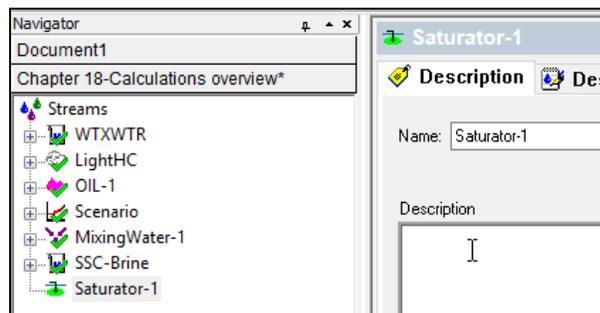


Figure 0-31 Description tab

- Go to **Design** tab
- And go to **Inlets** (vertical) tab

We will select objects that we have already defined.

- Enter a Brine flow of 1000 bbl/day
- Enter a Gas flow of 230 std Mft³/day
- Enter T=77 F and P=14.7 psia
- Set these units as custom units for all new objects in Units manager.

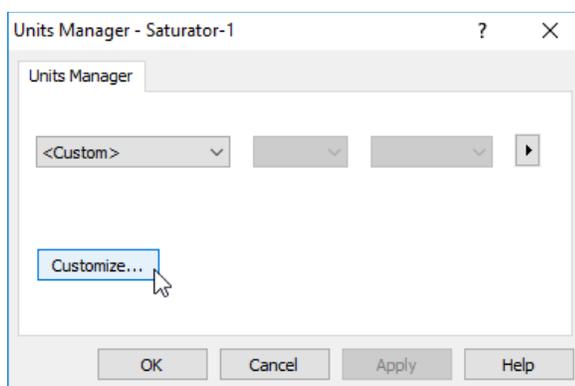
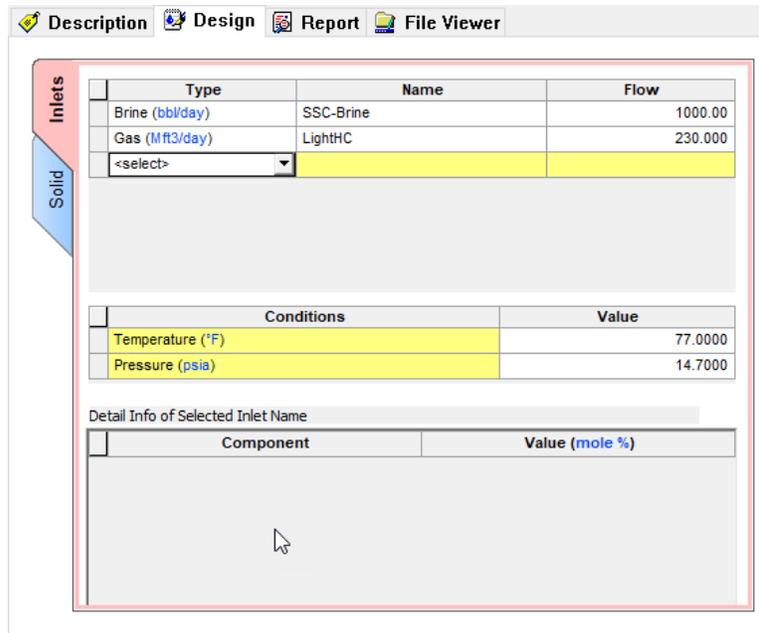


Figure 0-33 Customize the unit sets

The window should look like this:



- Go to **Solid** (vertical) tab
- Check the Standard box

We need to select solids inflow to vary for Saturator1. Under the table *Select Inflows to Vary*, choose the solid to vary from the dropdown list.

- Select BaSO₄ (solid) and hit enter. Automatically the inflow to vary BaSO₄ will appear.

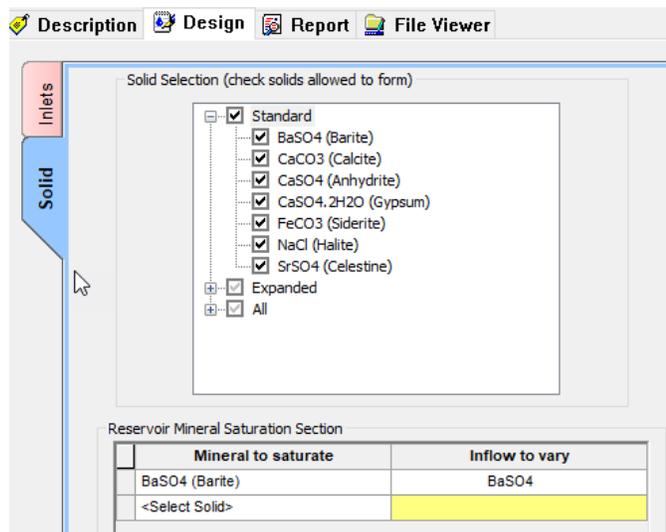


Figure 0-34 Selecting solids to vary

To study the Saturator-1 (Brine and Gas mix) at various locations we need to add a Scaling Scenario, as was performed in Chapter **Error! Reference source not found.**

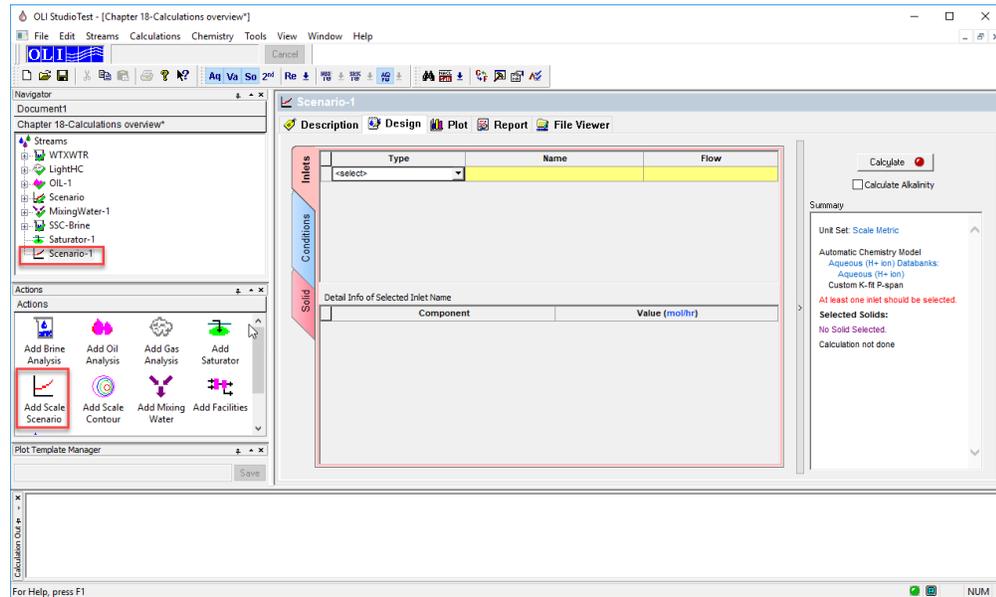
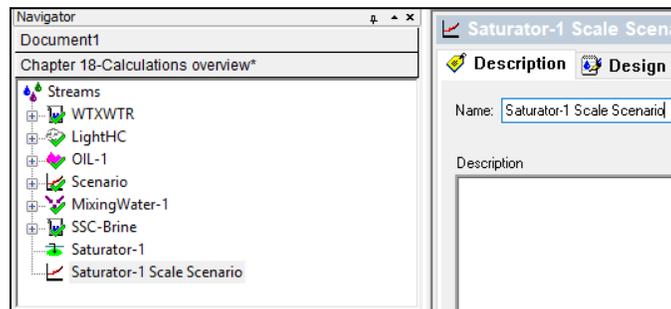
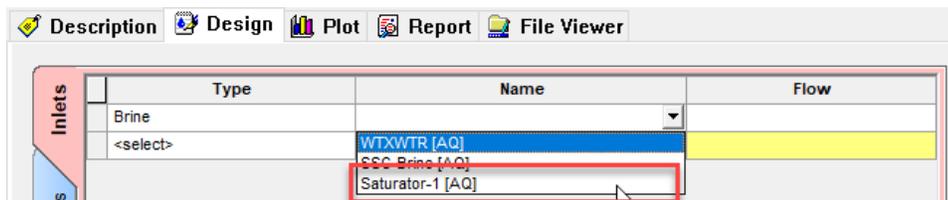


Figure 0-35 Adding a scaling Scenario

- Name the new Scale Scenario as *Saturator-1 Scale Scenario* under the **Description** tab.



- Go to the **Design** Tab
- Under the **Inlets** (vertical) tab, select *Brine* under the *Type* column
- Make sure to select Saturator-1, as is shown in the picture below:



Flow will be automatically controlled. Locations can be input under the **Conditions** tab.

- Go to **Conditions** (vertical) tab, and enter the information provided in the figure below:

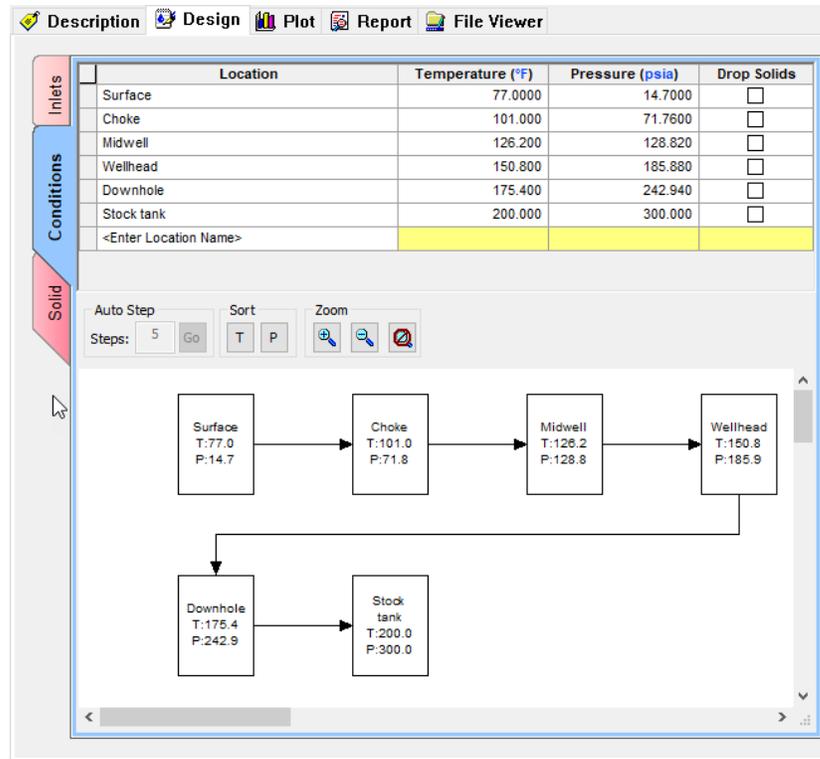


Figure 0-36 Conditions set up

- Go to **Solid** tab and check the Standard box
- Click the Calculate Button
- Go to **Plot** tab

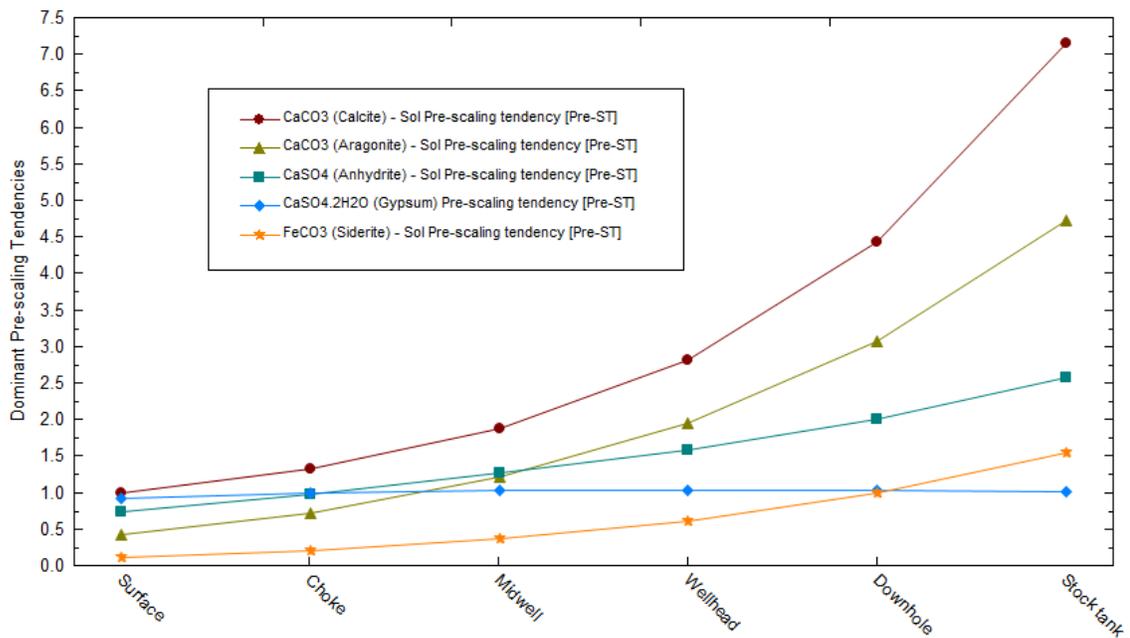


Figure 0-38 The plotted results

After the calculation is complete, the plot for scale scenario shows that other solids are appearing.

- Go to the Report tab, and look for Pre and Post Scaling Tendencies

Pre and Post Scaling Tendencies

Formula	Mineral	Excess Solute	Excess Solute	Pre-Scale	Pre-Scale	Post-Scale	Post-Scale
		mg/L	lb/1000bbl	S, ST	SI, Index	S, ST	SI, Index
CaSO4.2H2O	Gypsum	0.0	0.0	0.928262	-0.0323294	0.928262	-0.0323294
FeCO3	Siderite	0.0	0.0	0.114350	-0.941763	0.114350	-0.941763
SrSO4	Celestine	0.0	0.0	0.203747	-0.690908	0.203747	-0.690908
SrCO3	Strontianite			0.0120481	-1.91908	0.0120481	-1.91908
BaSO4	Barite	0.0	0.0	1.00000	-2.23307e-11	1.00000	0.0
CaSO4	Anhydrite	0.0	0.0	0.731753	-0.135635	0.731753	-0.135635
CaCO3	Calcite	0.0	0.0	1.00000	-1.46285e-11	1.00000	0.0
NaCl	Halite	0.0	0.0	0.0121174	-1.91659	0.0121174	-1.91659
KCl	Sylvite			6.71059e-4	-3.17324	6.71059e-4	-3.17324

Excess solute or Max Scale: The solids amount forming at equilibrium.

Pre-Scale: The saturation ratio before solids precipitate.

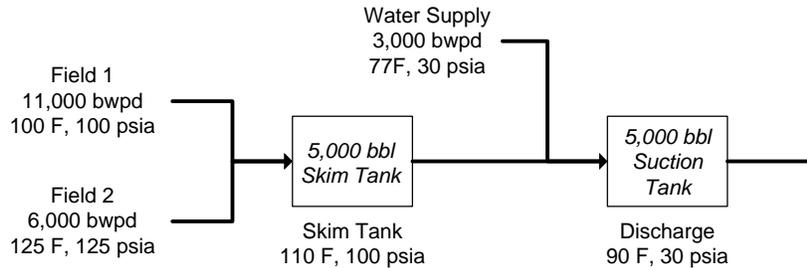
Post-Scale: The saturation ratio AFTER solids precipitate (if solids are selected).

S, ST – Saturation, Scale Tendency: The ratio of the concentration (activity) to its solubility (S=1).

SI – Scale Index: Log(S).

Facility Calculation: Overview

This section presents a new calculation objects, *Facilities*. The Facilities is a simplified process simulator; it mixes and separates. OLI Studio: ScaleChem has the ability to link together several individual calculations to create a flow sheet facility. An example of a facility calculation is shown in the figure below.



It is a simple process in which two field brines mix in a skim tank. The discharge from this tank then mixes with a water supply in a discharge tank. Below are the compositions and conditions of the inlet fluids.

Name	Field 1 mg/L	Field 2 mg/L	Water Supply mg/L
Na+	38209	27078	3074
Ca+2	6600	4480	910
Mg+2	1531	1191	249
Fe+2	120	6.6	0.77
Cl-1	73150	51134	4474
SO4-2	2453	1840	2960
HCO3-	421	677	439
HS-1	244	146.2	0
Conditions			
Temperature	100 F	125 F	77 F
Pressure	100 psia	125 psia	30 psia
pH	6.97	7.53	7.98
Alkalinity (As HCO3 mg/L)	421	677	439
Alkalinity End Point pH	4.5	4.5	4.5

Follow the steps below:

- Open a new Window for Simulation
- Create the above brines: Field 1, Field 2 and Water Supply
- Use the *Add Brine Analysis* object as you have done before to create them.

The **Data Entry** Windows should look like this:

Field 1 Data Entry

Variable	Value	Balanced
Cations (mg/L)		
Na+1	38209.0	38370.4
K+1	0.0	0.0
Ca+2	6600.00	6600.00
Mg+2	1531.00	1531.00
Sr+2	0.0	0.0
Ba+2	0.0	0.0
Fe+2	120.000	120.000
Anions (mg/L)		
Cl-1	73150.0	73150.0
SO4-2	2453.00	2453.00
HCO3-1	421.000	421.000
HS-1	244.000	244.000
C2H3O2-1	0.0	0.0
Neutrals (mg/L)		
CO2	0.0	0.0
H2S	0.0	0.0
SiO2	0.0	0.0

Field 2 Data Entry

Variable	Value	Balanced
Cations (mg/L)		
K+1	0.0	0.0
Ca+2	4480.00	4480.00
Mg+2	1191.00	1191.00
Sr+2	0.0	0.0
Ba+2	0.0	0.0
Fe+2	6.60000	6.60000
Anions (mg/L)		
Cl-1	51134.0	51257.9
SO4-2	1840.00	1840.00
HCO3-1	677.000	677.000
HS-1	146.200	146.200
C2H3O2-1	0.0	0.0
Neutrals (mg/L)		
CO2	0.0	0.0
H2S	0.0	0.0
SiO2	0.0	0.0
B(OH)3	0.0	0.0

Water Supply Data Entry

Variable	Value	Balanced
Cations (mg/L)		
K+1	0.0	0.0
Ca+2	910.000	910.000
Mg+2	249.000	249.000
Sr+2	0.0	0.0
Ba+2	0.0	0.0
Fe+2	0.770000	0.770000
Anions (mg/L)		
Cl-1	4474.00	4637.91
SO4-2	2960.00	2960.00
HCO3-1	439.000	439.000
HS-1	0.0	0.0
C2H3O2-1	0.0	0.0
Neutrals (mg/L)		
CO2	0.0	0.0
H2S	0.0	0.0
SiO2	0.0	0.0
B(OH)3	0.0	0.0

- Reconcile these three brines for *measured pH and alkalinity*.
- Make sure that the *Allow solids to form* box is unchecked at the bottom of the reconciliation options for all the brines.

Field 1 Reconcile

Calculate Brine Properties Using:

Concentration Data Only
 Gas-Phase CO2 Content (mole%)
 Measured pH and Alkalinity
 Measured pH Only
 Calculate Alkalinity

Allow solids to form

Calculate

Properties	Measured	Calculated
Temperature (°F)	100.000	
Pressure (psia)	100.000	
pH	6.97000	6.97000
Alkalinity (mg HCO3/L)	421.000	420.990
Alkalinity End Point pH	4.50000	
Density (g/ml)	0.0	1.07666
Elec Cond, specific (µmho/cm)	0.0	1.84894e5
Total Dissolved Solids (mg/L)	0.0	1.22617e5
Composition Adjustments		
Added titrant (mg/L) HCl		227.307
Add carbonate (mg/L CO2)		-238.440
Add Charge Balance (mg/L Na+1)		161.374

Figure 0-39 Reconcile for Field 1 Brine

- Select **Add Facilities** from the Action Panel.



- Go to the **Description** Tab and rename the object as Facilities-1

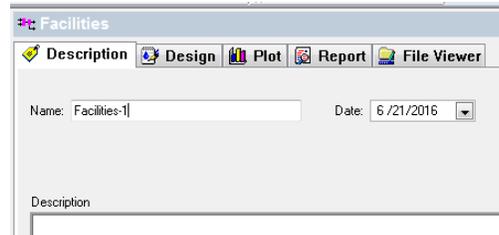


Figure 0-39 The Description tab for the Facilities

The facilities calculation is based upon transferring information between calculations through nodes. These nodes can be thought of as pseudo brines and gases.. These pseudo brines are not stored as individual brine rather they are used internally in the calculation. The concentration and flow rates for these nodes can be viewed in the output.

- Go to the **Design** tab
- Go to the **Inflow Specs** (vertical tab)

Within **Inflow Specs**, we can add Nodes via Node input options. There will be one default node added.

- Double click on the node name (where it says: Node 1) and type "Skim Tank".

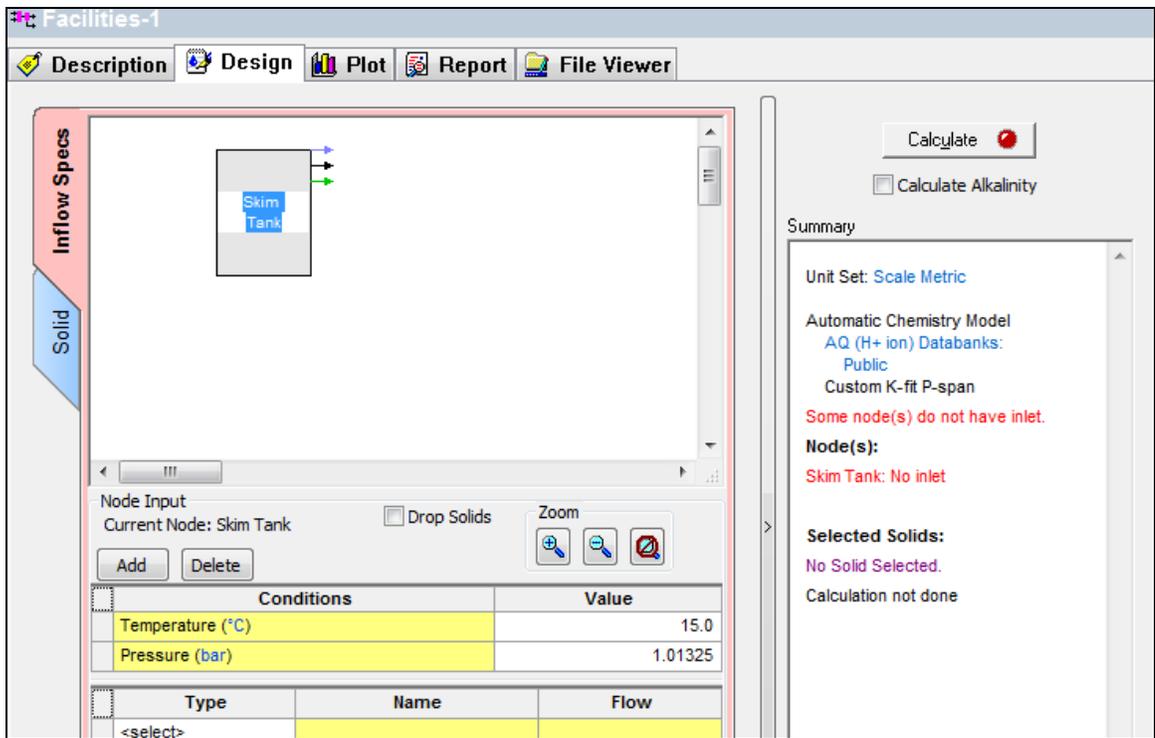


Figure 0-40 Node input Screen

- Enter the name, description, conditions, and streams for the Skim Tank shown in the table below:

	Flow	Temperature, F	Pressure, psia
Field 1	11000 bbl/day	100	100
Field 2	6000 bbl/day	125	125
Water Supply	3000 bbl/day	77	30
Skim Tank	5000 bbl/day	110	100
Suction Tank	5000 bbl/day	90	30

- Make sure to select drop solids checkbox at the Skim Tank node.

When complete, your screen should look like this.

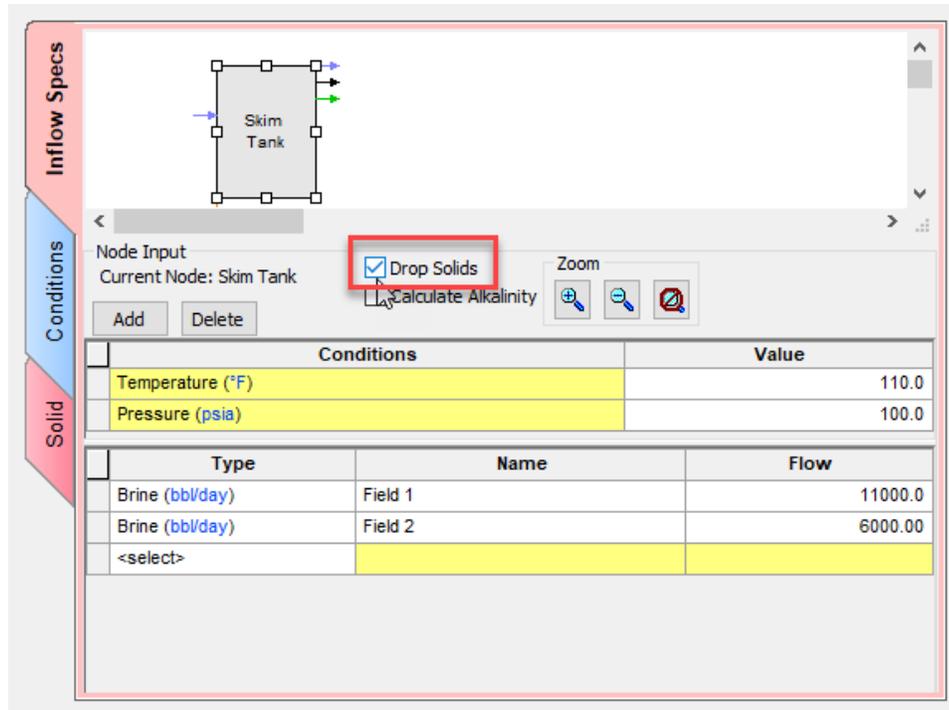


Figure 0-41 Node 1 is complete

The output of this calculation will go to the next node.

Next, enter the information for the second node, Suction Tank. We will select the output brine of the Skim tank, which is a **brine from node**. The temperature and pressure as well as the flow of the brine are calculated.

- Click on the Add button to add a second Node
- Change the name of the node to Suction Tank
- Change the conditions of this node to 90 F and 30 psia.

When complete your screen should look like this:

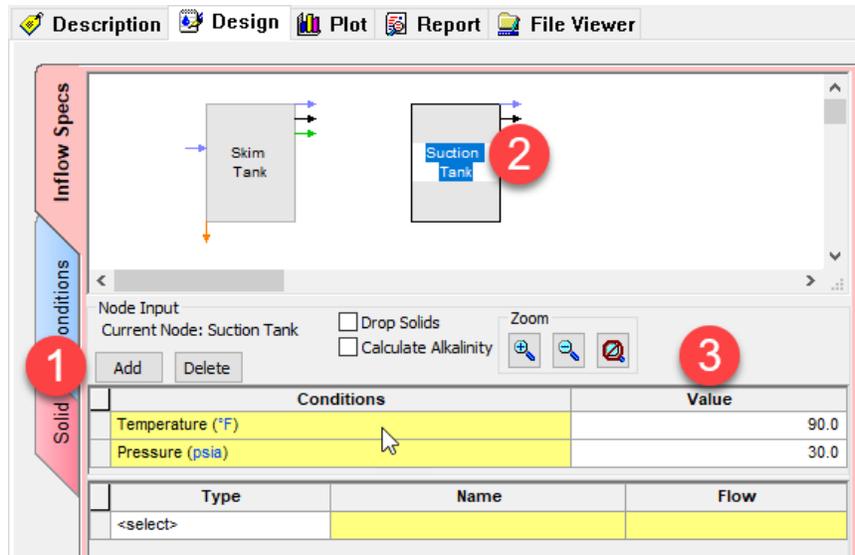


Figure 0-42 Node 2 is entered

When a brine is calculated in a facilities calculation, we have the option of allowing any produced solids to be considered (that is they traveled along with the brine) or to **eliminate** them as they precipitate out. We will eliminate the solids in this case. The orange downward arrow from Skim Tank indicate dropped solids.

We are also adding the **Water Supply** to this tank.

- In the Type column and first row select *Brine from*. In the Name column select *Skim Tank*. The *Flow* is calculated (since it comes from the Skim Tank).
- In the Type column and second row select *Brine*. In the Name column select *Water Supply*. Enter 3000 bbl/day in the Flow column.

When complete the screen should look like:

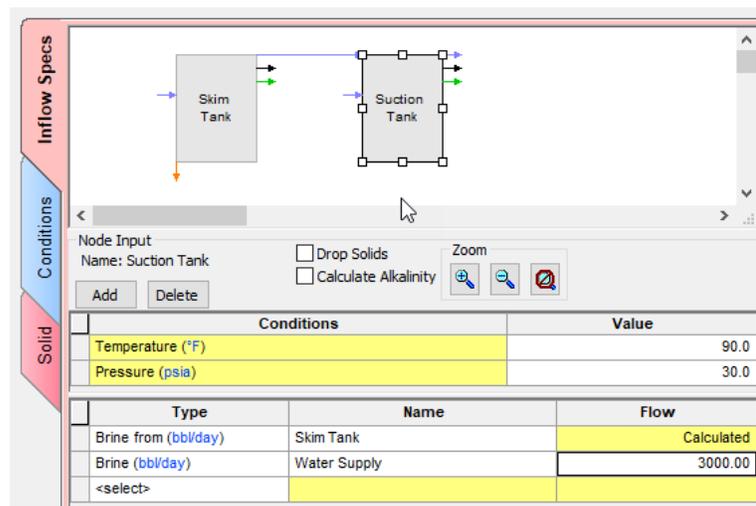


Figure 0-42 Suction Tank Definition

- Click on the Calculate button, or press <Ctrl+F9>
- Go to the **Report** tab, and check for the Pre-scaling Tendencies and Scaling Tendencies
- See the Results

Pre-Scaling Tendencies

Column Filter Applied: Values > 1.0e-4

Temperature Filter Applied: Active TRange Only.

Nodes	CaCO3 (Aragonite)	CaCO3 (Calcite)	CaSO4.2H2O (Gypsum)	CaSO4 (Anhydrite)	FeCO3 (Siderite)	Fe(OH)2 (Amakinite)
Temp Range °C	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Skim Tank	5.20710	8.91186	1.24207	1.39847	0.165109	3.48775e-4
Suction Tank	4.83533	9.86145	1.18226	1.09089	0.147451	1.58132e-4

Nodes	FeS (Pyrrhotite)	FeS (Mackinawite)	MgCO3.3H2O (Nesquehonite)	MgCO3 (Magnesite)	Mg(OH)2 (Brucite)	MgSO4.7H2O (Epsomite)
Temp Range °C	Invalid	Invalid	Invalid	Invalid	Invalid	Invalid
Skim Tank	41958.3	906.834	4.47209e-3	9.15709e-3	1.05810e-3	1.11430e-3
Suction Tank	41552.1	781.107	3.37396e-3	4.74809e-3	3.15204e-4	1.21290e-3

Figure 0-43 the reports tab

Based on these results, it is clear to see that the software predicts the formation of several solids in this process. Solids with a Pre-Scaling Tendency > 1 are predicted to form.

You can download a worked example file for this tutorial from here:

Putting together a calculation – A Tour

Now that we have defined some terms we are now ready to begin entering the information required to run a calculation. In this calculation we will be entering the concentrations of a single brine.

OLI Studio: ScaleChem can be accessed via the Stream Analyzer. Objects for OLI Studio: ScaleChem are Brine, Gas, Oil, Saturator and Contour plots.

To access these objects, click on Streams in the Navigator and you will see these objects amongst others in the Actions Panel.

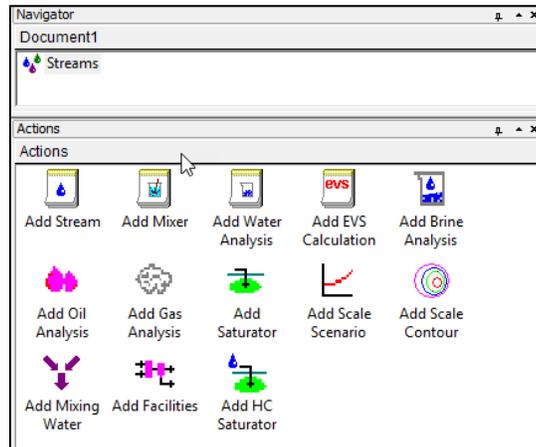


Figure 0-2 OLI Studio: ScaleChem objects.

Task 1 – Create a Brine Analysis

In this tour we will show the main interface of a Brine Analysis, followed by an example of a brine (water analysis) and calculate its scale tendency. Let's begin. Steps for the simulation will be given with bullet points.

- Add Brine Analysis from Actions Panel.



Click on the description Tab. If the **Description** tab is not currently displayed, click on the tab.



Figure 0-3 Brine description tab

The chemistry of the brine needs to be entered. This information includes concentrations, alkalinity, pH and density.

The table below describes the hypothetical water that we will create:

TABLE 3. BRINE ANALYSIS

Cations mg/L		Anions mg/L		Measured Properties		
Na+1	36000	Cl-	57000	Temperature	25 C	
K+1	300	SO4-2	250	Pressure	1 atm	
Ca2+	600	H3CO3-1	600	pH	7.67	
Mg2+	150			Alkalinity	600	
Sr+2	80			Density (mg/L)	1.064	
Ba+2	5			Total Dissolved Solids (mg/L)	96280	

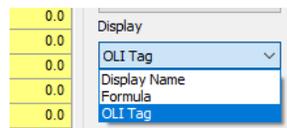
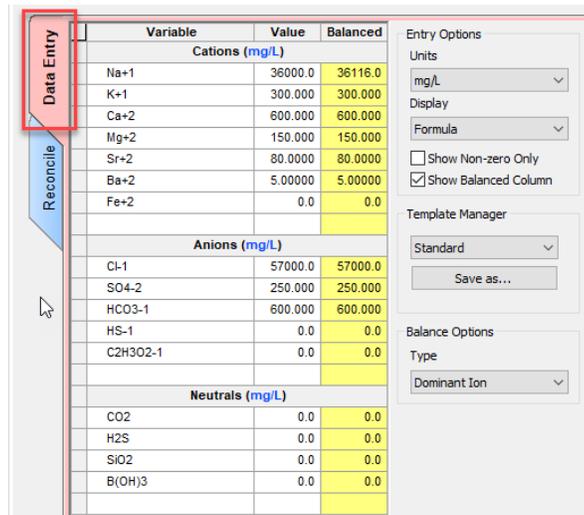


Figure 0-4

- Select **Formula**

You can display an easier-to-read table by showing only the species that have actual concentrations.

- Select the Show **non-zero only** box

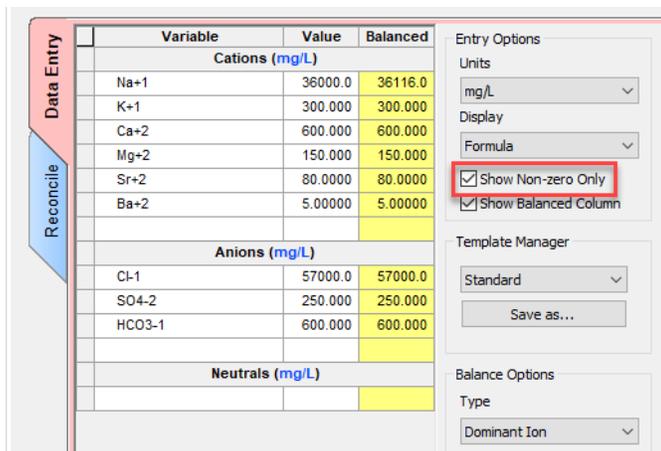


Figure 0-5 Show non-zero only box

Another thing to consider is which **Balance Option** to select.

It is highly unusual for the data to be electrically neutral. Therefore, samples are reconciled for Electroneutrality. After entering each species concentrations, you will notice that Balanced values show up in the column next to values. The Column header says **Balanced**.

The screenshot shows the same software interface as Figure 0-5, but with the 'Balanced' column highlighted with a red box. The table data is the same as in Figure 0-5.

Variable	Value	Balanced
Cations (mg/L)		
Na+1	36000.0	36116.0
K+1	300.000	300.000
Ca+2	600.000	600.000
Mg+2	150.000	150.000
Sr+2	80.0000	80.0000
Ba+2	5.00000	5.00000
Anions (mg/L)		
Cl-1	57000.0	57000.0
SO4-2	250.000	250.000
HCO3-1	600.000	600.000
Neutrals (mg/L)		

Figure 0-6 Electroneutrality balance column

When adding or removing ions to balance charge, the solute mass is altered. We must decide as to whether we keep the mass of the solution constant (thereby adjusting the amount of water) or keeping the amount of water constant and adjusting the solution mass.

The user can select from a variety of balancing options:

Dominant Ions	The dominant ion of the deficient charge is added.
Proration Anion	The complete set of anions is prorated (all concentrations are multiplied by the same ratio).
Proration Cation	The complete set of cations is prorated
Make Up Ion	The selected ion is either added or removed to balance the solution.

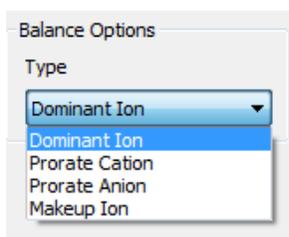


Figure 0-7

- Select **Dominant Ion** balance option type.

You can review the Dominant Ion Charge and Ions needed to balance in the tables presented in the Summary Box.

Summary	
Unit Set: Metric (mass concentration)	
Automatic Chemistry Model	
Aqueous (H+ ion) Databanks:	
Aqueous (H+ ion)	
No Solid phase(s)	
Custom K-fit P-span	
Stream Parameters:	
Temperature (°C)	25.0000
Pressure (atm)	1.00000
Stream amount (L)	1.00000
Dominant Ion Charge Balance (eq/L):	
Cation Charge	1.61776
Anion Charge	-1.62280
Imbalance	-5.04367e-3
Ion(s) needed to balance (mg/L):	
Na+1	115.954
Concentration Data Only.	

Figure 0-8

The summary box shows additional detail about the brine's chemistry and balance option. The stream parameters table shows default values. The Dominant Ion Charge Balance shows the total cations or anions, and the total imbalance.

Now is time to enter the measured property data in the **Reconcile Tab**.

For this example:

- Select **Concentration Data Only** Option
- Check the **Calculate Alkalinity** box
- Enter the measured pH (7.67), density (1.064 g/mL) and TDS (96280 mg/L)
- Leave the **Allow solids to form** unchecked.

We will leave the Allow solids to form unchecked because generally the industry uses acid to preserve water samples, which prevent solids to form. Acidified samples contain the unprecipitated ion concentration, which is what we entered into the brine. In this step, we will eliminate solids because allowing solids to form would change the brine's composition significantly.

See the example set-up in Figure 0-9.

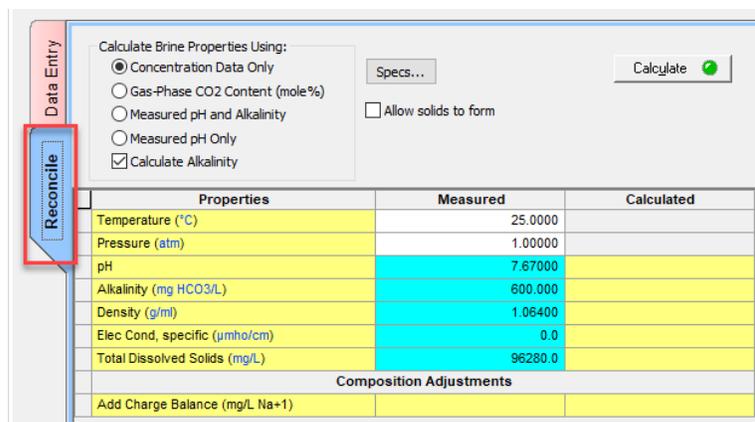


Figure 0-10 Reconcile options

- Select the Calculate Button or press the <F9> key

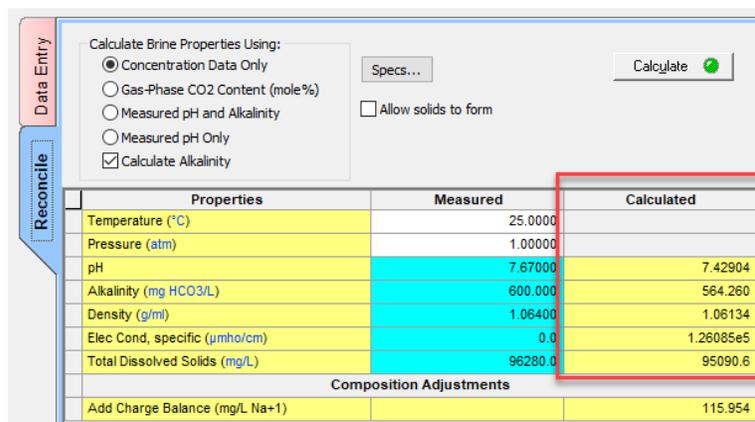


Figure 0-11 Results

Once the calculation is done, the calculated column displays results based on the concentration that were entered in the Data Entry Tab. The calculated results of note are pH=7.43 and 564.26 mg/L as HCO₃ in total alkalinity.

Experimental inaccuracies in sample measurement may, on occasion, result in a calculation that indicates that solid is supersaturated. This can normally be ignored providing that the super saturation is not excessive.

Aqueous Phase Properties:

pH	7.42904
Ionic Strength (mol/mol)	0.0288607
Density (g/ml)	1.06134

Calc. elapsed time: 7.905 sec.
Calculation complete

The brine is supersaturated with 3 solids:
BaSO4 (Barite), CaCO3 (Calcite), SrCO3 (Strontianite)

Alkalinity: 564.260mg HCO3/L

Figure 0-12 Super saturation warning.

More details of the Brine composition can be found in the **Report** Tab.

In the Report tab, scroll down to the Pre and Post Scaling Tendencies, where you will find the results of Scaling Tendencies with Solids off.

Brine-2

Description Design Report File Viewer

Jump to: Brine Analysis Data

Pre and Post Scaling Tendencies

Scale Mineral	Pre-scaling	Pre-index	Post-scaling	Post-index
BaCO3 (Witherite)	7.09380e-4	-3.14912	7.09380e-4	-3.14912
BaSO4 (Barite)	6.22755	0.794317	6.22755	0.794317
CaCO3 (Calcite)	6.35375	0.803030	6.35375	0.803030
CaSO4.2H2O (Gypsum)	0.0174237	-1.75886	0.0174237	-1.75886
CaSO4 (Anhydrite)	0.0142718	-1.84552	0.0142718	-1.84552
KCl (Sylvite)	7.36476e-4	-3.13284	7.36476e-4	-3.13284
NaCl (Halite)	0.0324630	-1.48861	0.0324630	-1.48861
SrCO3 (Strontianite)	2.38156	0.376861	2.38156	0.376861
SrSO4 (Celestine)	0.123629	-0.907879	0.123629	-0.907879

Brine Composition

Cations	Value (mg/L)	Anions	Value (mg/L)	Neutrals	Value (mg/L)
K(+1)	300.000	Cl(-1)	57000.0		
Na(+1)	36116.0	HCO3-(*)	600.000		
Ba(+2)	5.00000	SO4-2	250.350		
Ca(+2)	600.000				
Mg(+2)	150.000				
Sr(+2)	80.0000				

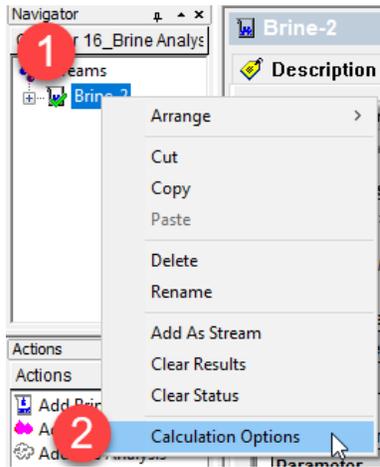
(*) This is total system carbonate including dissolved CO2. THIS IS NOT ALKALINITY!

Figure 0-13 Scaling tendencies and Brine composition with solids off

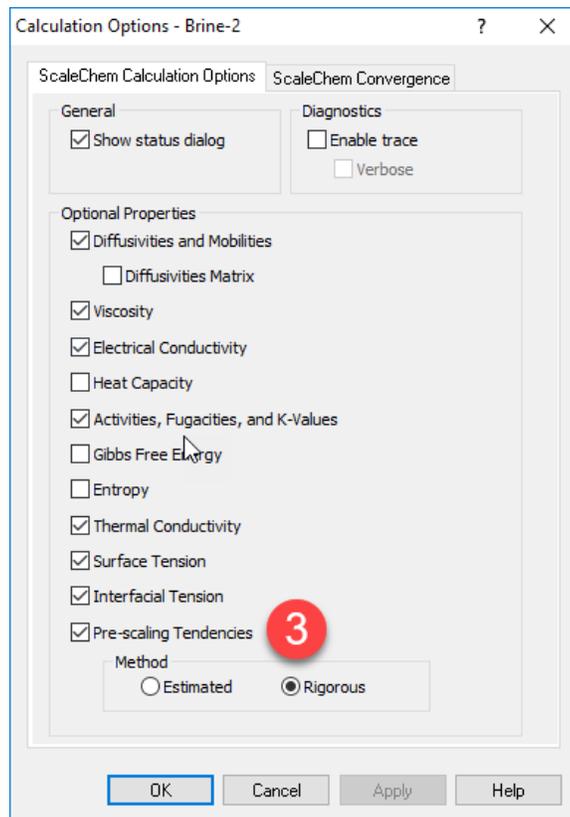
If we would have allowed solids to form, these concentrations would not be as close to the initial values.

Note: If scaling tendencies did not show up in the Report Tab, follow these steps:

- Right click on the brine analysis icon
- Select **Calculation Options**



- Enable **Pre-scaling Tendencies**



Task 2 – Create a Scaling Scenario

The next task is to calculate the brine scaling tendencies. Once the Brine Analysis data is entered and the sample reconciled, we can begin the **Scaling Scenario** calculation.

- Select **Add Scale Scenario** from Actions panel.

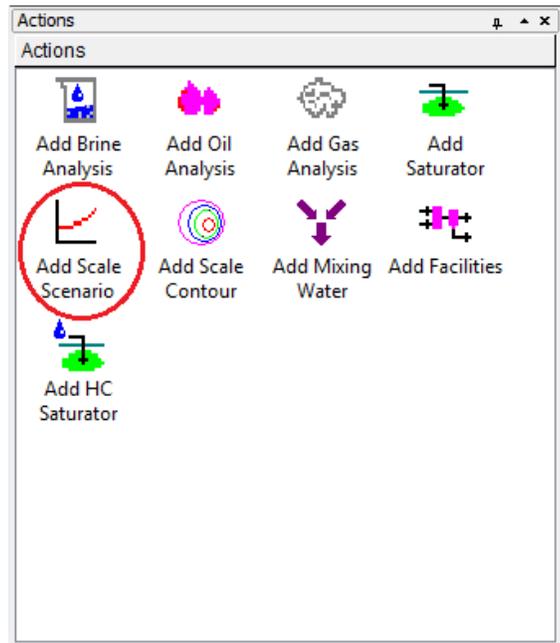


Figure 0-14 Scaling Scenario object

Once we add a **Scale Scenario** object, the software opens to a new **Design** screen containing three vertical tabs: **Inlets**, **Conditions**, and **Solid**. We will work in each of these sections to set up the scaling calculation.

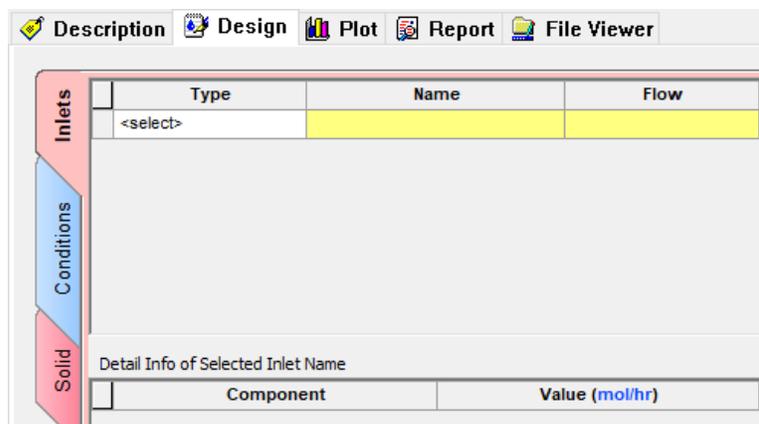


Figure 0-15 Design screen of a newly added Scale Scenario Object

Inlet Tab

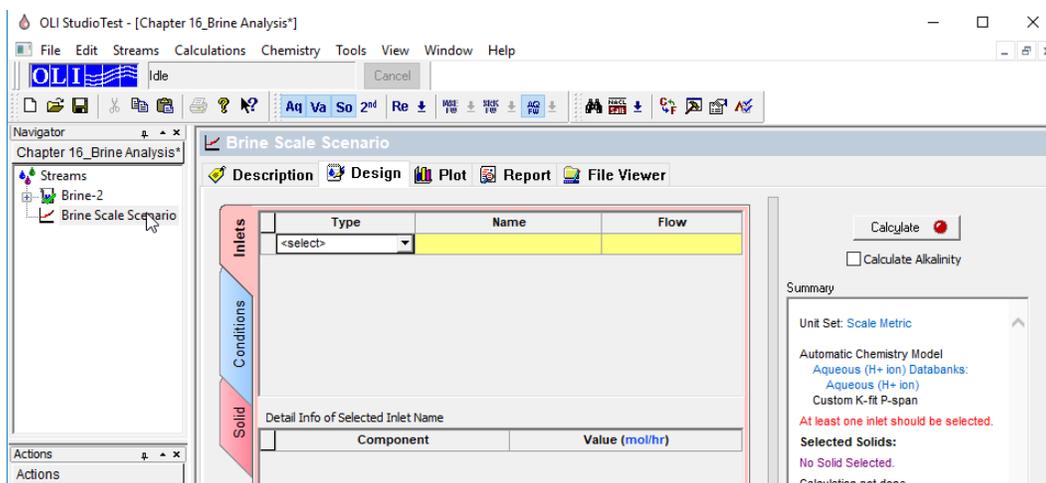
Type You can select the brine, gas or hydrocarbon of interest

Name Click in the Name field. As you position the cursor in the field, a Down Arrow will appear. You can then select from a list of brines, gases or oils already entered into this OLI Studio: ScaleChem document.

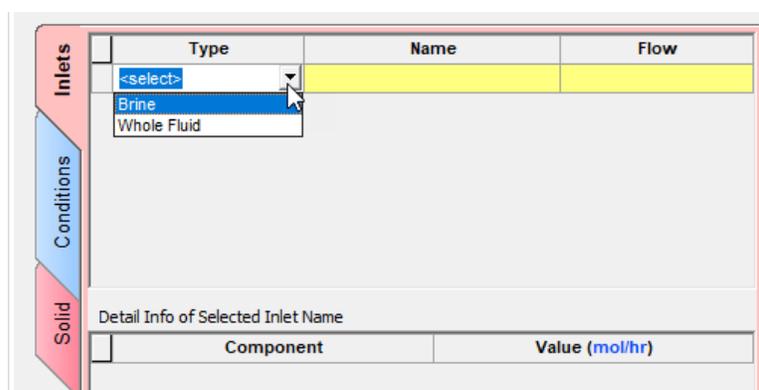
Flow Enter the flow rate for the gas, hydrocarbon or brine.

- Click on the **Description** tab and rename the Scale Scenario as “ Brine Scale Scenario”.
- Then click the **Design** tab.

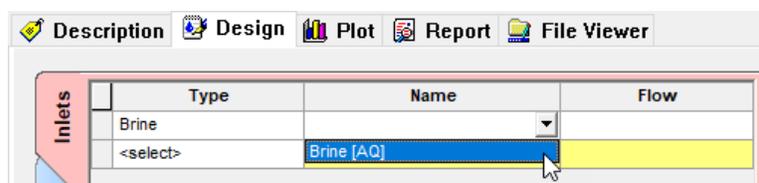
Your screen should now look like image **Error! Reference source not found.**



- Select the **Inlets** tab
- Select the right corner of the first cell in the Type column then select Brine (bbl/day)



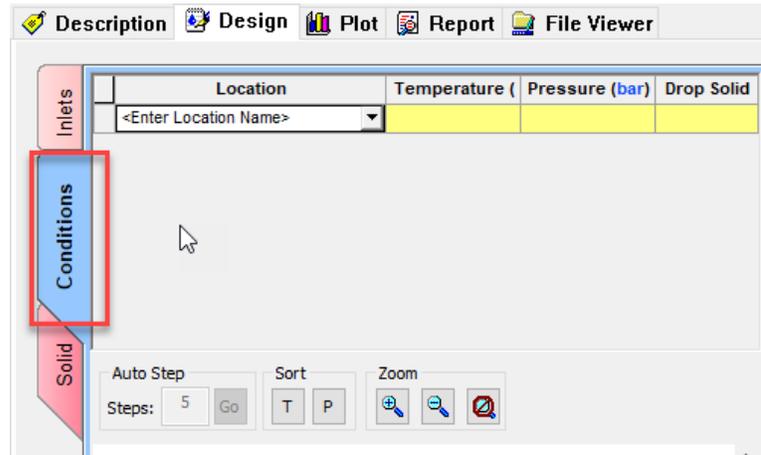
- Select Brine from the drop-down menu in the Name column.



- Enter 1400 (bbl/day) in the Flow Column. Please change units if necessary.

Conditions Tab

- Select the **Conditions** Tab (vertical blue tab on the left-hand side of the Design screen)



The **Conditions** section is where we enter points along the production scheme. The first column is Location. We can use the dropdown menu in each row to select a location or type in our own location name.

- Type in the following conditions or use the dropdown menu within the Location cells.

TABLE 4. SCALE SCENARIO LOCATIONS

Location	Temperature (C)	Pressue (bar)
Reservoir	125	275
Bottomhole	125	280
Downhole	115	190
Midwell	105	130
Wellhead	100	100
Choke	90	80
Separator	60	30

The diagram within the Conditions screen and the list of locations in the Summary box both show the locations in the order that we entered. This screen has options for zooming, auto steps, sorting by temperature or pressure, and dropping solids at particular conditions.

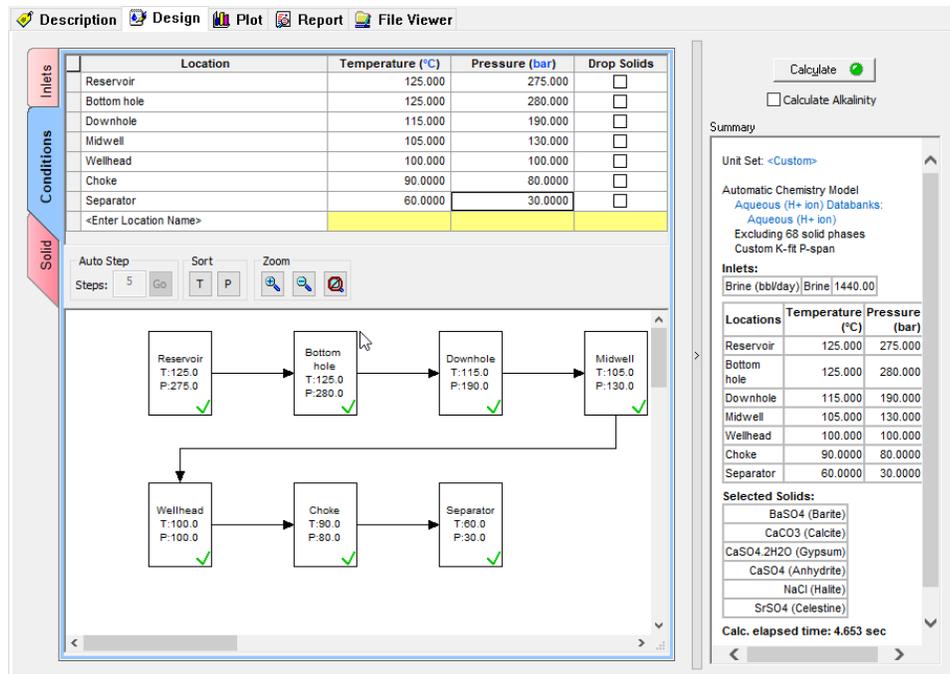


Figure 0-16 List of locations entered

The graphical view clearly shows the five locations and their Temperature and pressure conditions.

The Drop Solids checkbox column at the very end of the grid is designed to help the users decide if they want to carry forward solids from certain locations or not.

Solid Tab

- Select the **Solid** Tab
- Make sure that the solid button in the menu bar is selected.



- Select the Standard checkbox

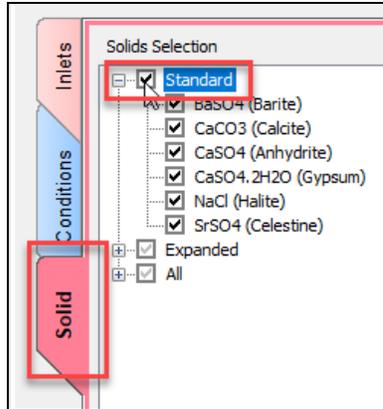


Figure 0-17 Solid Tab Options

- Press the **Calculate** Button or select the <F9> key
- Select the **Plot Tab**

You can customize which curves are visible by selecting the *Variables* button.

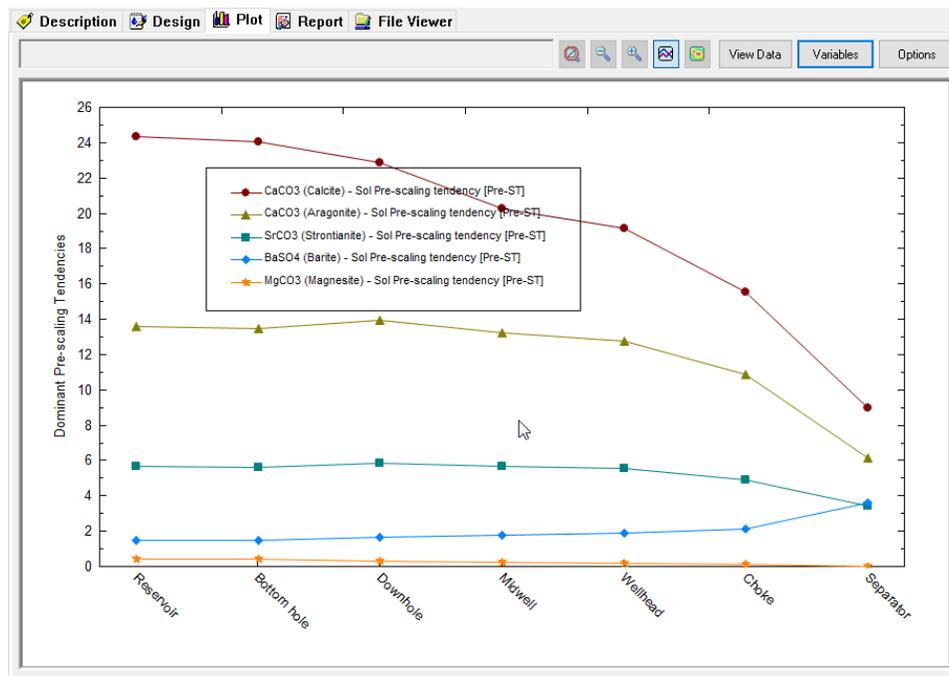
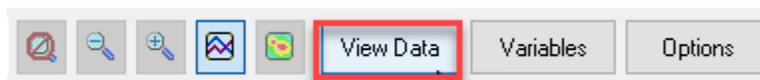


Figure 0-18 Plot Results

- Select the View Data button

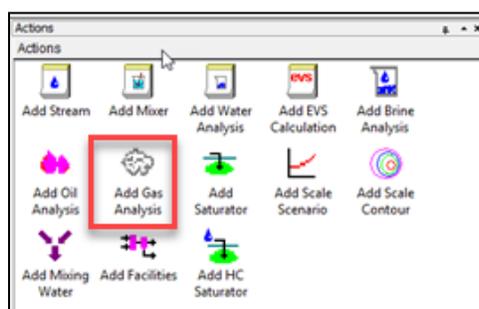


The *View Data* button shows the pre-scaling tendency at each location. We can copy the results of this table to a program like Excel by selecting the top left cell then selecting <Ctrl>+<C> on the keyboard.

Task 3 – Create a Gas Analysis

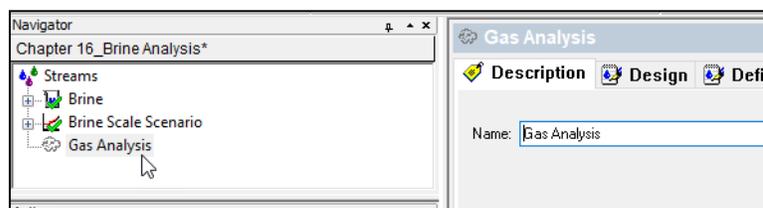
This Task introduces the Gas Analysis object. It is a very simple object with a limited number of functions. Its purpose is to provide a quick way to enter a pure-component hydrocarbon gas.

- Double click on the **Add Gas Analysis** object in the Actions Panel



This adds a Gas object to the Navigator panel.

- Select the **Description** tab, then rename the object Gas Analysis.



Enter the following composition and values in the Inflows grid:

TABLE 5. GAS ANALYSIS

Formula	Component Name	mole %	Formula	Component Name	mole %
H2O	Water	1.80	C3H8	Propane	8.00
N2	Nitrogen	3.00	i-C4H10	Isobutane	1.00
CO2	Carbon dioxide	1.50	n-C4H10	n-Butane	3.00
H2S	Hydrogen sulfide	0.50	i-C5H12	Isopentane	0.50
CH4	Methane	65.5	n-C5H12	n-Pentane	0.70
C2H6	Ethane	14.0	n-C6H14	n-Hexane	0.50

The *Inflows* grid will look like one of the two below, depending on the Names view you select.

Component	Value	Normalized
Subtotal: 100.0		Subtotal: 100.000/
H2O	1.80000	1.80000
N2	3.00000	3.00000
CO2	1.50000	1.50000
H2S	0.500000	0.500000
CH4	65.5000	65.5000
C2H6	14.0000	14.0000
C3H8	8.00000	8.00000
i-C4H10	1.00000	1.00000
n-C4H10	3.00000	3.00000
i-C5H12	0.500000	0.500000
C5H12	0.700000	0.700000
C6H14	0.500000	0.500000

Figure 0-19 Inflows Tab

A brief description of the Inflows tab is given below:

Gas The gas composition is entered as mole% or volume% (these are equivalent for an ideal gas). The total must be 100% and can be adjusted by normalizing, or by letting the program determine the amount of hydrocarbon gases present. The gases that are displayed here will be either the standard gases or expanded gases. Toggling from the standard to expanded can be achieved by clicking the Gases button.

Normalizing You can enter just the amounts of carbon dioxide, hydrogen sulfide and water and let the program Calculate Hydrocarbon Percent (default) or enter all values and then normalize to 100%.

Displaying Gases You can display the name of the gases by Name (the default) or by Formula. OLI Studio: ScaleChem will assume that all of the hydrocarbon gas is methane (CH4). If you want to use a more detailed list of hydrocarbon gases, click on Gases to expand the list.

Frequently the data received by the user refers to gas compositions that are reported on a "Dry" Basis. Any water that was present in the actual gas has been removed mathematically and reported as a dry sample.

This is the extent of the gas entry step. There are modifications that can be part of the gas analysis entry step (in the Reconcile Tab), but in this case, they are not considered. Now that the gas is entered, the scale scenario considered in Task-2 will be recomputed.

Component	Normalized	Reconciled Gas
H2O	1.80000	1.75645
N2	3.00000	3.00133
CO2	1.50000	1.50066
H2S	0.500000	0.500221
CH4	65.5000	65.5290
C2H6	14.0000	14.0062
C3H8	8.00000	8.00355
i-C4H10	1.00000	1.00044
n-C4H10	3.00000	3.00133
i-C5H12	0.500000	0.500222
C5H12	0.700000	0.700310
C6H14	0.500000	0.500222

Conditions	Value
Temperature (°C)	15.5556
Pressure (atm)	1.00231

Summary

Unit Set: Metric (mole fraction)

Automatic Chemistry Model
Aqueous (H+ ion) Databanks:
Aqueous (H+ ion)
Second Liquid phase
Custom K-fit P-span

Stream Parameters:
Temperature (°C) 15.5556
Pressure (atm) 1.00231

Makeup Normalization: CH4.

Equilibrium Calculation.

Phase Amounts:
Aqueous (mol) 0.0443276
Vapor (mol) 99.9557
Solid (mol) 0.0
2nd Liquid (mol) 0.0

Aqueous Phase Properties:
pH 4.75178
Ionic Strength (mol/mol) 3.20591e-7
Density (g/ml) 0.999257

Calc. elapsed time: 0.846 sec.
Calculation complete

In the *Reconcile* Tab, under Conditions, you can saturate the Gas with Water at determined conditions.

Saturated with At the entered conditions, the amount of water that the gas can contain before an aqueous liquid will form is determined. If the Water Vapor field is entered, then that value is used as an initial guess to the calculation.

The calculated value is NOT updated in the actual gas composition. The user must enter that value manually if desired.

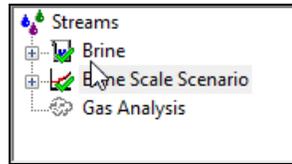
At Conditions Enter the temperature, pressure and water content of the gas. Click the Calculate button to start the calculation.

You can change the units of the calculation by clicking the Units button. When the calculation is complete, you may view the internal files by clicking the View Files button (currently grayed-out in the above example).

Task 4 – Recalculate Scale Scenario with Gas

The gas analysis will be added to the Scale Scenario so that it is considered during the scale evaluation.

- Select the Brine Scale Scenario icon in the navigator panel



- Select the **Design** Tab (horizontal tab) if not automatically sent there
- Select the **Inlets** tab (vertical) if not automatically sent there
- In the **Type** Column Add **Gas**

Type	Name	Flow
Brine (bbl/day)	Brine	1400.00
Gas (std E3m3/day)		
Brine		
Whole Fluid		
Gas		

- In the **Name** column select **Gas Analysis**

Type	Name	Flow
Brine (bbl/day)	Brine	1400.00
Gas (std E3m3/day)		
<select>	Gas Analysis	

- Enter a flowrate of 250 std E3m3/day in the flow cell

Type	Name	Flow
Brine (bbl/day)	Brine	1400.00
Gas (std E3m3/day)	Gas Analysis	250.000
<select>		

- Calculate (Press <F9>)
- Select **Plot** Tab

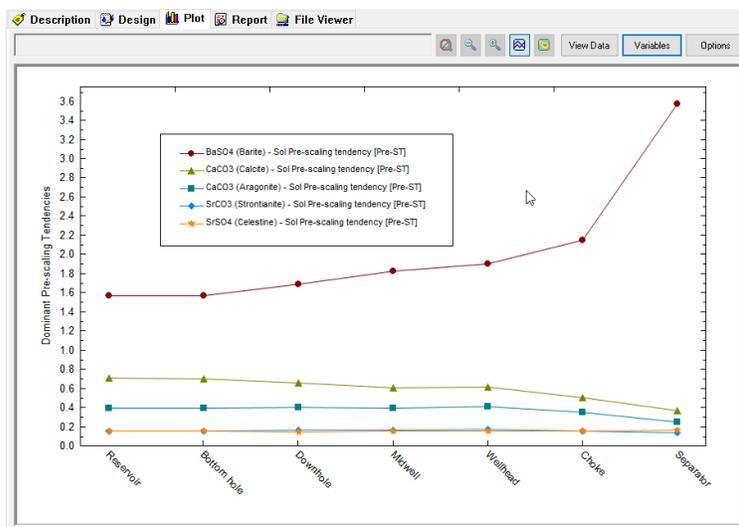
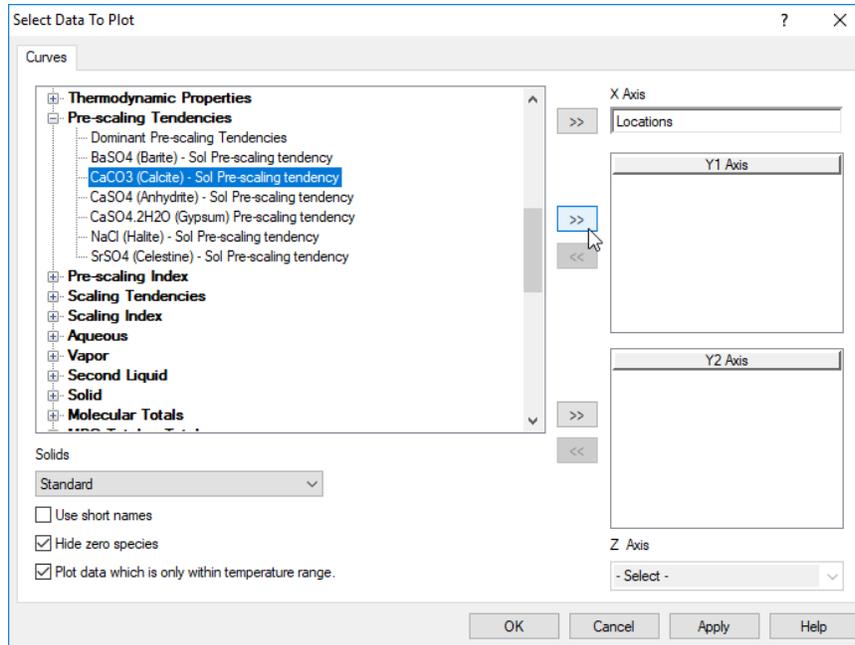


Figure 0-20 Plot Results

- Select Variables button
- Remove all the variables from the Y1 Axis and the Y2 axis by double-clicking on the variables (this removes them from the list). Alternatively, highlight each variable and click on the double-arrow.

You will replace the existing variables with the calcite pre-scaling tendency.

- Expand the Pre-scaling Tendencies button by clicking the + sign
- Double-click on the CaCO3 (Calcite) variable to move it to the Y1 Axis
- Expand the Additional Stream Parameters and add pH to the Y2 axis
- Click **OK**



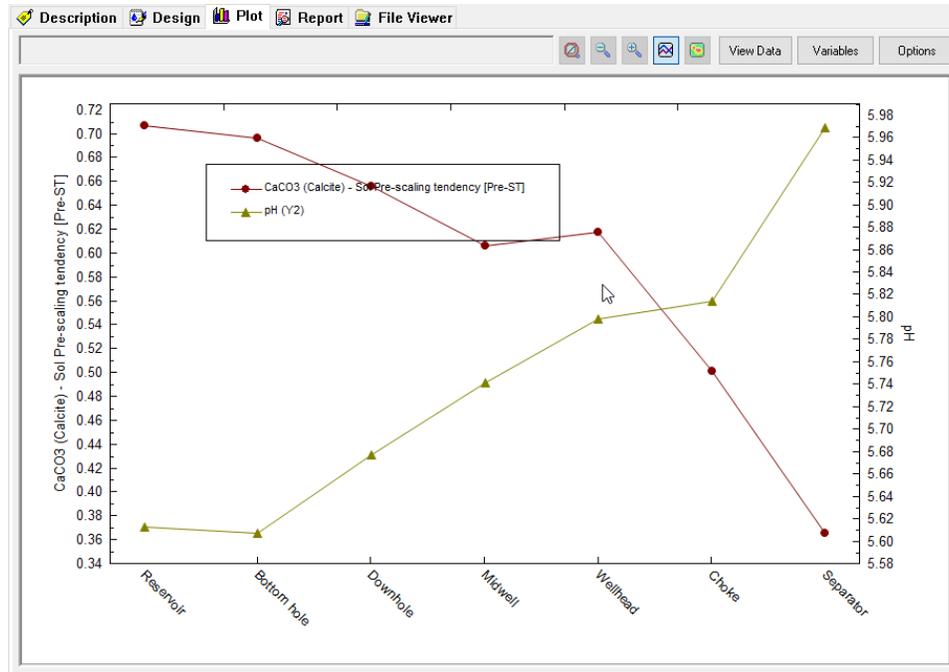
If you are in the *View Data* view, then the table should be similar to the one below.

	Locations	CaCO3 (Calcite) - Sol Pre-scaling tendency	pH
		Pre-ST	
1	Reservoir	0.705312	5.61211
2	Bottom hole	0.694891	5.60661
3	Downhole	0.655192	5.67654
4	Midwell	0.604697	5.74096
5	Wellhead	0.616784	5.79768
6	Choke	0.500689	5.81369
7	Separator	1.24448	6.14419

Calcite is sub-saturated ($S < 1$) at all locations, except the separator.

- Select the *View plot* button

The decreasing calcite saturation trend and the increasing pH is easier to see from the plot view.



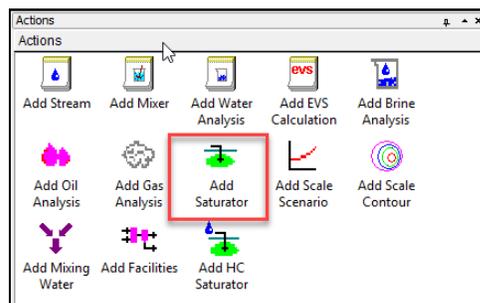
You are done with this Tour! Don't forget to save your file.

Task 5 – Creating a Saturator Object

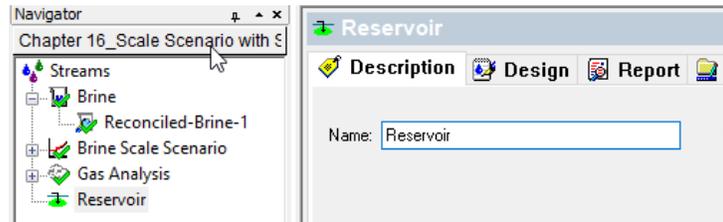
You will use the *Saturator* object to set the reservoir minerals at equilibrium with the produced fluid. It is reasonable, in some cases, to saturate the produced fluid with common evaporite and secondary minerals like CaCO_3 , $\text{CaSO}_4 \cdot \text{H}_2\text{O}$, FeCO_3 , and NaCl . This is based on the assumption that as the reservoir fluid flows through the rock pores, there is sufficient time to interact with the surface minerals. This is based on a second assumption that the vertical column of liquid and gas are in complete equilibrium and that the saturating minerals are distributed throughout the reservoir matrix, such that complete water-mineral contact is possible.

In this case we are going to simulate a particular oil & gas well: ABC. This well produces from calcite-cemented sandstone. Barite is also present in minor quantities in the rock matrix. You will, therefore, create a reservoir called ABC Reservoir and saturate the Brine (previously calculated) with calcite and barite. You will then recalculate the Brine Scale Scenario.

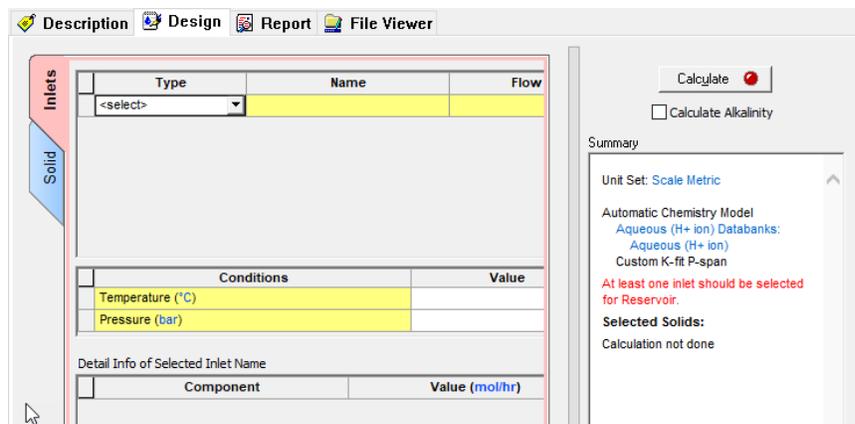
- Add a Saturator Object.



- Select the **Description** Tab to rename the Object **Reservoir**



- Select the **Design** Tab

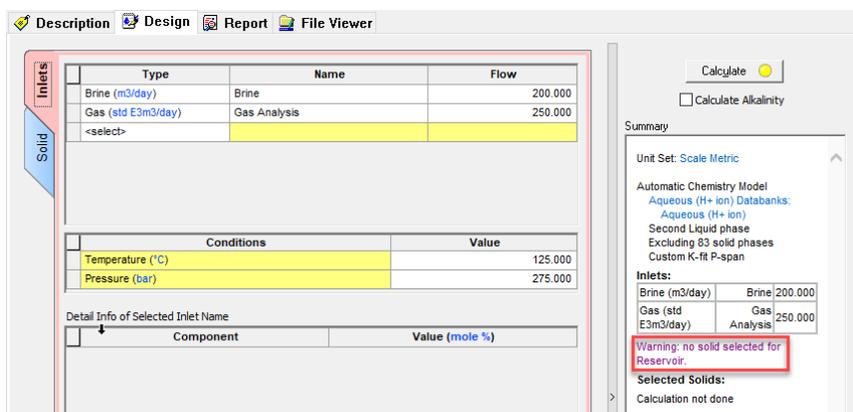


The Saturator has two vertical tabs: Inlets and Solid.

In the **Inlets** Tab the Fluids are entered in the top grid and the Conditions are entered in the bottom grid.

Solids are selected and saturated in the **Solid** Tab.

- Enter the Brine calculated in Task 1
- Enter the Gas calculated in Task 3
- Enter the Reservoir conditions: 125 C and 275 bar in the conditions section.



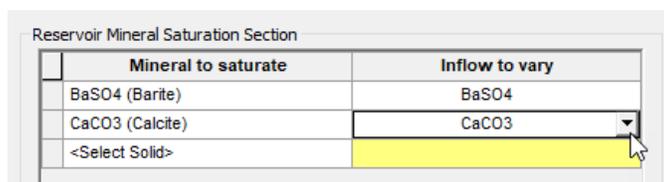
The Saturator's calculate button is yellow. This is because solids have not been selected yet. A warning also appears in the summary box. A yellow button is allowable, and a calculation may continue; it is merely a warning that the case is incomplete.

- Select the **Solid** Tab (vertical tab)
- Select the Standard checkbox

This last step instructs the software to allow the selected solids to precipitate – to include solid-liquid equilibrium equation in the calculation. It **does not** instruct the software to saturate these solids. Rather, if the phase is supersaturated, then it will precipitate. It is in the lower section that saturated solids are chosen.

This section contains two columns. The first (Solid) is the mineral to be saturated, and the second (inflow) is the cation and anion to be adjusted. If, for example, Barite is subsaturated in the existing fluid, then Ba+2 and SO4-2 are added. The amount of each added is stoichiometrically equivalent; one Ba+2 with one SO4-2, which maintains charge balance. If, for example, (again) Calcite is supersaturated, then equal mole amounts of Ca+2 and CO3-2 will be removed from the fluid. This inflow will be positive if the solid is subsaturated in the existing fluid, or it will be negative if the solid is supersaturated.

- Use the Solid drop-down menus to select BaSO4 (Barite) and CaCO3 (Calcite) as solids to saturate
- Use the Inflow drop-down menu to select BaSO4 and CaCO3 as solids to saturate (it should have been selected automatically).



At this point, the Calculate button is green indicating that the specifications are complete.

- Calculate (or press the <F9> key)
- Click the **Report** tab

The Saturator Report tab contains several tables: Saturation Details, Inlet Summary, Stream/Phase Properties, Pre and Post Scaling Tendencies, Brine Composition, Gas Composition, and if selected an inlet summary.

- Scroll down to the Pre and Post Scaling Tendencies Table

Pre and Post Scaling Tendencies

Formula	Mineral	Excess Solute mg/L	Excess Solute lb/1000bbl	Pre-Scale S, ST	Pre-Scale SI, Index	Post-Scale S, ST	Post-Scale SI, Index
CaSO4.2H2O	Gypsum	0.0	0.0	0.0179366	-1.74626	0.0179365	-1.74626
SrSO4	Celestine	0.0	0.0	0.148191	-0.829178	0.148191	-0.829178
SrCO3	Strontianite			0.209852	-0.678087	0.209852	-0.678087
BaSO4	Barite	2.64658e-5	9.27644e-6	1.00000	1.82534e-6	1.00000	0.0
CaSO4	Anhydrite	0.0	0.0	0.0934633	-1.02936	0.0934633	-1.02936
CaCO3	Calcite	1.13495e-5	3.97806e-6	1.00000	-4.81593e-8	1.00000	0.0
Mg(OH)2	Brucite			4.98480e-4	-3.30235	4.98479e-4	-3.30235
NaCl	Halite	0.0	0.0	0.0245553	-1.60985	0.0245553	-1.60985
KCl	Sylvite			2.14382e-4	-3.66881	2.14382e-4	-3.66881

Excess solute or Max Scale: The solids amount forming at equilibrium.

Pre-Scale: The saturation ratio before solids precipitate.

Post-Scale: The saturation ratio AFTER solids precipitate (if solids are selected).

S, ST – Saturation, Scale Tendency: The ratio of the concentration (activity) to its solubility (S=1).

SI – Scale Index: Log(S).

The Max scale column shows that trace amounts of BaSO₄ and CaCO₃ are present in the water. These exceedingly small values (in the parts-per-trillion range) are the specifications or targets for the calculation. The software sets these target solid concentrations and then adjusts up or down, the BaSO₄ and CaCO₃ inflows until it reaches these targets. These part-per-trillion values may look arbitrary, but in fact the values are equivalent to 1e-10 moles of solid/kg water.

Notice also, that the pre-scale tendency for BaSO₄ and CaCO₃ are set to 1.0, by saturation definition. That is, these are not calculated, they are defined. The remaining scale tendencies are computed.

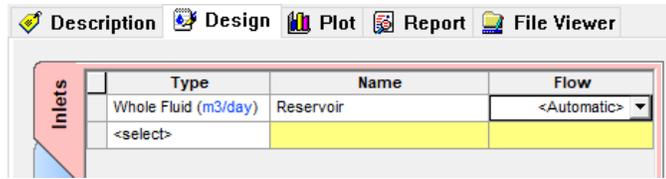
Task 6 – Recalculate the Scale Scenario with the Saturated Reservoir

Considerable time is spent creating what is hoped to be a more representative brine. The Brine is reconciled for charge balance, and where needed, alkalinity and pH; the gas is saturated with water as needed (though not done in this case), and lastly the fluids are set to equilibrium with important reservoir minerals. It is only after these steps are complete, and that there is confidence that the assumptions and calculations are representative of the process, that a final scaling calculation is run.

The **Reservoir** calculation contains the representative fluid. It is, therefore, the output of this calculation that will be used in all subsequent calculations. To access this output, a new Type of fluid, Whole Fluid is defined. The Whole Fluid type represents 100% of the contents of a previous calculation, regardless of phase.

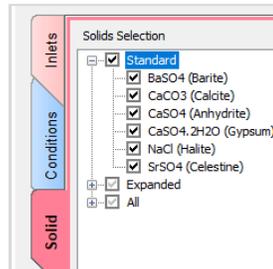
You will use the Whole Fluid from the Reservoir to rerun the scaling calculations.

- Select *Brine Scale Scenario* in the Navigator Pane and rename it **Reservoir Scale Scenario**
- Select the **Design** tab
- In the **Inlets** tab in the **Type** column delete the Brine and Gas from the Type column
- Add **Whole Fluid**
- In the **Name** column select **Reservoir**
- In the **Flow** column select **<Automatic>**

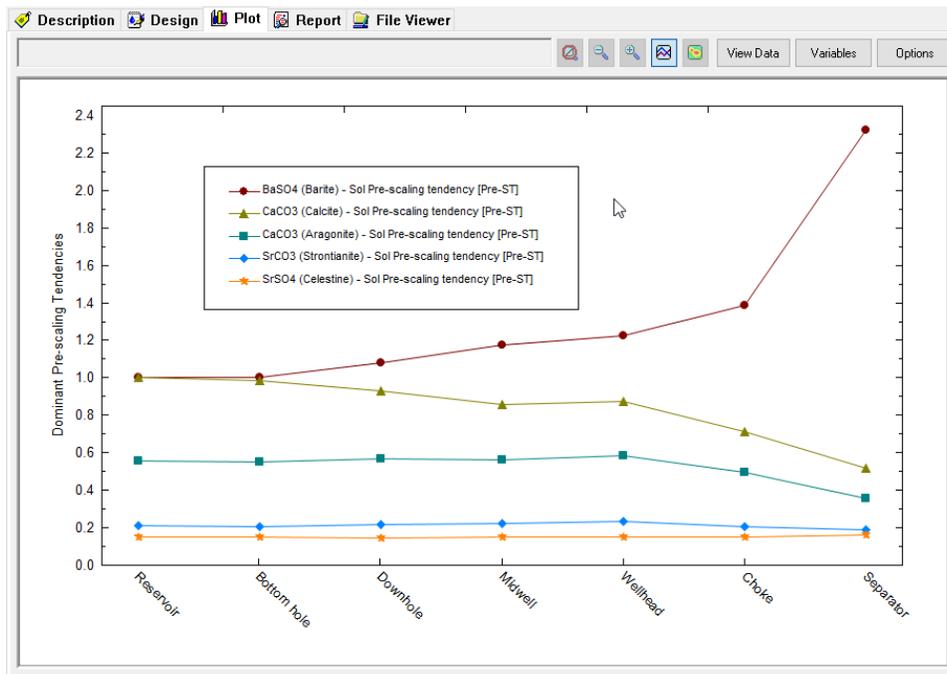


Note: The Whole Fluid type refers to all the phases within the fluid. The Automatic option takes the final flow rate phase of the separator and automatically enters this as the flow rate in the Scale Scenario calculation.

- Go to the **Solid** tab and make sure that the Standard box is checked



- Calculate (Press <F9>)
- Select **Plot** tab and select *View Plot*



The Saturator is a tool for normalizing the thermodynamics of a reservoir system. The purpose of this calculation is to apply the constraint of solid-liquid equilibrium on a system to create a specific compositional starting point.

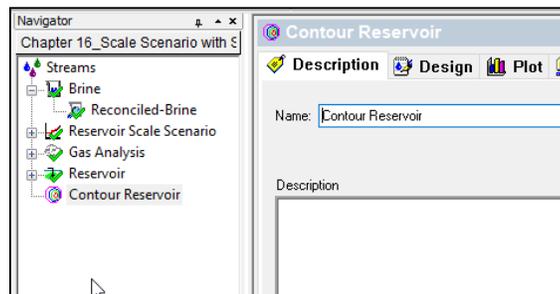
The basis of this calculation is that water in the pores of a rock matrix is at equilibrium with the mineral surface. Some questions to consider are whether it is reasonable to assume that a reservoir gas, oil, water, and rock are in equilibrium. Furthermore, we should also consider over what vertical and radial distance we can make this claim.

Regardless of the inconsistencies, the industry widely accepts this approach. It is up to the analyst to decide if the Saturator produces a more representative fluid than the original data.

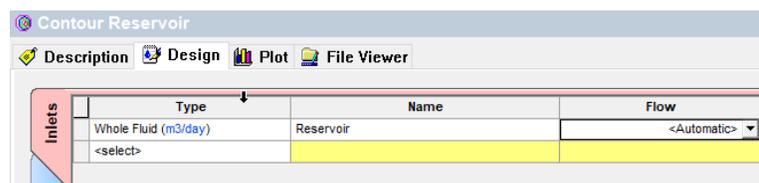
Task 7 – Add a Contour Diagram

An alternative to the *Scale Scenario* calculation is the *Contour Diagram*. The conditions defined in the Scale Scenario are specific to production locations, and generally no more than ten are entered. By comparison, the conditions defined in the Contour Diagram are a range of temperatures and pressures. The object then computes a matrix of temperature and pressure conditions and creates a presentation-quality contour diagram.

- Add Scale Contour
- Rename the Object **Contour Reservoir**



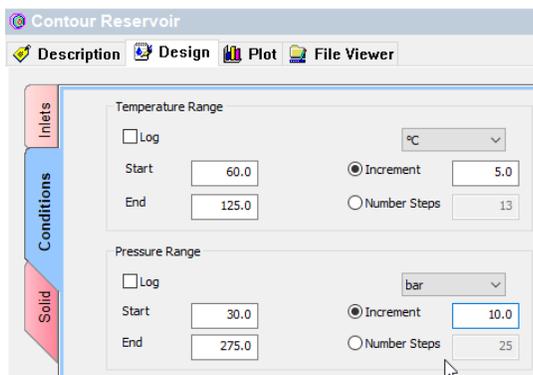
- Select the **Design** Tab
- Select the **Inlets** (vertical) tab
- Select the bottom right corner of the 1st cell in the Inlet grid and choose **Whole Fluid**
- Select **Reservoir** in the 2nd column
- Keep the **<Automatic>** flow rate option in the 3rd column



- Click Conditions (vertical) tab

The minimum and maximum conditions are at the Separator 60C, 30 bar and Reservoir 125C, 275 bar. These are the start and end range of the study. To create a reasonable number of calculations (~300) and to keep the matrix somewhat symmetric, we will use increments of 2 C and 10 bar.

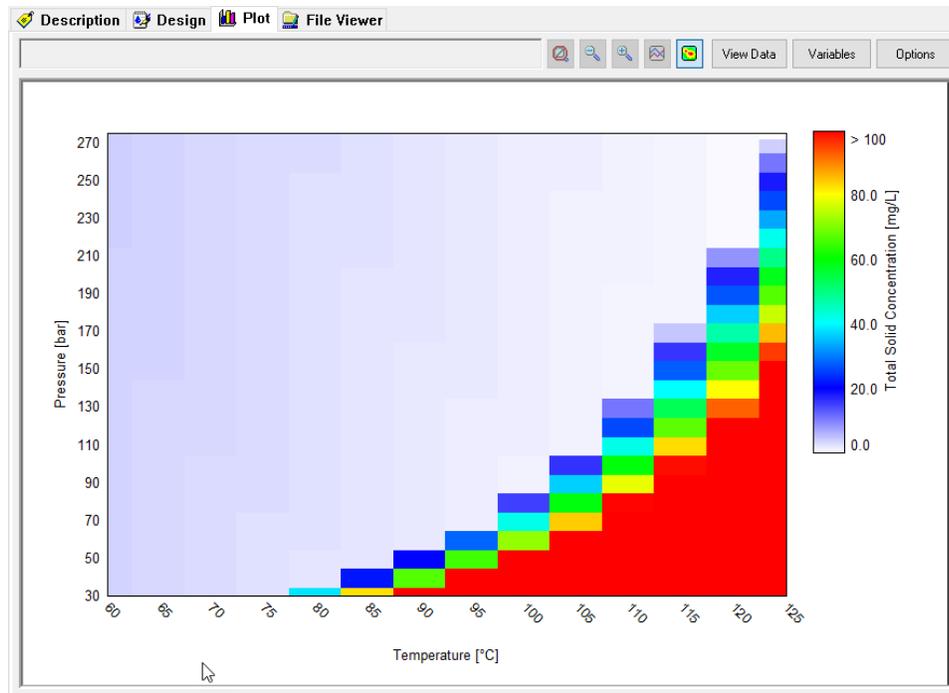
- Change the Start to 60
- Change the End to 125
- Select the Increment radio button
- Enter 5 as the increment
- Uncheck the Log box (if it is checked)
- In the Pressure Range box, change the Start to 30
- Change the End to 275
- Select the Increment radio button (uncheck the Log box first)
- Change the Increment to 10



This produces a matrix of 13 temperature and 15 pressure steps. This produces a 14x16 matrix, or 224 calculations.

	Temperature	Pressure
Units	°C	bar
Start	60.0	1.01325
Stop	125.0	10.1325
Step Size	5.0	0.60795
No. Steps	13.0	15.0
Calculations	224	

- Select the **Solid** Tab
- Check the Standard box
- Calculate. The calculation should take less than 10 min to be complete
- When calculation is done, go to the **Plot** tab



The default plot is the total solids forming. The color scale represents a different numerical range. The red cells indicate heavier solid precipitation, and the faint purple-white in the center and left of the screen indicate that little to no scale forms. The upper right corner is the Reservoir conditions (125C and 275 bar). The lower left represents Separator conditions (60C and 30 bar). At both points, minimal solids are computed to form. The fluid traveling through the piping traverses this plot as temperature and pressure decreases. Layering production conditions (e.g., early to late life) over this plot provides an indication as to whether production will be at risk now or in the future. For example, if the pressure decline is significant (e.g., 60 bar), then the fluid will be unstable at the higher temperatures (bottom of well).

This completes our Tour in OLI Studio: ScaleChem.

You can download a worked example file for this tutorial from here: [Chapter 16 – Basic OLI Studio: ScaleChem.](#)

Chapter V – Plotting Options

To view OLI Studio: ScaleChem Plot Options click on Plot tab. This is located next to the design tab. This will show a default plot.

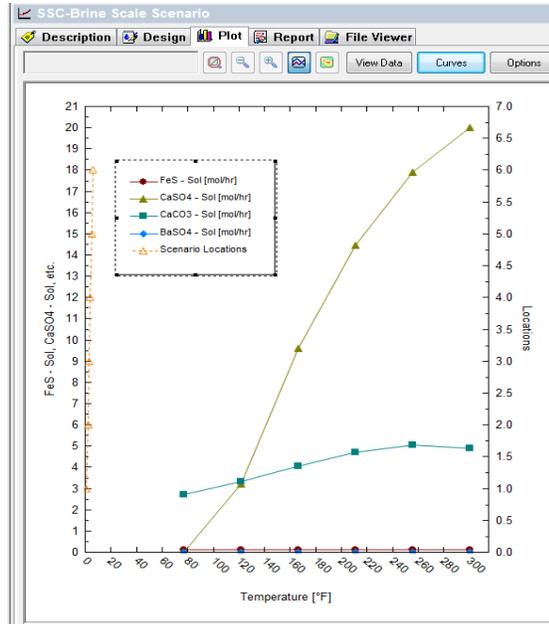


Figure 0-15 Displaying the Default plot

Determining the Default Plot

After returning from the OLI Solver, OLI Studio: ScaleChem analyzes the output file to determine an acceptable default plot. The precedence followed is this:

X axis Variable

Y axis variable

If the temperature varying, use Temperature else if Pressure varying, use Pressure else use Case number or Mix Ratio

If any precipitates, use the solids else user any pre-scaling indices > 0 to a maximum of 8 variables

Viewing Data

The data which is used to create the plot can be viewed by using the View Data button. In general, the View Data button shows the report which has been created. Use the View Plot button to return to the plot.

Selecting Data

To add to the variables displayed or to change the variables which are displayed, use the Select Data button, which is to the right of the Plot. Right click on the X or Y axis will pop up a format plot window. It has options like Format X-axis, Adjust Scale, Label Axes etc. Curves Button will prompt a Select data window.

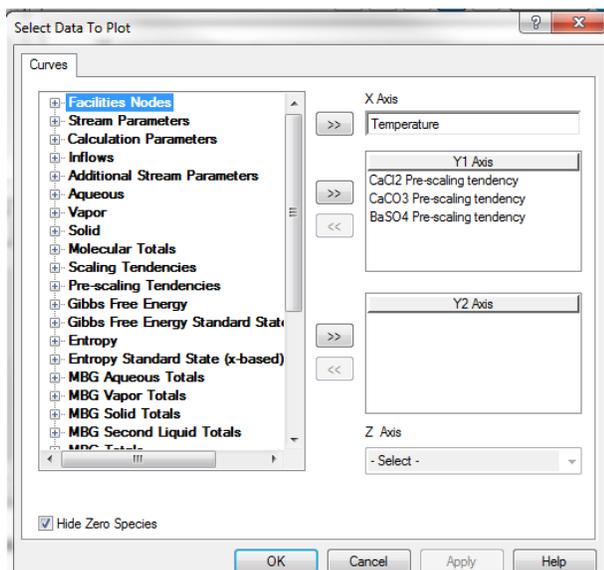


Figure 0-16 Selecting Data

Data Available

The list of variables which can be displayed are shown as Data Available. Stream parameters include Temperature and Pressure etc. Additional Stream parameters contain density, viscosity etc.

Selecting Data

To select different X and Y axis variables, highlight the variable in the Data Available box, and then click on >> button either before X or Y Axis. Of course, variables can also be removed from the axis variables by highlighting the selected variable, and clicking the << button.

Minimum Data Required

A minimum of one X variable and one Y variable must be selected from the Select Data facility, in order to leave Select Data. Of course, you always have the option of canceling, and returning to the original plot.

Modifying the plot

Hiding Curves

One nice feature of the OLI Analyzers is that you can generate a lot of points to plot many variables. You can also perform multiple series of plots such as plotting temperature curves as a function of pressure. This is what we are showing below. This is a pre-run temperature survey with pressure selected as the secondary (*then by...*) survey.

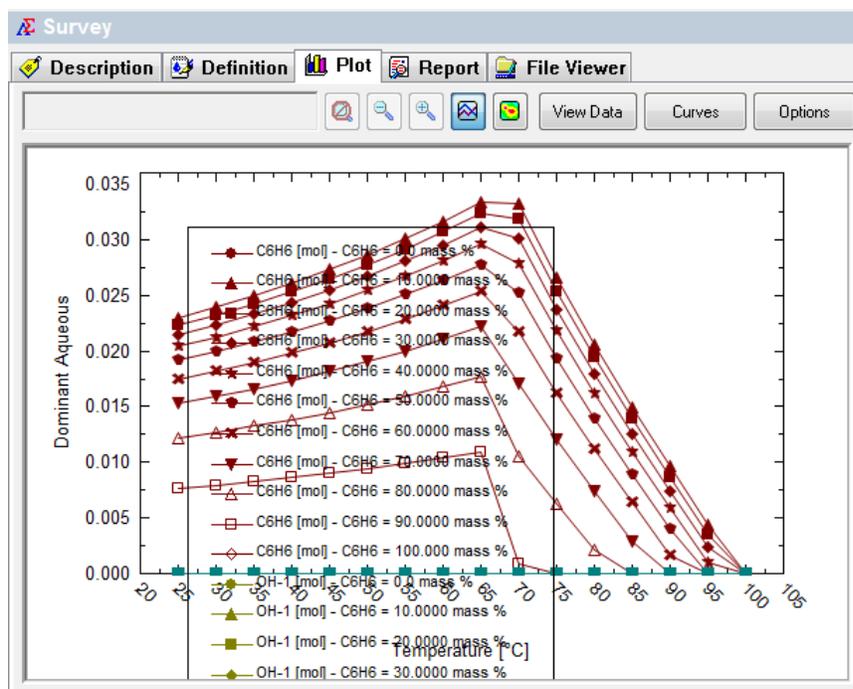


Figure 0-1

As you can see there is a lot of data, the plot is very hard to read. Fortunately, we have created a tool to clean up the plot. Click the **Options** button in the upper right-hand corner.

This will display the **Customize Plot** dialog. Select the **Curves** category.

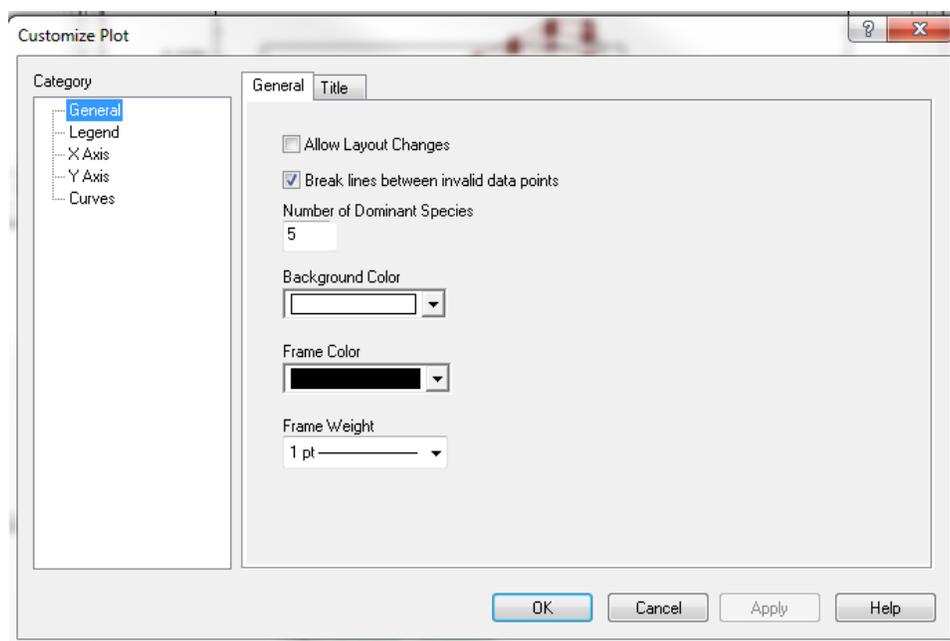


Figure 0-2

Each data series in the current plot is displayed. As you can see in the dialog below there are many series currently displayed. You could hide each one individually or select groups to hide. We are first going to hide all the curves. Select the first item in the list and hold the **Shift Key**.

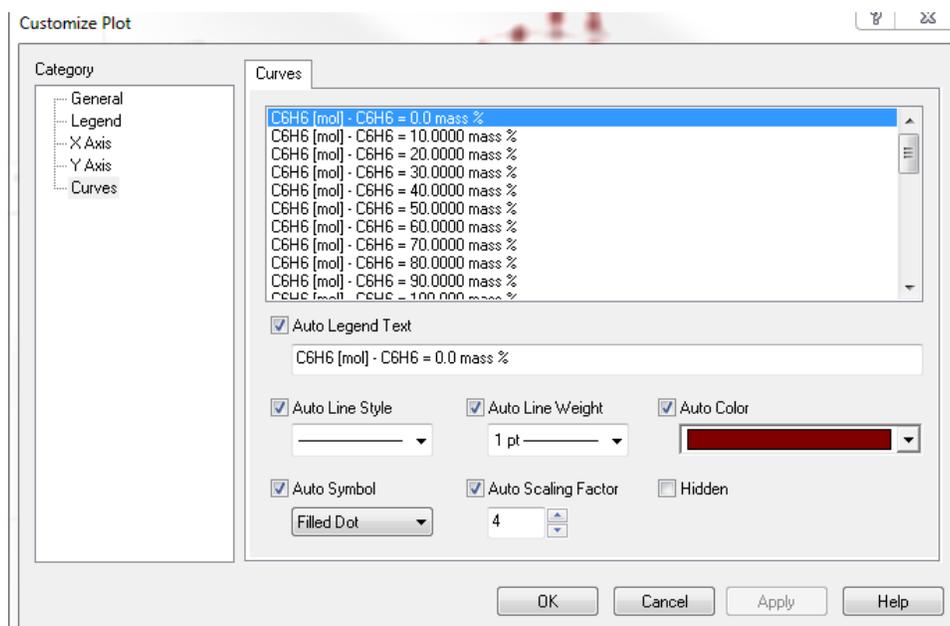


Figure 0-3

Scroll down to the last item in the list

```
H3O+1 [mol] - C6H6 = 10.0000 mass %  
H3O+1 [mol] - C6H6 = 20.0000 mass %  
H3O+1 [mol] - C6H6 = 30.0000 mass %  
H3O+1 [mol] - C6H6 = 40.0000 mass %  
H3O+1 [mol] - C6H6 = 50.0000 mass %  
H3O+1 [mol] - C6H6 = 60.0000 mass %  
H3O+1 [mol] - C6H6 = 70.0000 mass %  
H3O+1 [mol] - C6H6 = 80.0000 mass %  
H3O+1 [mol] - C6H6 = 90.0000 mass %  
H3O+1 [mol] - C6H6 = 100.0000 mass %
```

Figure 0-4

We have now selected all the items. Click the **Hidden** check box to hide these curves.

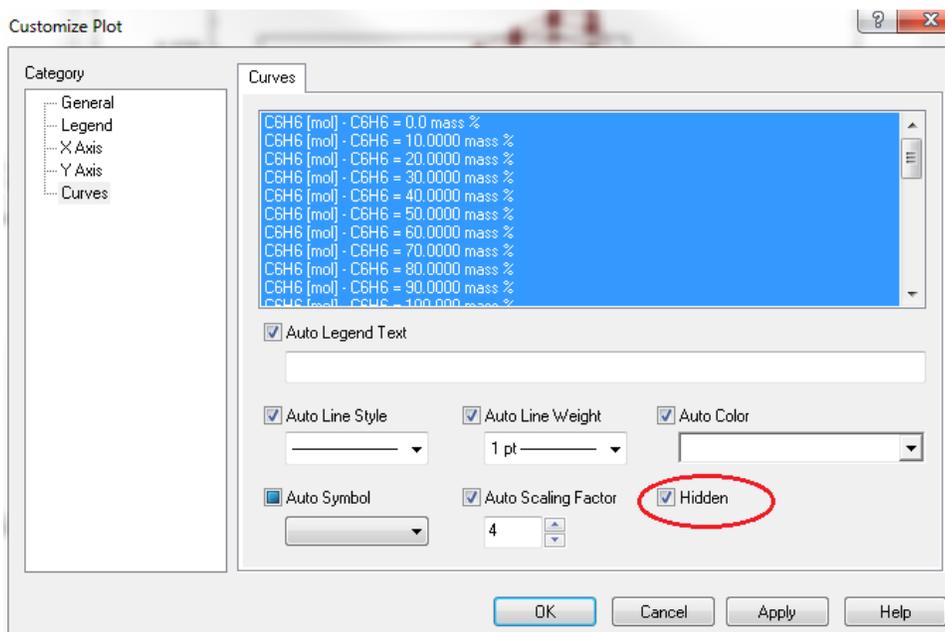


Figure 0-5

Click the **Apply** and then **OK** buttons to see the plot.

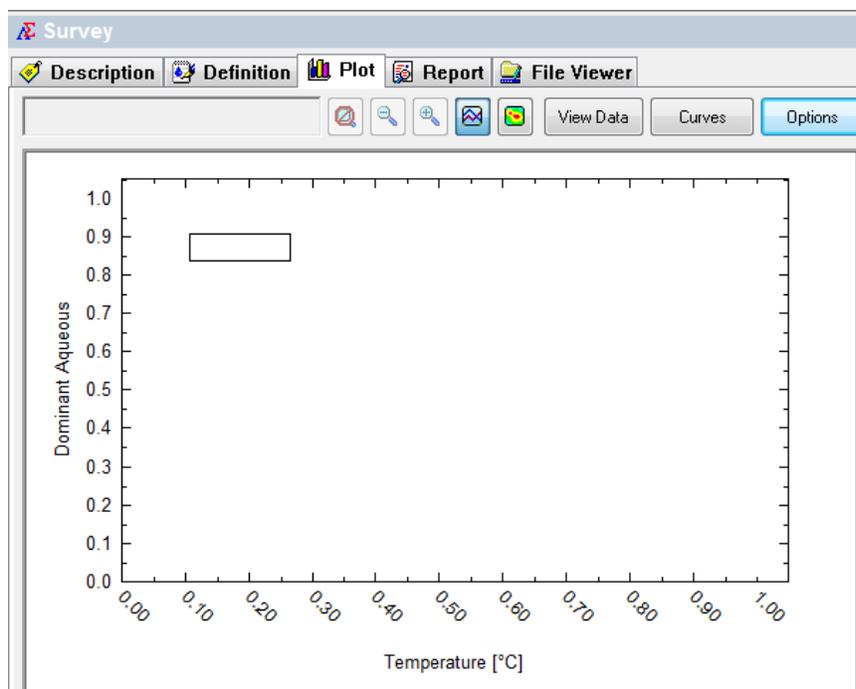


Figure 0-6

This is not very helpful. We need to "Unhide" some curves. Once again, click the **Options** button and then reselect the **Curves** category.

For this example, we want to see the highest pressure for this dual survey. Scroll to the bottom of the list and then uncheck the **Hidden** box.

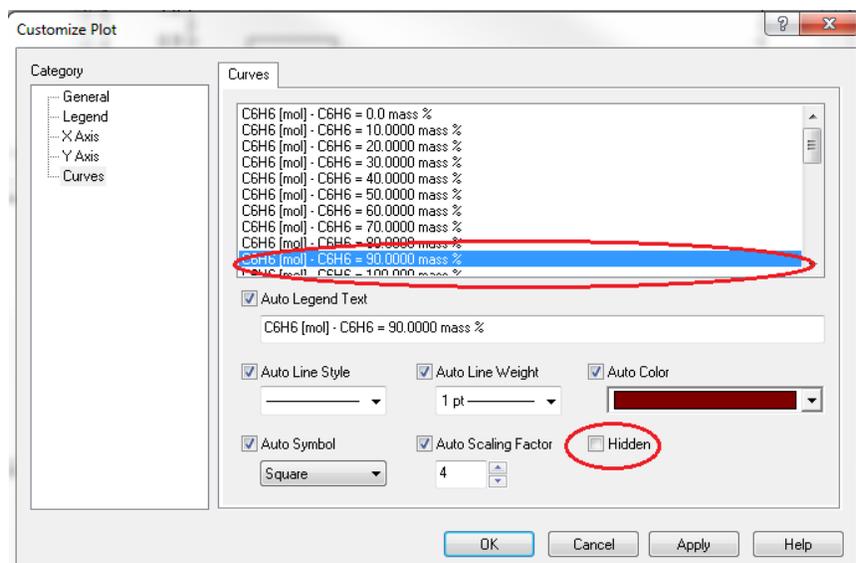


Figure 0-7

Click the **Apply** and **OK** buttons to display the plot.

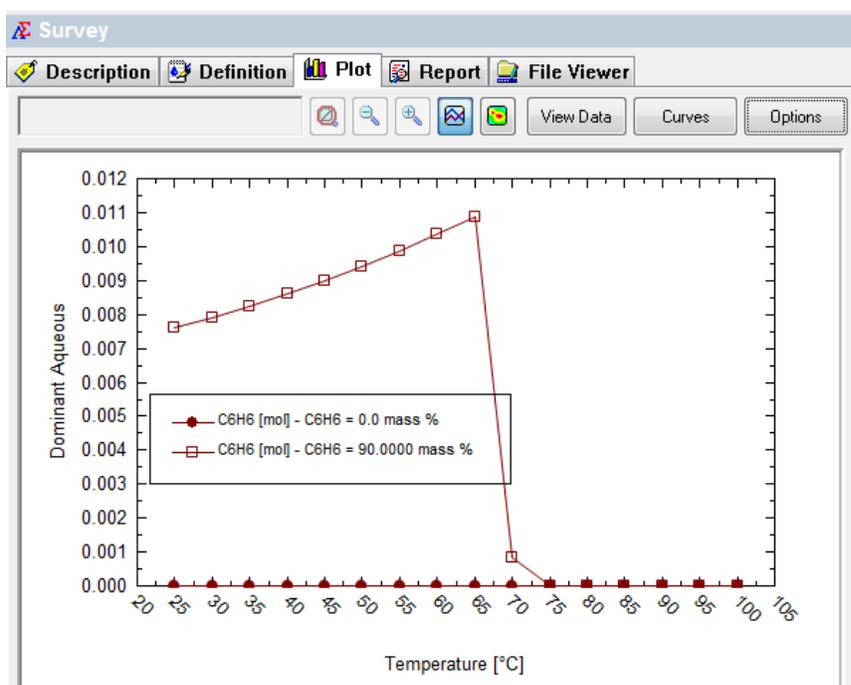


Figure 0-8

We now have our plot without all the clutter of extra points. We can now go back and add (or unhide) additional curves. Once again, click the **Options** button and then reselect the **Curves** category.

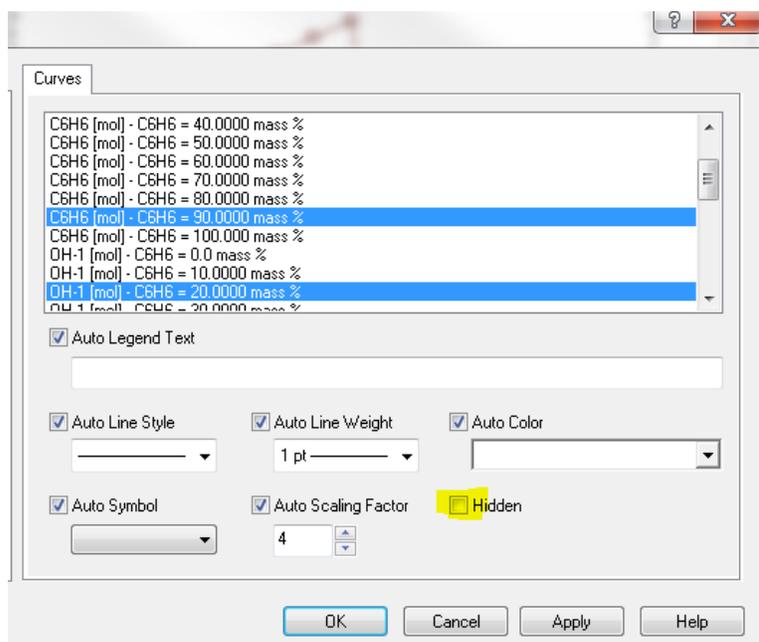


Figure 0-9

Locate a curve midway in the list (here we have chosen a different variable also at the highest pressure). Uncheck the **Hidden** check box. Click the **Apply** and **OK** buttons to display the plot.

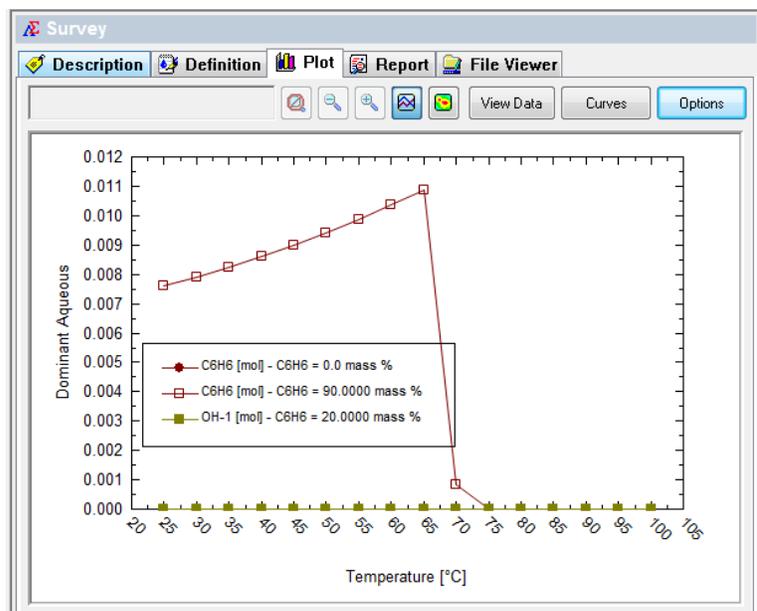


Figure 0-10

We now have to curves displayed. It is helpful to note that all the other curves are still present in the diagram. If you export this plot to a spreadsheet, all the data, not just the displayed values, will be used.

We can modify the plot directly without the use of the Options button. **Right-click** any displayed curve. We have chosen the upper curve.

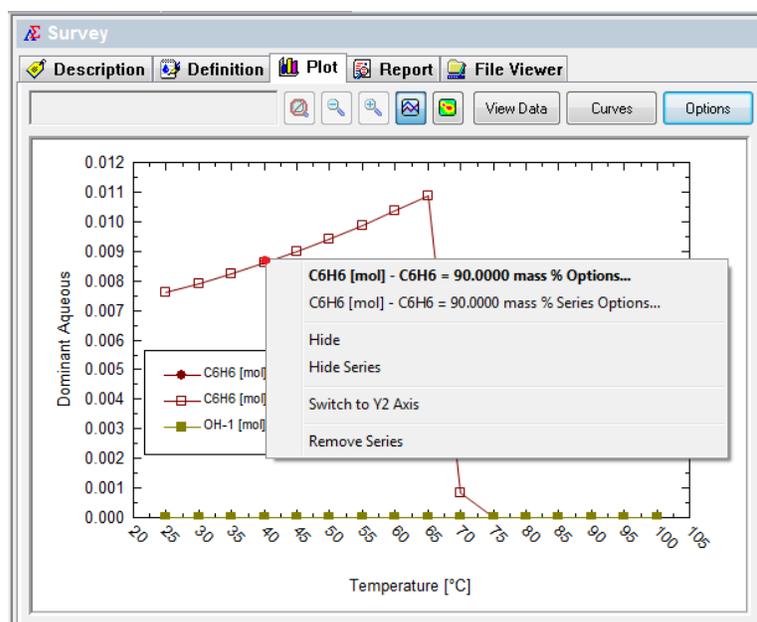


Figure 0-11

This will display a pop-up menu. The name of the series is displayed. Select **Hide Series**.



Figure 0-12

This removed the series from display. Unfortunately, the only method to "Unhide" the series is to use the Options button as we did above.

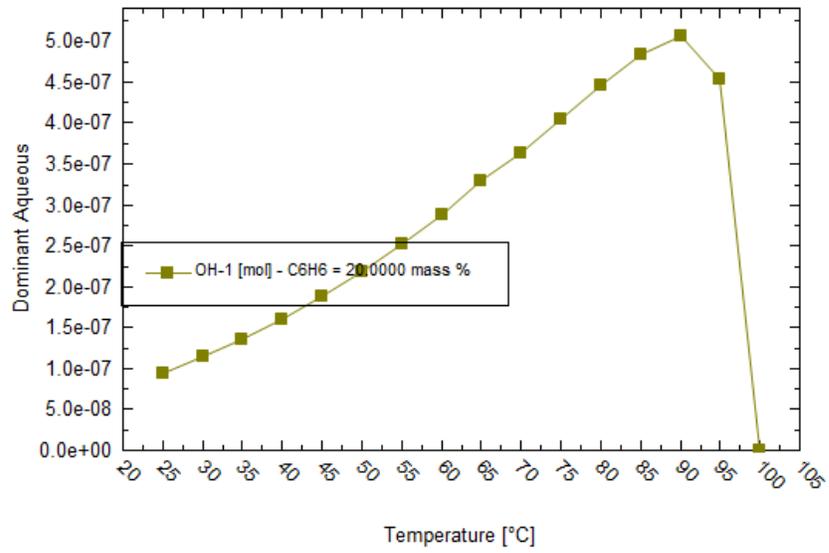


Figure 0-13

Switching Variables between plots

Occasionally it is necessary to quickly switch variables between the Y1 axis and the Y2 axis. This is frequently necessary because the range of the variables plotted is vastly different. In this example, we are using the files created in Chapter 8. See: http://wiki.olisystems.com/wiki/images/5/53/Chapter_08.zip for the latest version of the worked file or **pH Survey**

In the Survey **by pH**, the software adjusts **the flowrate of acid or basic titrants to at a predefined set of pH values and computes the solution properties of a solution based on a given composition of species (or set of species) at a specific temperature and pressure.**

Example 21: A Speciation Diagram for the Carbonic Acid System as a Function of pH

In this survey calculation, a 1 molal CO₂ solution is titrated with HCl and NaOH. Instead of defining the amount of acid/base to add, the pH will be specified, and the software will compute the amounts of HCl and NaOH needed.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

pH Survey Calculation			
Calculation Settings		Stream Composition and Conditions	
Calculation Type	Survey	Stream Amount	Calculated
Stream Name	pH Survey	Temperature	25 °C
Survey Name	Carbonic Acid System	Pressure	1 atm
Name Style	Display Formula	H ₂ O	55.5082 moles
Unit Set	Metric, Moles	CO ₂	0.001 moles
Framework	AQ	pH range	4-12
		Step Size	Increment by 0.1

15. Add a new **Stream**
16. **Click** on the new Stream and press **<F2>** to change the name to *pH Survey*
17. Select the **AQ** thermodynamic Framework
18. **Click** on the **Names Manager** Icon and select the **Formula** option
19. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
20. **Enter** the composition of the stream given in the table above
21. Go to the **Add Calculation** button and select **Survey** calculation
22. Select **pH** as Type of Survey
23. Change the **Survey** name to **Carbonic Acid System** using the **<F2>** key

The calculation can be run without modification. The default titrants are **HCl** and **NaOH**, and the default pH range is set from **0** to **14** with a step size of **1** increment. However, this pH range is too broad for the carbonate system, in which most of the speciation occurs between pH=4 and 12. Additionally, it is ideal to specify finer increments to see a smoother curve.

24. Click on the **Specs** button. This will open the **Survey Options Window**

25. In the **pH Titrants** tab, leave the default pH Titrants: **HCl** and **NaOH**

pH Titrants Survey Range

Select an acid and base to adjust to meet the specified pH.

Use Single Titrant Hide Related Inflows

Acid	Base
CO2	CO2
H2O	H2O
HCL	NAOH

26. Now, click on the **Survey Range** tab. Enter the pH range from 4 to 12, with increments of 0.1. Then click **OK**.

pH Titrants Survey Range

Target pH Range Unit:

Selected Range

4.0 to 12.0 in 80 steps of 0.1

Linear Log Point List

End Points

Start

End

Step Size

Increment } Select one, the other is calculated

Number Steps

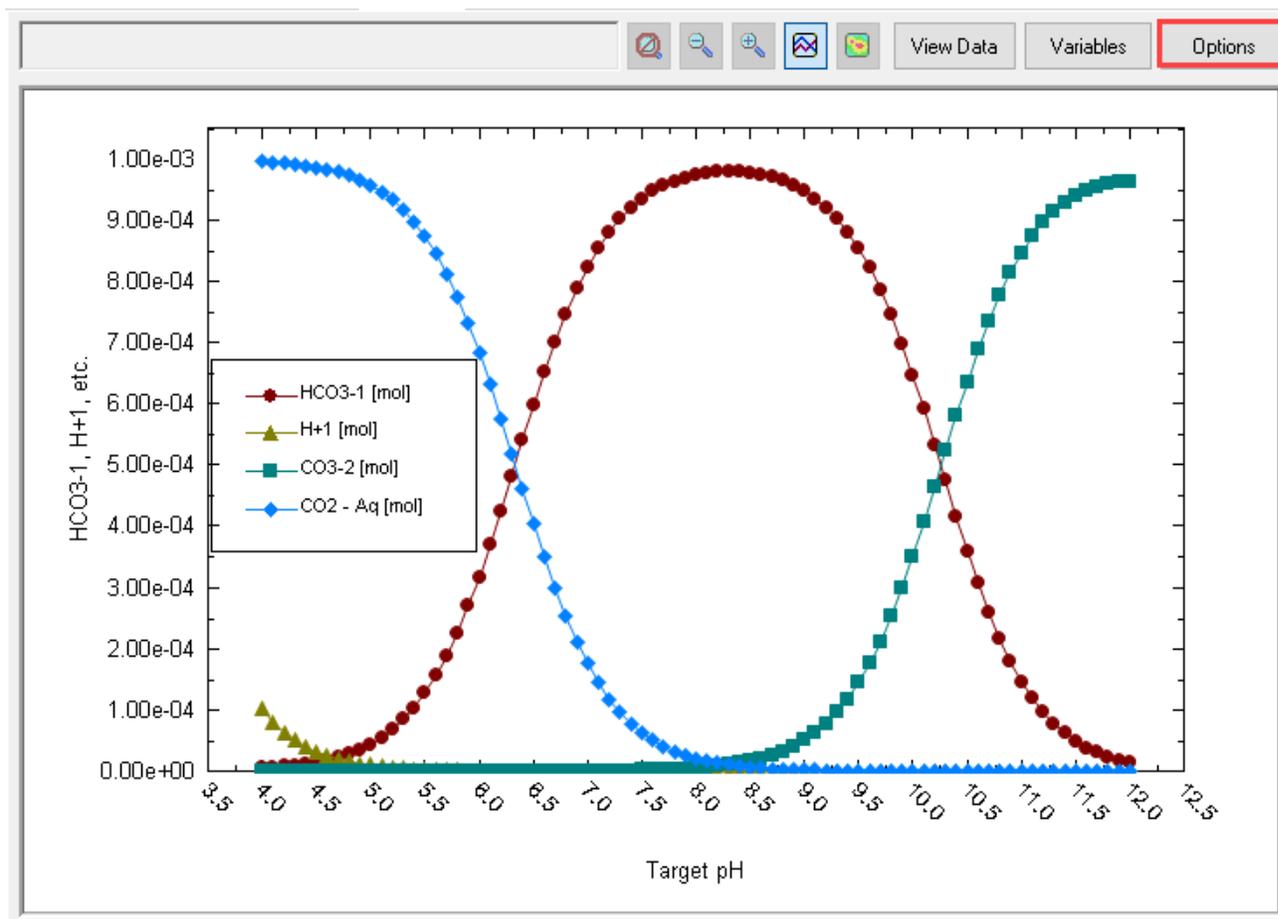
27. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key

28. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( Plot). The default plot is the moles of added HCl and NaOH vs Target pH. This is not the target variable and you will change it to display the carbonate-containing species.

8. Click on the **Variables** button
9. Remove the **NaOH** and **HCl** from the Y1 axis (double click or use the << button)
10. Look for **Aqueous** section and click on the  box to show all the available species. **Select** the following species: CO₂-Aq, HCO₃⁻¹, CO₃⁻², and H⁺ and put them in the Y1 Axis using the >> button or by double clicking. When you are done, click **OK**.

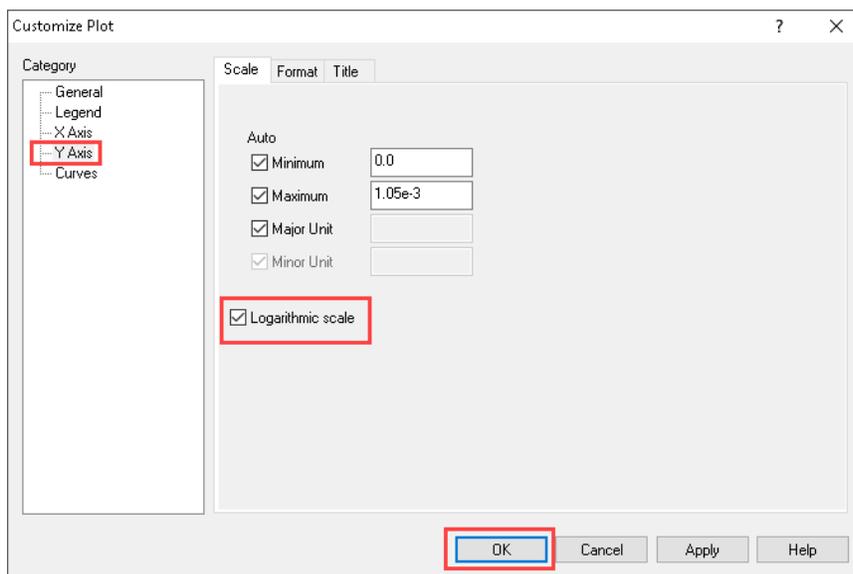


You can also present this plot on a semi-log scale.

11. Click on the **Options** button. This will bring the **Customize Plot** window

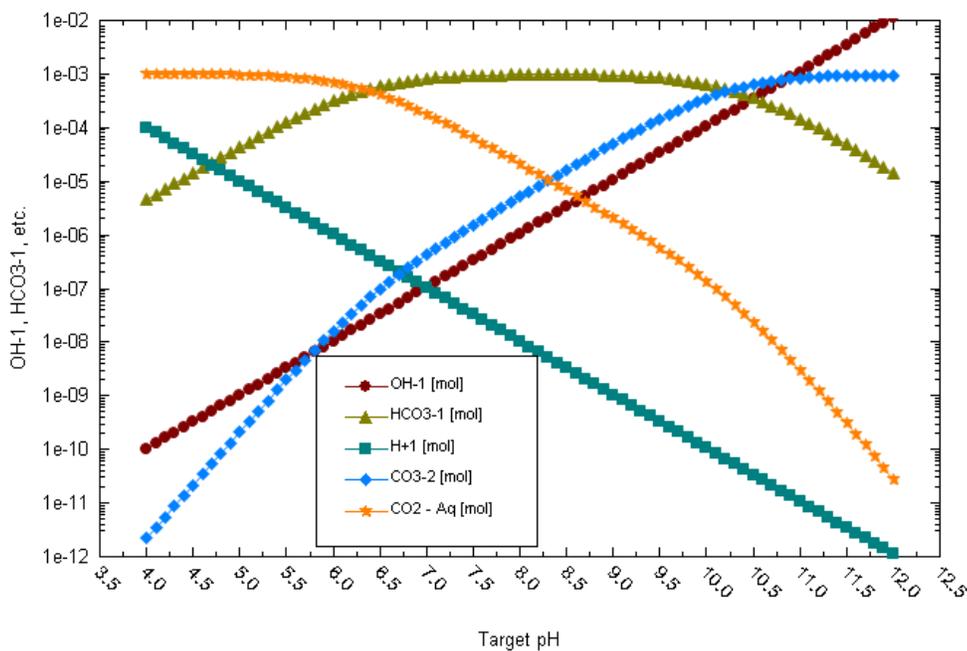
12. Select **Y Axis** in the Category window

13. **Check** the Logarithmic scale box, and then click **OK**.

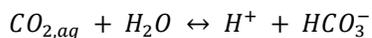


Before analyzing the plot, let's add the OH⁻ species.

14. Click on the **Variables** button, look for OH⁻ in the **Aqueous** section, add it to the Y1 Axis, and then click **OK**. Now we are ready to analyze the plot.



At lower pH, CO₂-Aq dominates the system, and notice how the HCO₃⁻ slope is 1 and the CO₃²⁻ slope is 2. Likewise, in the pH region where CO₃²⁻ dominates (high pH), the HCO₃⁻ slope is -1 and the CO₂-Aq slope is -2. These $\frac{\text{mole}}{\text{pH}}$ slopes are based on the number of H⁺ ions added or removed in the chemical reactions. See reactions below.



Note the pH where the CO₂-Aq and HCO₃⁻ lines intersect (pH~6.3), and where the HCO₃⁻ and CO₃²⁻ lines intersect (pH~10.3). These pH values are the same as the pK_a values (the equilibrium equations the specific equilibrium reactions).

As NaOH is added to convert HCO₃⁻ to CO₃²⁻, a portion of the NaOH remains as free base, OH⁻. This fraction increases at higher pH values, and its concentration is reflected in the calculated pH. A similar pattern is seen at pH below ~3 for HCl and H⁺.

i. Vapor Fraction / Vapor Amount Survey

The purpose of the **Vapor Fraction/Vapor Amount Survey** calculation is to set a specific fraction of the stream to the vapor phase, and compute the temperature or pressure required to achieve the specified Vapor Fraction/Vapor amount.

Example 22: Seawater Evaporation

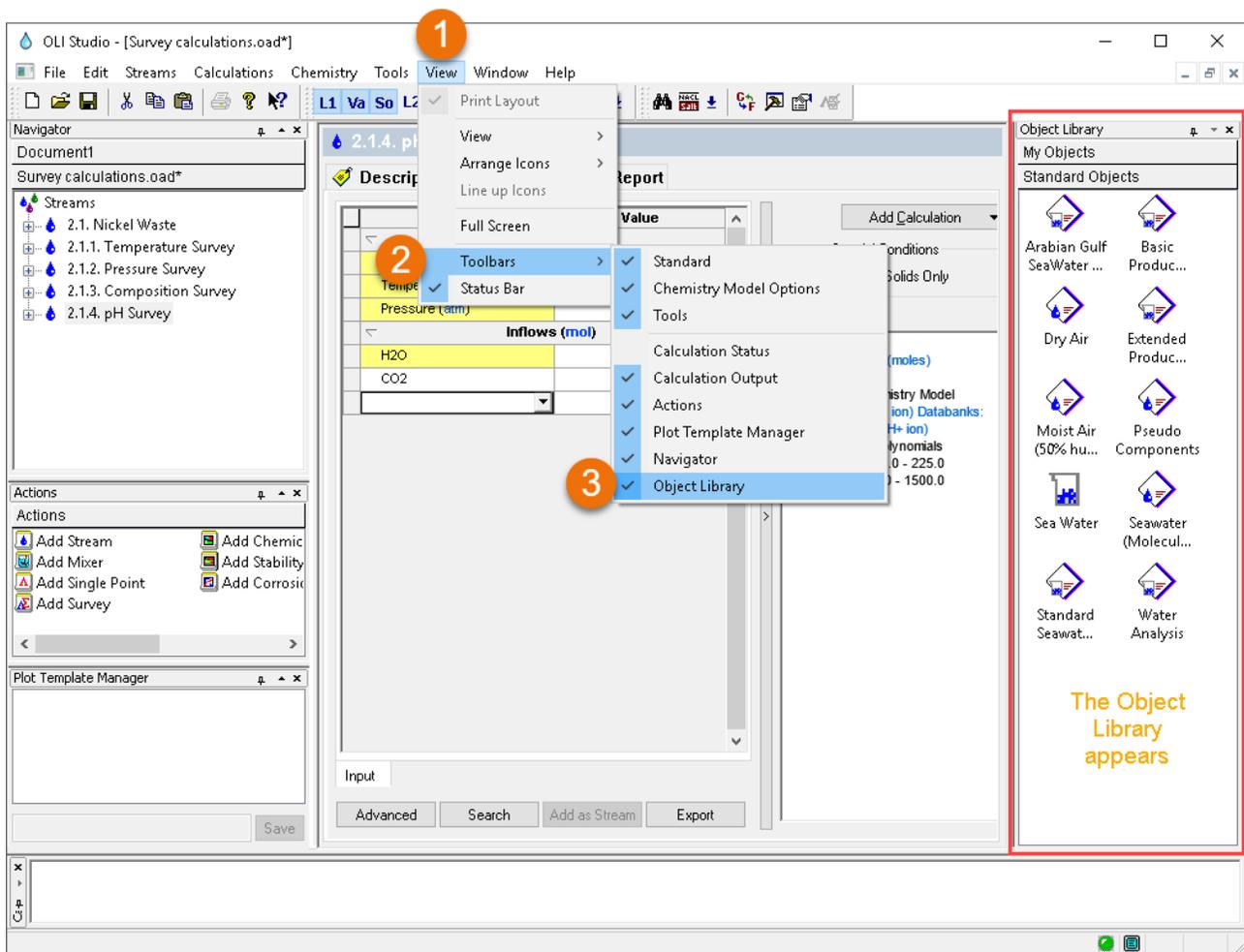
Seawater contains a variety of salts, and when seawater evaporates, these solids are left behind. The most abundant salt in seawater is sodium chloride (NaCl) which is also technically referred to as halite.

You will evaporate seawater to dryness and look at the solids that form. What is interesting is the number of phases that can be produced when seawater evaporates, giving you a sense of how certain natural systems build up sediment of a particular nature.

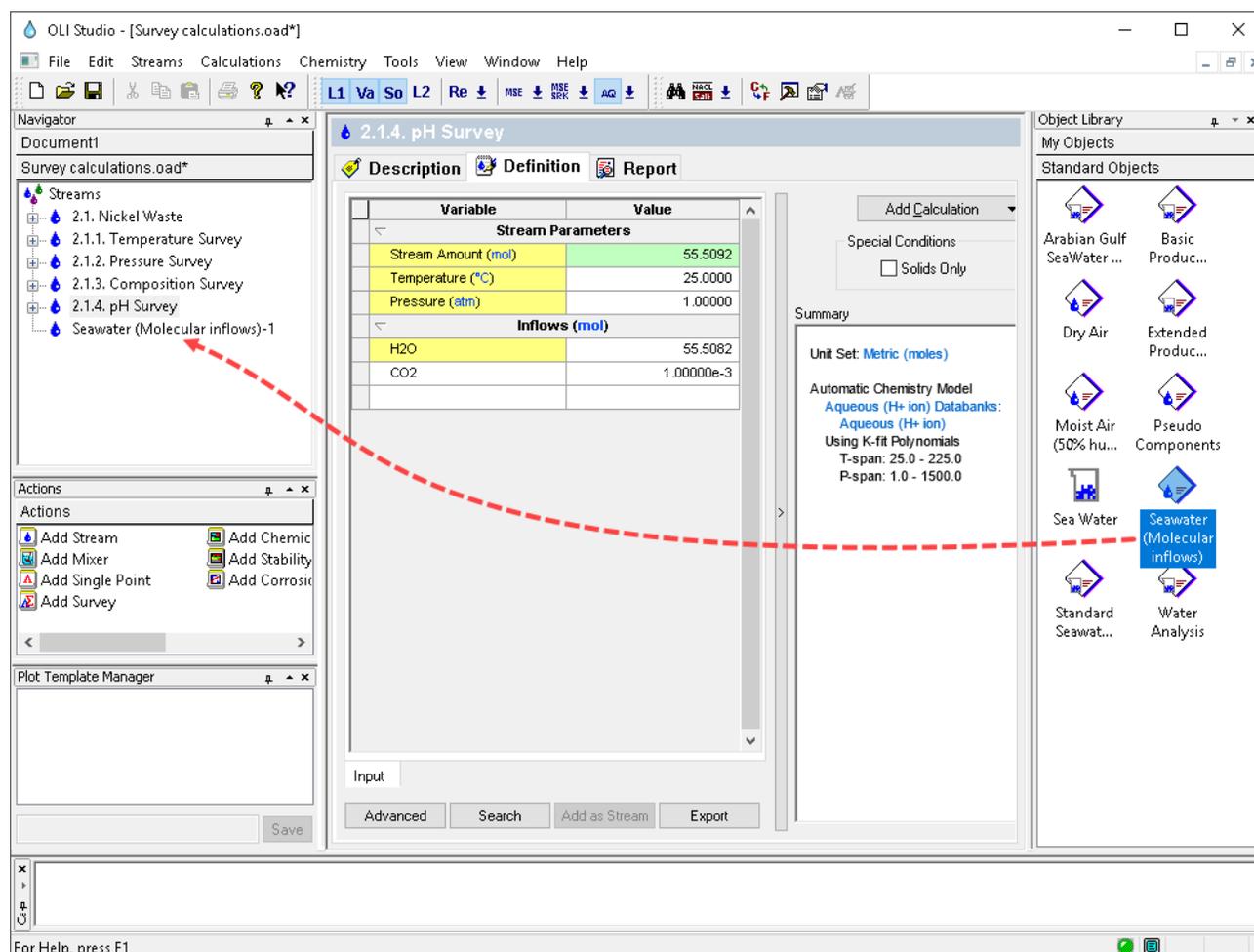
In this example we will also introduce the **Object Library** tool.

Starting the Simulation

11. Open the **Object Library** window – from the menu, View > Toolbar > Object Library. The Object Library appears in the right-hand side of the window.



12. Drag the **Seawater (Molecular inflows)** stream to the navigation panel (in the white-space below the other streams and calculation objects)

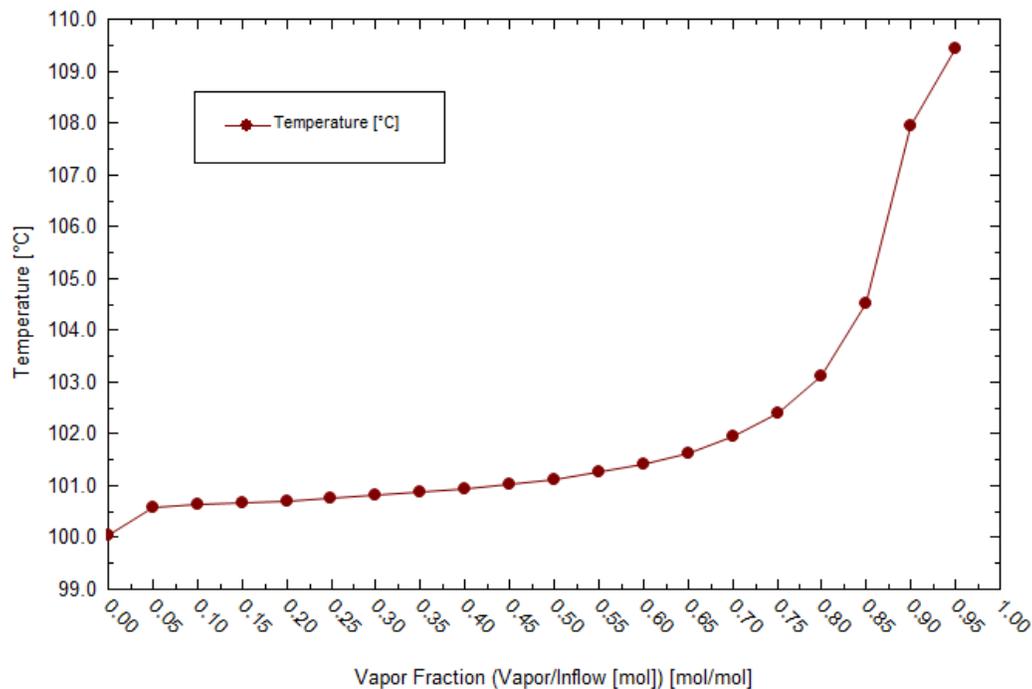


The inputs and parameters are automatically populated when selecting the Seawater (molecular inflows) from the Object Library.

13. **Click** on the new Stream and press **<F2>** to change the name to *Vapor Fraction Survey*
14. Go to the **Add Calculation** button and select **Survey** calculation
15. Select **Vapor Fraction** as Type of Survey
16. Change the **Survey** name to **Seawater Evaporation** using the **<F2>** key
17. Click on the **Specs** button. This will open the **Survey Options Window**
18. The default Vapor Fraction range is from 0-1 with an increment of 0.1. Change the **Vapor Fraction Range** to **Survey End** to 0.95. Set the **Step Size** to **0.05** increments. Then click **OK**.
19. We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key
20. It is time to **save** your file (**File > Save as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

Analyzing the Results

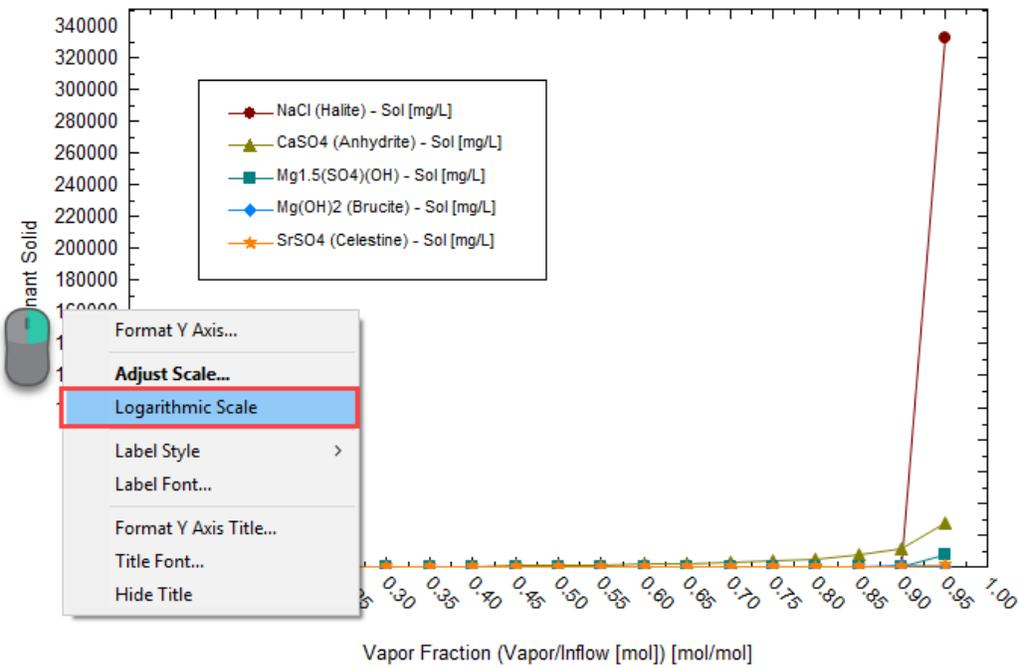
Click on the **Plot** tab ( **Plot**). The default plot is the Vapor Fraction plot (as the dependent variable) vs Temperature. It shows that seawater boils initially at 100°C, and at near complete evaporation (95%) the temperature is 109.4°C.



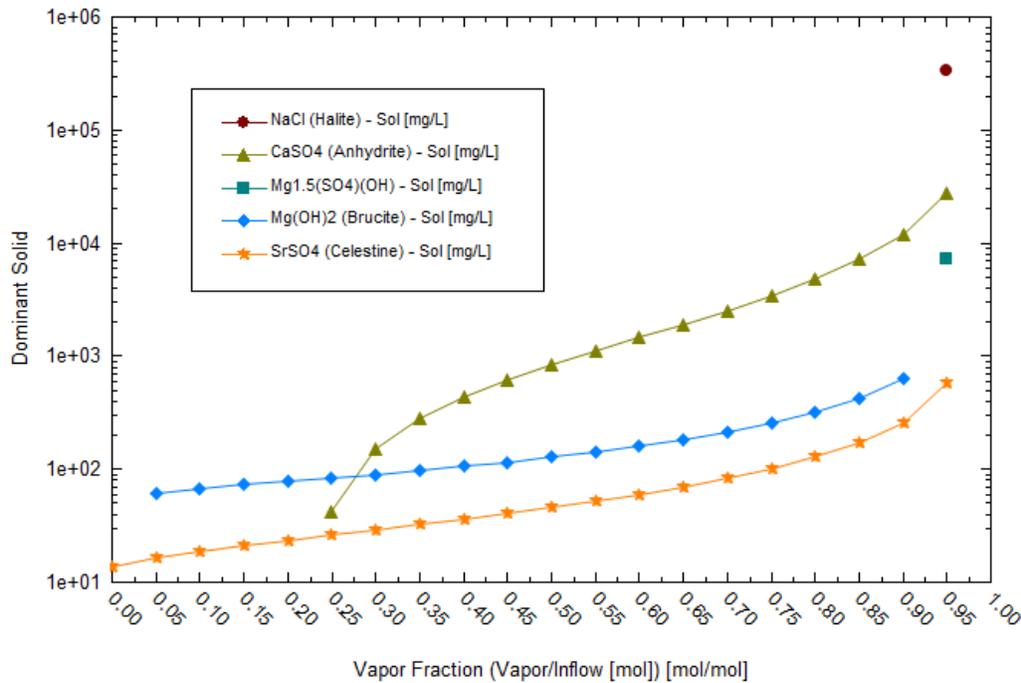
We are also interested to know which solid phases precipitate as the water evaporates.

5. Click on the **Variables** button
6. Remove **Temperature** from the Y1 axis (double click or use the << button)
7. Look for **Solid** section and click on the  box to show all the available species. **Select** the option **Dominant Solids** and put it in the Y1 Axis using the >> button or by double clicking. When you are done, click **OK**.

The default plot is not very easy to read. To see the plot more clearly, right click on any number in the Y axis, and select the **Logarithmic Scale** option.



Plot in semilogarithmic scale



As the water evaporates CaSO4, Mg(OH)2 and SrSO4 salts precipitate at all temperatures. NaCl and a Mg/SO4 double salt start to precipitate at 95% vapor fraction.

Dual Surveys

Dual Surveys allow you to study the effect of two independent variables on your system under study.

- The option for the dual survey is highlighted in red box highlighted in the image below. **There** are three options available, survey by Temperature, Pressure and Composition.
- Additionally**, you have the option of varying the selected variables independently or together. We will explore this in more detail in the upcoming examples.

The screenshot shows a software interface with a table of variables and a control panel for defining a dual survey.

Variable	Value
Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	
Pressure (atm)	
Inflows (mol)	
H2O	55.5082

The control panel on the right is highlighted with a red box and contains the following settings:

- Survey by:** Temperature (dropdown menu)
- Then by (optional):** Pressure (dropdown menu)
- Vary:** Independently, Together
- Calculate:** (button with a green checkmark)

The **Summary** section on the right provides the following details:

- Temperature survey:**
 - Range: 25.0 to 100.0 °C
 - Step size: 5.0 °C
 - No. steps: 15
- Pressure survey:**
 - Range: 1.0 to 10.0 atm
 - Step size: 1.0 atm
 - No. steps: 9
- Primary and secondary survey variables:** move independently
- Total points:** 160
- Unit Set:** Metric (moles)
- Automatic Chemistry Model:** Aqueous (H+ ion) Databanks

Temperature and Pressure Survey

In this type of survey two variables are adjusted simultaneously, temperature and pressure. This type of survey creates a matrix of results, which can then be interpreted using the plot function in different ways.

Example 23: Dissolution of CO₂ in water as a Function of Temperature and Pressure

In Example 19, the dissolution of CO₂ in water was studied only as a function of pressure. In this case, we are going to study the effect of both temperature and pressure on the CO₂ dissolution.

a. In this example the Contour Plot will be used to analyze the results.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Temperature and Pressure Survey Calculation				
Calculation Settings		Stream Composition and Conditions		
Calculation Type	Survey	Stream Amount	Calculated	
Stream Name	T/P Survey	Pressure Range	5-100 atm	
Survey Name	CO ₂ dissolution – T/P	Step Size	Increment by 5 atm	
Name Style	Display Formula	Temperature Range	5-100 °C	
Unit Set	Metric, Moles	Step Size	Increment by 5 °C	
Framework	MSE-SRK	Vary	Independently	
		H ₂ O	55.5082 moles	
		CO ₂	10 moles	

- 29.
30. Add a new Stream
31. **Click** on the new Stream and press **<F2>** to change the name to *T/P Survey*
32. Select the **MSE-SRK** thermodynamic Framework
33. **Click** on the **Names Manager** Icon and select the **Formula** option
34. **Click** on the **Units Manager** Icon, and select Metric, Batch, Moles
35. **Enter** the composition of the stream given in the table above
36. Go to the **Add Calculation** button and select **Survey** calculation

37. Select **Temperature** and then by Pressure

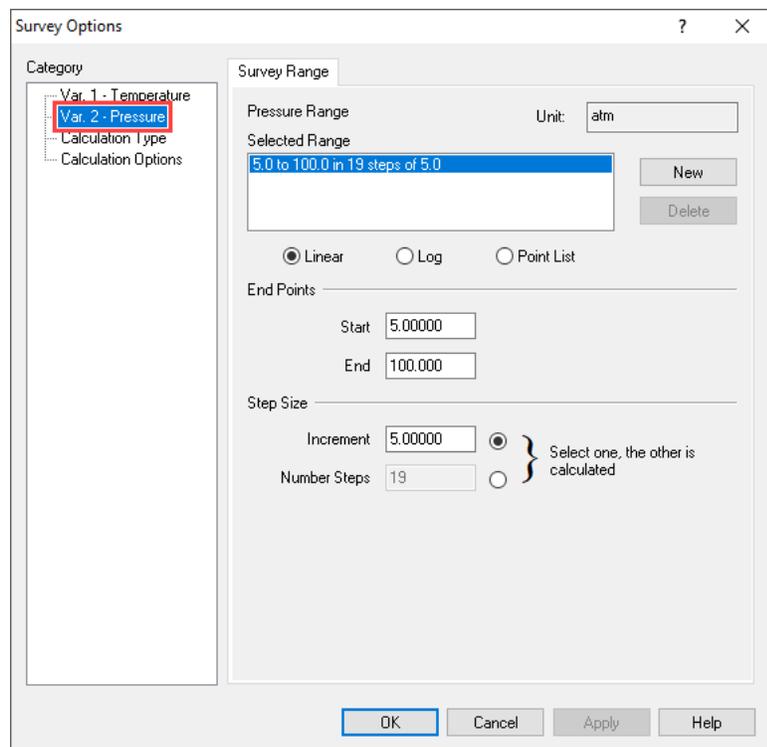
38. Change the **Survey** name to **CO₂ dissolution T/P** using the <F2> key

Click on the Temperature Specs button. This will open the Survey **Options** Window

Change the Temperature Range to 5-100 °C. Set the Step Size to 5 °C increments.

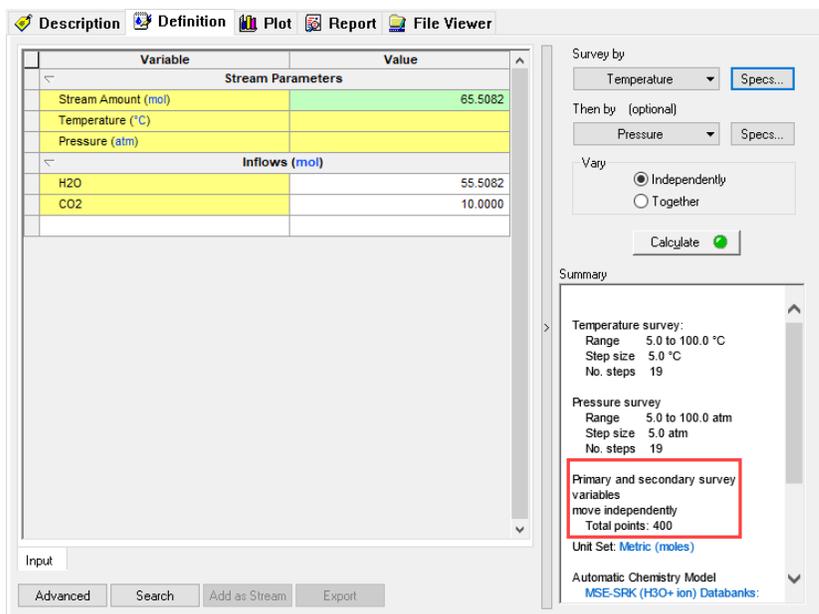
Click on Var. 2 – Pressure, in the Category Window to define the Pressure Range.

Change the Pressure Range to 5-100 atm. Set the Step Size to 5 atm increments. Then click OK.



In the summary box, notice that a total of 400 points will be calculated. We are ready to perform the calculation.

Click on the Calculate button or press the <F9> key



39.

40. It is **time** to save your file (File > **Save as...**) **or** using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

41.

42. Analyzing the Results

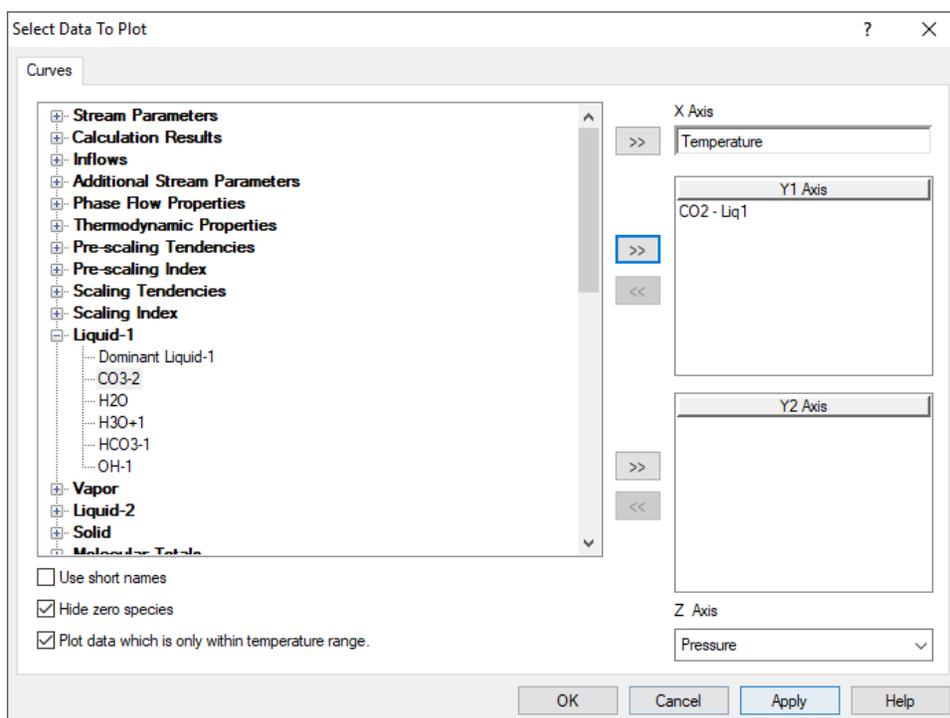
43. Click on the Plot tab ( **Plot**). The default plot is the phase amounts in grams of Liquid-1 (Aqueous Phase), Liquid-2 (Organic Phase), Solid and Vapor.

We are interested in the solubility of CO₂ in water, i.e. in the Liquid-1 phase. We can change the default plot to show the molecular CO₂ dissolved in water (CO₂-Liq1).

44. Click on the Variables button. **This** will open the Select Data to Plot window.

45. Double click or use the << **button** to remove the **Phase Amount** variables.

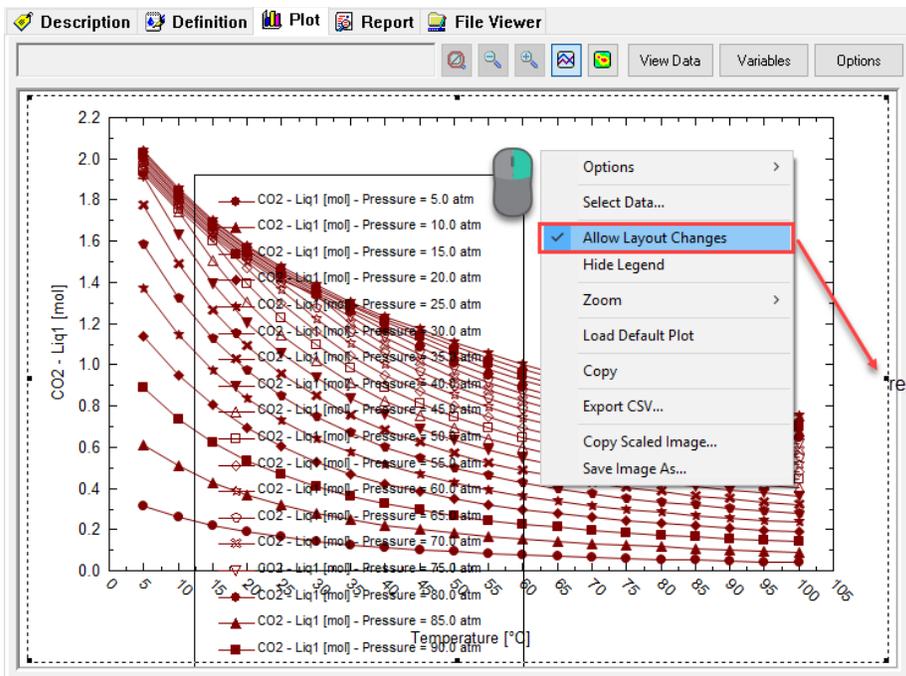
Look for **Liquid-1** and click on the  box to show all the available variables. **Select** CO₂-Liq1 and put it in the Y1 Axis using the >> button. Then click **OK**.



46.

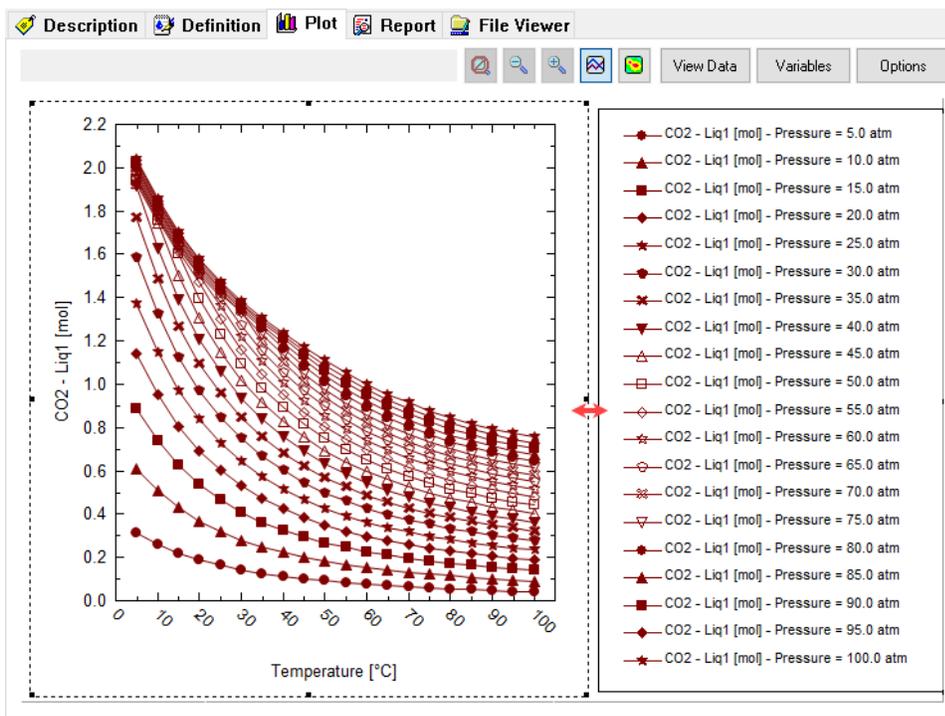
48. The default plot now is showing **the** dissolved CO2 **in** the water (Liquid-1 **Phase**) in the Y1 Axis as function of pressure. Unfortunately, the legend is covering the plot.

49. To move the legend **to** the side without **interfering with the results**, right click on any white space within the plot and Allow Layout Changes. This option allows you to select and reposition the *plot*.



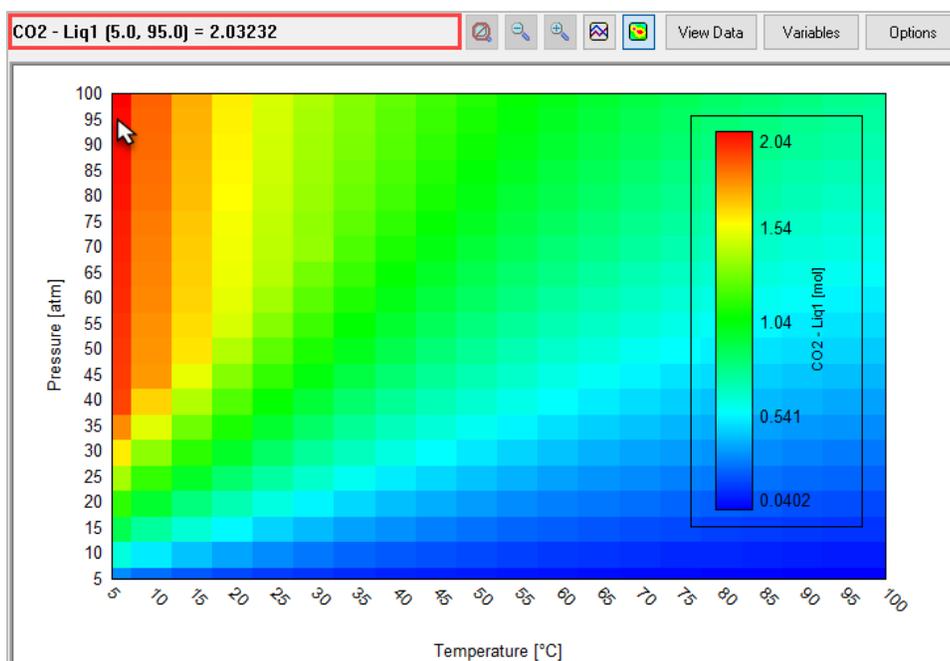
50.

Resize the plot to make it smaller and create space for the legend. Drag the legend to the right.



As the **temperature** increases (at a fixed pressure) the solubility of CO₂. This is to be expected since at higher temperatures it is easy to overcome the vapor pressure and CO₂ is released as gas. As the pressure increases (at a fixed temperature) the solubility of CO₂ in solution increases.

15. The plot above **can** be represented better using a **Contour Plot**. To convert the results into a contour plot view, simply click on the contour plot icon (📊).
16. The resulting **plot** is **now** a pixelated color plot showing the moles of molecular CO₂ **dissolved** in the Liquid-1 (Aqueous) phase, at each T and P value.
17. The number **of** moles of CO₂ is characterized by a different color that is shown in the legend (maximum value is given in red, and minimum value is given in blue). You can **mouse** over any location in the plot and the moles of CO₂ dissolved in the Liquid-1 phase at each T and P value will be shown in the left corner box.

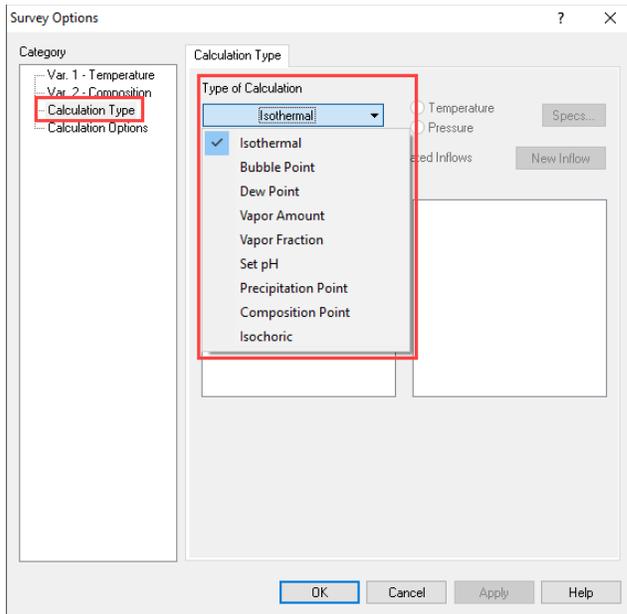


Note: The legend scale can also be optimized by either right-mouse-clicking on the Legend and selecting Options>Plot Options>Contour or clicking on the Options button in the upper right and selecting Contour. Both open to the Contour options window, where the color and range can be modified.

In the contour plot, you can see the effect of both Temperature (x-axis) and Pressure (y-axis) on the solubility of CO₂ in water. Higher solubilities are obtained at high pressures and low temperatures, while lower solubilities are obtained at high temperatures and low pressures.

- 18.
- 19.
- 20.

22. Survey by changing the single point calculation **type**
23. **Sections 2.1 and Error! Reference source not found.** so far have presented single and dual surveys. In addition to adjusting these survey variables, you can select one of several single point calculations embedded within the survey. The embedded single point calculations include: Isothermal (default), bubble point, dew point, vapor amount, vapor fraction, set pH, precipitation point, composition point, and isochoric.



- 24.
25. **Temperature Survey** with a Precipitation Point Calculation
26. In this Temperature Survey, the Calculation Type will **be** changed from Isothermal Calculation to **Precipitation Point**. This will allow us to model the solid solubility vs temperature.

Example 24: Solubility of Halite as a Function of Temperature

In this example, we are going to study the solubility of NaCl (halite) as a function of temperature.

27. Starting the Simulation
28. **Use** the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Temperature Survey with a Precipitation Point Calculation			
Calculation Settings	Stream Composition and Conditions		
Calculation Type	Survey	Stream Amount	Calculated

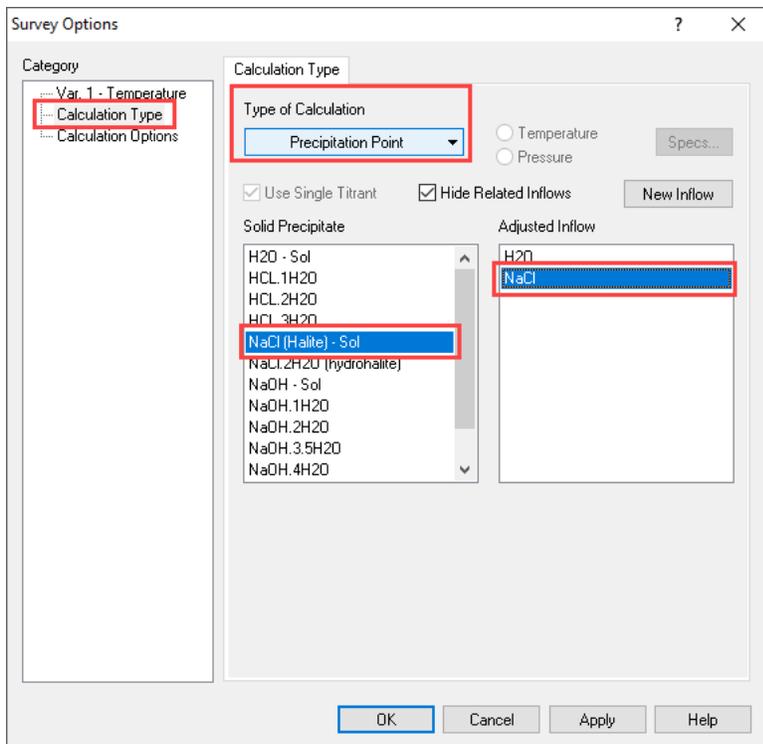
Stream Name	Solubility vs T	Pressure	1 atm
Survey Name	Halite Solubility vs T	Temperature Range	5-100 °C
Calculation Type	Precipitation Point	Step Size	Increment by 5 °C
Name Style	Display Formula	H ₂ O	55.5082 moles
Unit Set	Metric, Moles	NaCl	0 moles
Framework	MSE		

Add a new **Stream**

51. Click on the **new** Stream and press **<F2>** to change the name to *Halite Solubility vs T and P*
52. **Select** the MSE thermodynamic Framework
53. Click on **the Names** Manager Icon and select the *Formula option*
54. Click on **the** Units Manager Icon, and select Metric, Batch, Moles
55. **Enter** the composition **of the** stream given in the **table** above
56. **Go** to the **Add Calculation** button and select Survey calculation
57. Select Temperature as the type of survey
58. **Change** the Survey name to Halite Solubility vs T using the **<F2>** key
59. Click on the **Temperature Specs** button. This will **open** the **Survey Options Window**
60. Change **the** Temperature Range to 0-100 °C. Set the **Step Size** to **5** °C increments.
61. Click on **Calculation** Type, in **the Category Window** to define **the** Type of Calculation

Under Type of Calculation Change the Default Isothermal to Precipitation Point (**use** the **drop-down** arrow)

Select NaCl (Halite)-Sol as the Solid Precipitate and NaCl as the Adjusted Inflow. **Then** click OK.



The Calculation Parameters section is now shown in the Definition Tab, highlighting the Precipitant (NaCl (Halite)) and the Adjusted Inflow (NaCl).

Stream Parameters	
Stream Amount (mol)	55.5082
Temperature (°C)	
Pressure (atm)	1.00000
Calculation Parameters	
Precipitant:	NaCl (Halite)
Adjusted Inflow:	NaCl
Inflows (mol)	
H2O	55.5082
NaCl	0.0

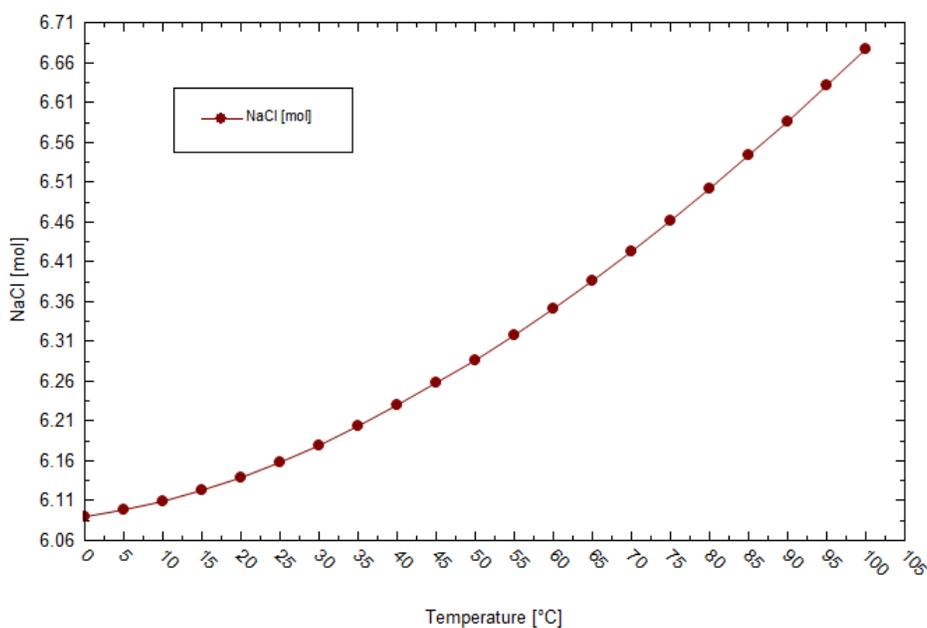
We are ready to perform the calculation. Click on the **Calculate** button or press the <F9> key

62. It is time **to** save your file (File >Save **as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

63.

64. Analyzing the Results

65. Click on the Plot tab ( Plot). The default plot is the amount of NaCl in moles added to 1 kg of water before Halite precipitates as a function of Temperature.



66. Halite solubility increases slightly with temperature, from 6.16 moles/1kg H2O at 25°C to 6.68 moles/1kg H2O at 100°C.

Example 25: Solubility of Halite as a Function of Temperature and Pressure

67. The effects of pressure on mineral solubility is **generally** less important **than** temperature. There is **still an** effect that can be observed. The same stream created on [Example 24](#) will be used.

68. Starting the Simulation

69.

70. Under the Solubility vs **T stream add a new Survey** (see **Stream** information in Example 24)

71. Change the Survey name to Halite Solubility vs T and P using the <F2> key

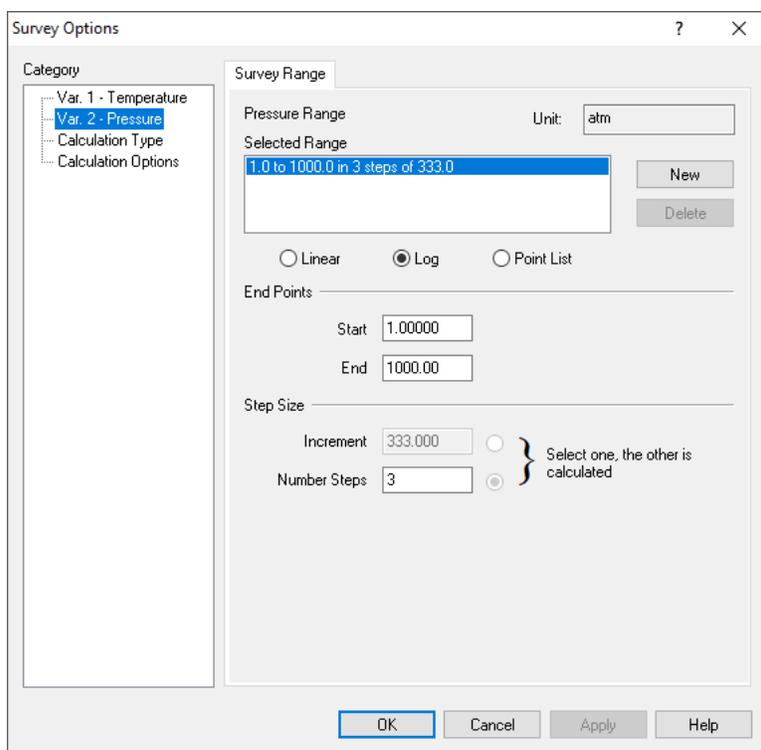
72. Select Survey by **Temperature** and then by **Pressure** (This is a dual survey)

*Click on the **Temperature Specs** button. This will open the **Survey Options Window***

Change the Temperature **Range** to 0-100 °C. Set the Step Size to 5 °C increments.

Click on Var. 2 – Pressure, in the Category Window to define the Pressure Range.

Change the Scale to Log, change the **Pressure Range** from 1 to 1000 atm, and set the **Number of Steps** to 3 (i.e. it will plot the following pressures: 1, 10, 100 and 1000 atm). Then click **OK**.



29.

30. Click on **Calculation** Type, in the Category Window to define the Type of Calculation

31. Under Type of Calculation **Change** the Default Isothermal to Precipitation Point (use the drop-down **arrow**)

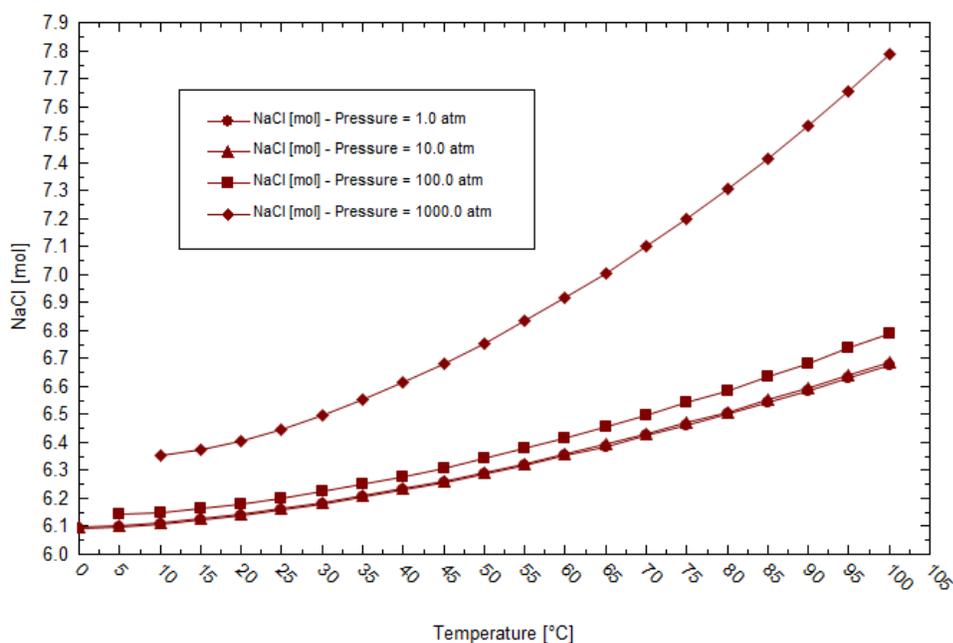
32. Select NaCl (**Halite**)-**Sol** as the **Solid Precipitate** and **NaCl** as the **Adjusted Inflow**. Then click **OK**.

33. We are **ready** to perform the calculation. Click on the Calculate button or press the <F9> key.

34. It is time to save your file (File >Save as...) or using the save **icon** in the tool bar. You can save under the same file **that** we created before named as *Survey Calculations*.

Analyzing the Results

Click on the **Plot** tab ( **Plot**). The default plot is the amount of NaCl in moles added to 1 kg of water before Halite precipitates as a function of Temperature.



The effect of pressure is significant between 100 and 1000 atm relative to the effects between 1 and 100 atm.

35. We can also **present** the Halite Solubility using a Contour Diagram. It would be ideal to define a finer range of temperature and pressure.

36. Return **to the** Definition Tab

37. Click on the **Temperature Specs** button.

38. **Change** the Temperature Range to 0-150 °C. Set the **Step Size** to 2 °C increments.

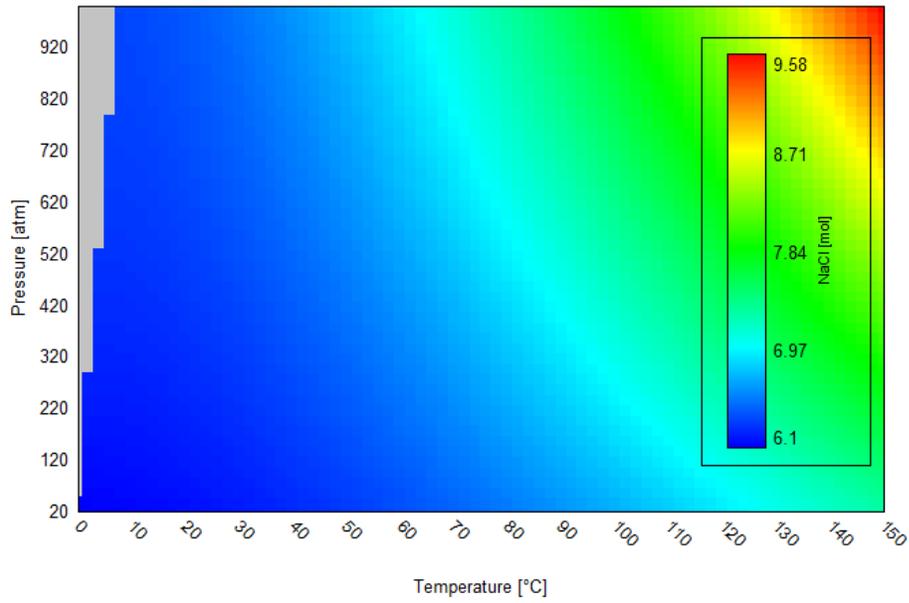
Click on **Var. 2 – Pressure**, in the Category Window to define the Pressure Range.

Change the survey to Linear scale, change the Pressure Range from 20 to 1000 atm, and set the **Step Size** to **20 atm** increments. Then click **OK**.

39. Note: In the Summary box we can see that survey **creates** a matrix of 75 steps x 49 steps for a total of 76 temperature and 50 pressure points, or 3800 points in total.

Click the **Calculate** button. This calculation will take a few minutes to compute.

Click on the Plot tab and change the Plot to contour ().



The solubility is shown to increase as temperature and pressure increase. The increase is up to 50% from the low values. A few of the points failed to converge at the low temperature and high-pressure conditions (shown in gray).

Composition Survey with a Bubble and Dew Point Calculation

In this Composition Survey, the Calculation Type will be changed from Isothermal Calculation to **Bubble and Dew Point calculations**. This will allow us to model the vapor liquid equilibria (VLE) of mixtures.

Example 26: Ethanol-Water Azeotrope

In this example, you are going to calculate both the bubble point and dew points as a function of Ethanol-Water composition.

The two data sets will then be transferred to a spreadsheet where the curves will be plotted together to locate the azeotrope. You will need a spreadsheet/plotting software to complete this case.

Starting the Simulation

Use the inputs and parameters from the table below to create the stream's composition. Certain inputs, such as the name style, units, etc. will require further adjustments, and will be described as necessary.

Composition Survey with a Bubble and Dew Point Calculation				
Calculation Settings		Stream Composition and Conditions		
Calculation Type	Survey	Stream Amount	Default – 1kg	
Stream Name	Composition survey - Azeotrope	Pressure	1 atm	
Survey Name	Ethanol-Water Azeotrope	Temperature	It will be calculated	
Calculation(s) Type	Bubble Point / Dew Point	H2O	100 mass % - default	
Name Style	Display Name	Ethanol	0 mass%	
Unit Set	Metric, Mass Frac.	Composition Range	0 -100 mass%	
Framework	MSE	Step Size	Increment by 2 mass%	

73. Calculating the Bubble Point

74. Add a new Stream

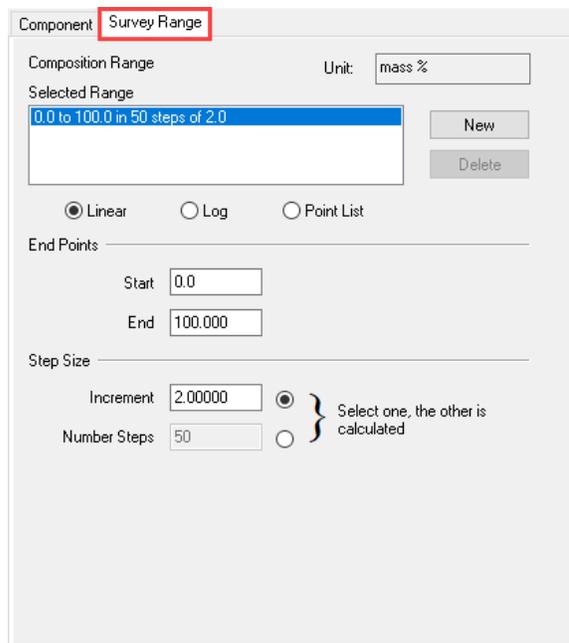
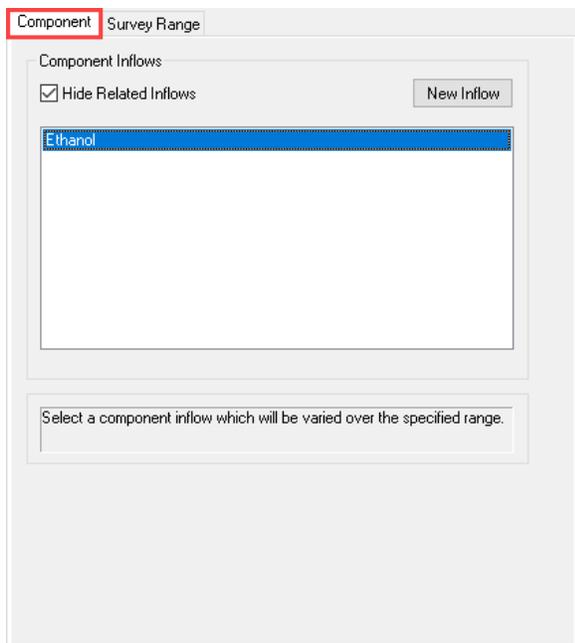
75. Click on the **new Stream** and press <F2> to *change the name to Composition survey - Azeotrope*

76. Select the **MSE** thermodynamic Framework

77. **Click** on the **Names Manager** Icon and select the **Display** Name option
78. **Click** on the **Units Manager** Icon, and select Metric, Batch, Mass Frac.
79. **Enter** the composition of the stream given in the table above
80. Go to the **Add Calculation** button and select **Survey** calculation
81. Select **Composition** as the type of survey
82. Change the **Survey** name to ***Ethanol-Water Azeotrope using*** the <F2> key
83. Click on the **Composition Specs** button. This will open the **Survey Options Window**

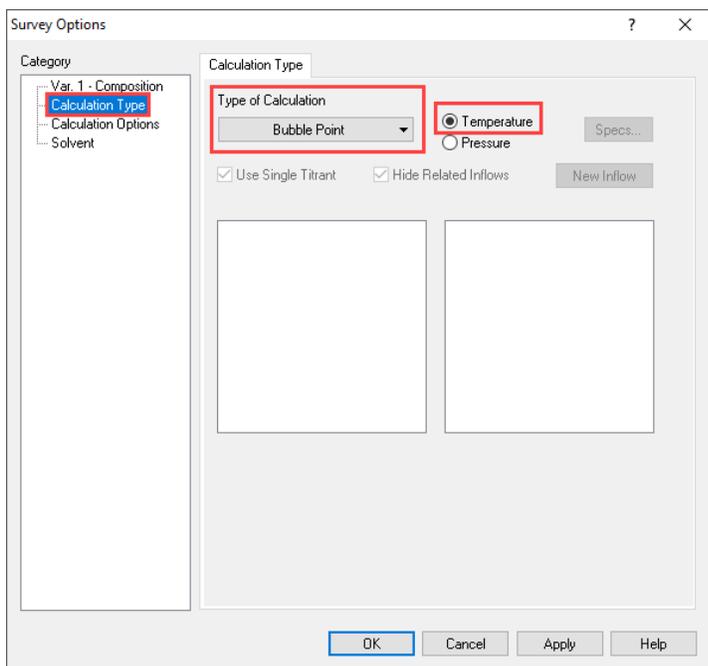
Under the Component tab, select Ethanol

Click on the Survey Range tab. **Change** the Composition Range to 0-100 mass%. Set the Step Size to 2 mass% increments.



Click on Calculation Type, in the Category Window to define the Type of Calculation

Under Type of Calculation Change the Default Isothermal to Bubble Point (use the drop-down arrow). Then click OK.



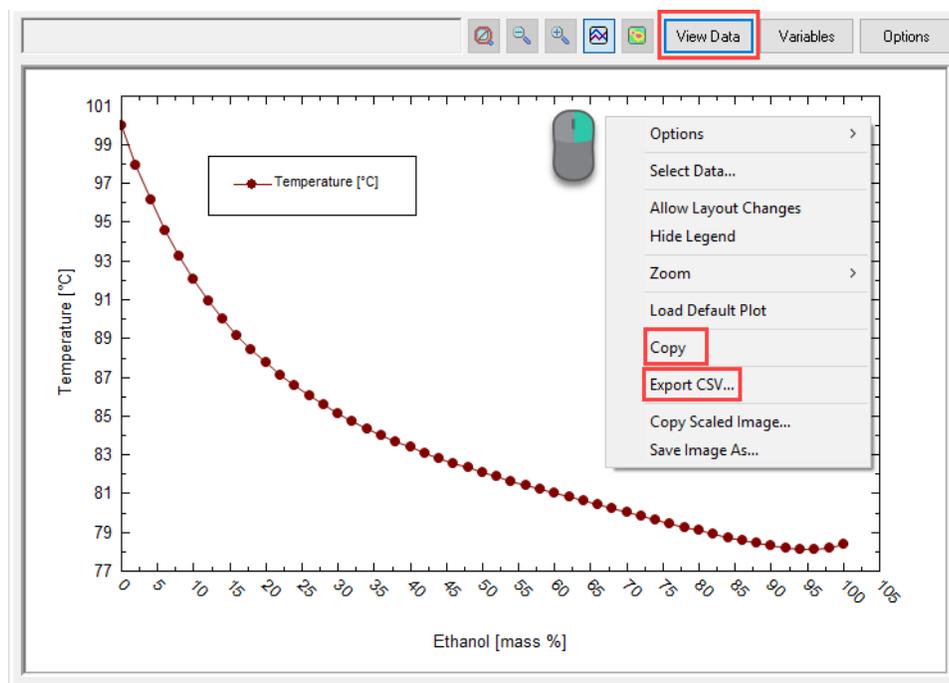
We are ready to perform the calculation. **Click** on the **Calculate** button or press the **<F9>** key.

84. It is time **to** save your file (File >Save **as...**) or using the **save** icon in the tool bar. You can save under the same file that we created before named as *Survey Calculations*.

85.

86. Analyzing the Results

87. Click on the Plot tab ( Plot). The **default** plot is the bubble point temperature vs the mass fraction ethanol. As the mass% of ethanol increases the bubble point temperature decreases.



88. You have 3 different options to retrieve this data to use it in your preferred plotting software.

89. Option 1: Right-click on **the** white region of the plot to open the drop-down menu and select **Copy**.

Option 2: **Right-click** on the white region of the plot to open the drop-down menu and select **Export CSV**.

90.

91. Option 3: Click on the View Data **button**, select **all** data by clicking on **the upper** left corner of the table, and copy the data using **Ctrl+C**.

	Ethanol	Temperature
	mass %	°C
1	0.0	99.9976
2	2.00000	97.9141
3	4.00000	96.1248
4	6.00000	94.5734
5	8.00000	93.2174
6	10.0000	92.0237
7	12.0000	90.9664
8	14.0000	90.0246
9	16.0000	89.1815

92.

93. In this case let's use Option 1. **Right click and Copy the data**, then open your preferred plotting tool and Paste the data.

94. Calculating the Dew Point

95. Return to the Definition tab

96. Click on the **Composition Specs** button. This will open the **Survey Options Window**

Click on Calculation Type, in the Category Window to define the Type of Calculation

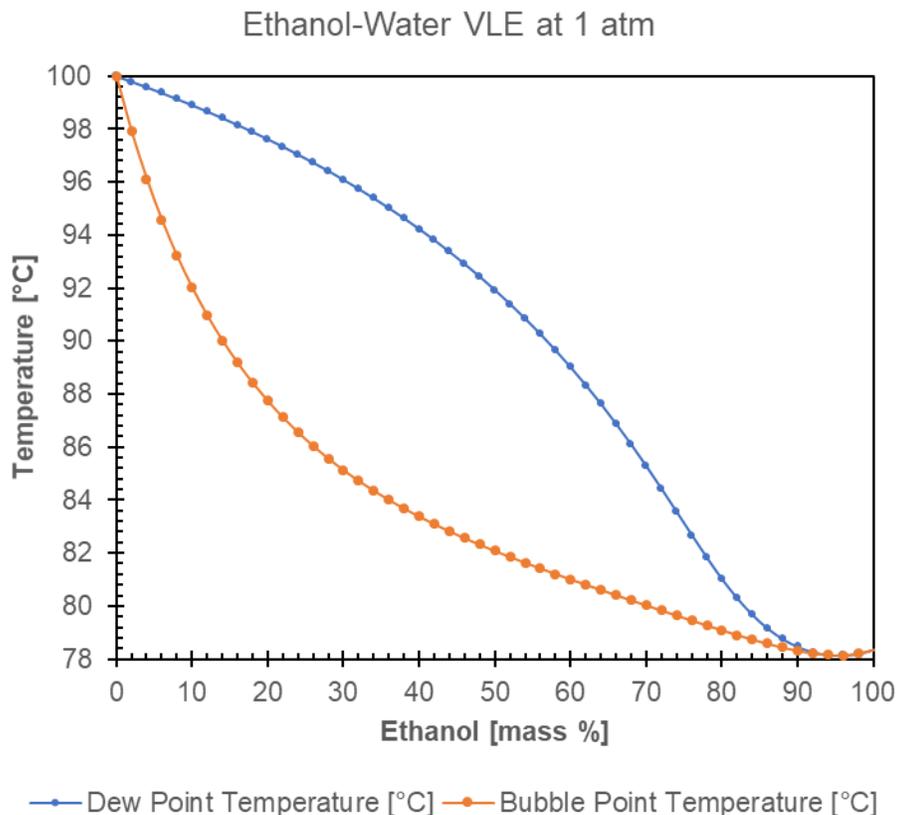
Change the calculation **type** to Dew Point (use the drop-down arrow). Then click OK.

Recalculate, and click on the Plot tab

Right click and Copy the data, then open your preferred plotting tool and Paste the data

40. Plot the two **temperature** curves vs mass% of ethanol and format as needed

41.



42.

43. The azeotrope occurs at about 95% ethanol where the two curves intersect, at 78.15 °C.

44.

in Chapter 8 on page 150 above.

In this example, we are mixing an acidic stream containing citric acid with a basic stream containing NaOH. Here is the resultant plot. Here is the resultant plot:

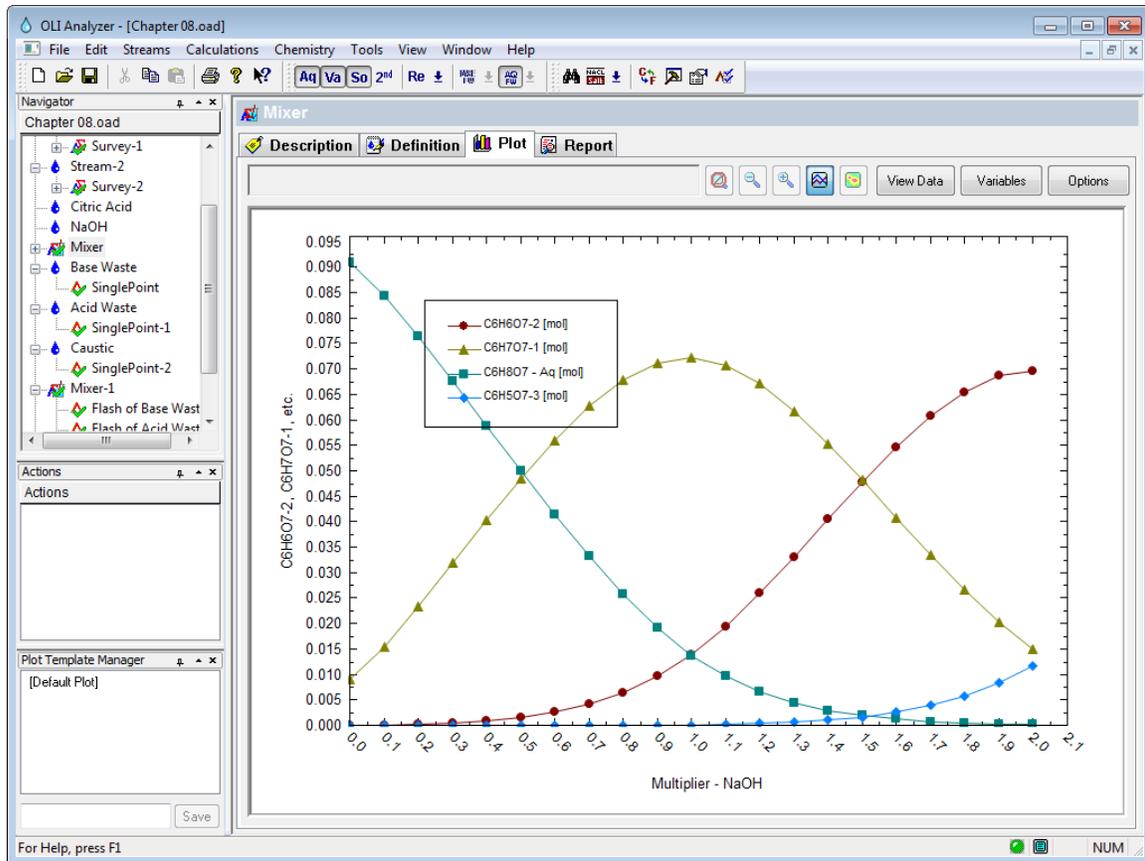


Figure 0-14 Chapter 8 citric acid survey

Perhaps we want to see an additional variable such as pH on this plot. Using the **Variables** button, select pH from the *Additional Stream Parameters* category.

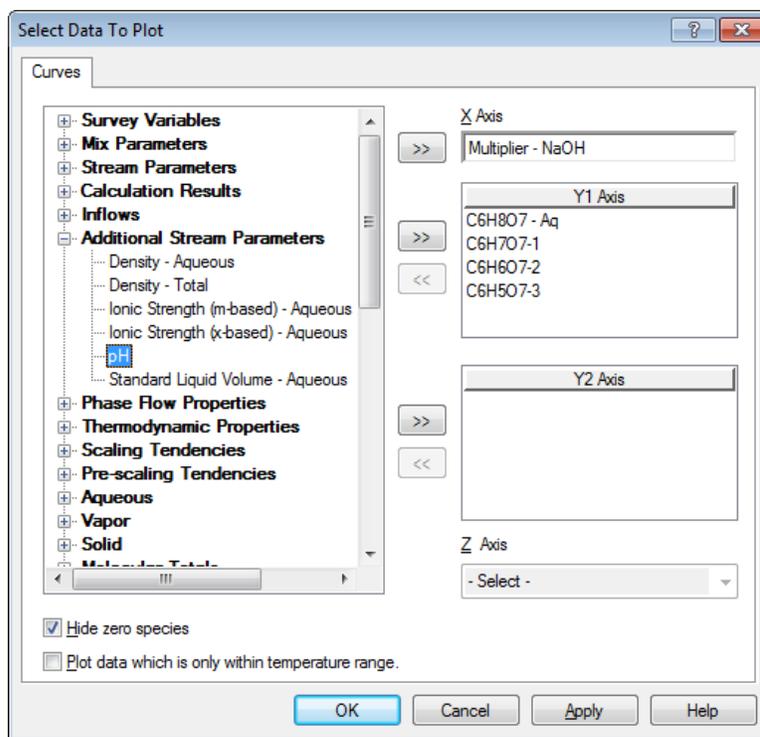


Figure 0-15 Selecting pH from the Additional Stream Parameters

This will put the pH on the Y1 axis by default. Here is the resultant plot:

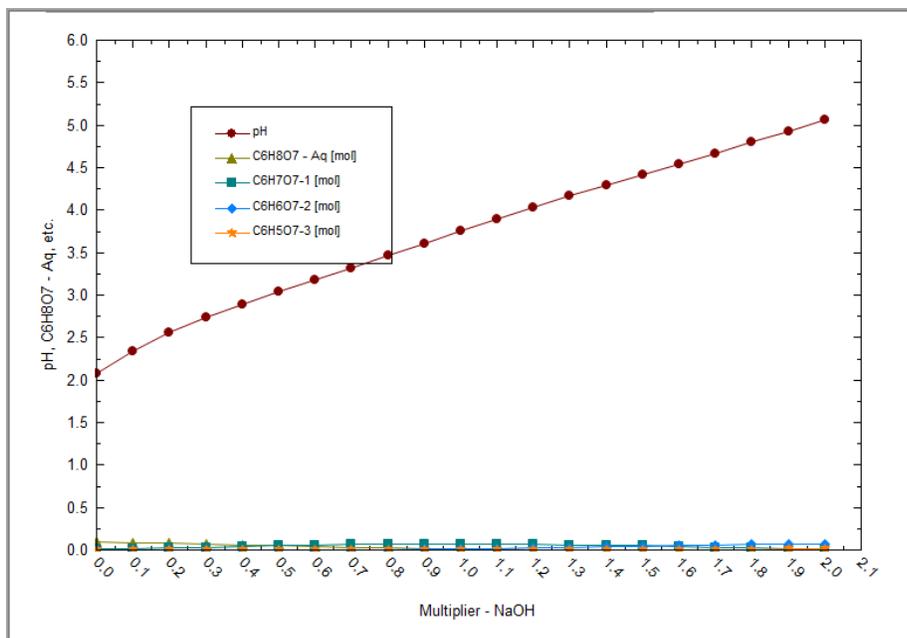


Figure 0-16 pH plotted, this skews the view

The variable "pH" has dominated the plot. Its values dwarf the values of the ions. The pH variable should be plotted on the Y2 axis.

We can switch the variables easily. Using the **Variables** button. Highlight the pH variable in the Y1 axis box.

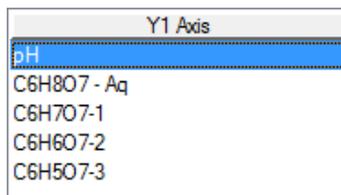


Figure 0-17

Now right-click the variable

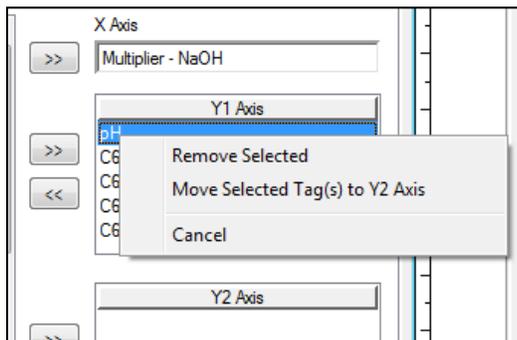


Figure 0-18 Right-clicking "pH"

Select **Move Selected Tag(s) to Y2 Axis**

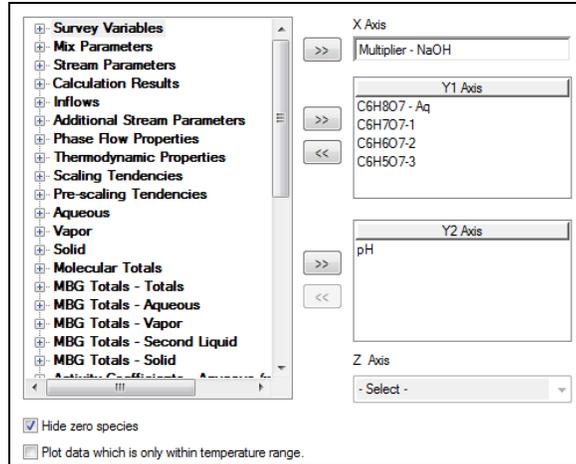


Figure 0-19 Variable moved

Here is the updated plot.

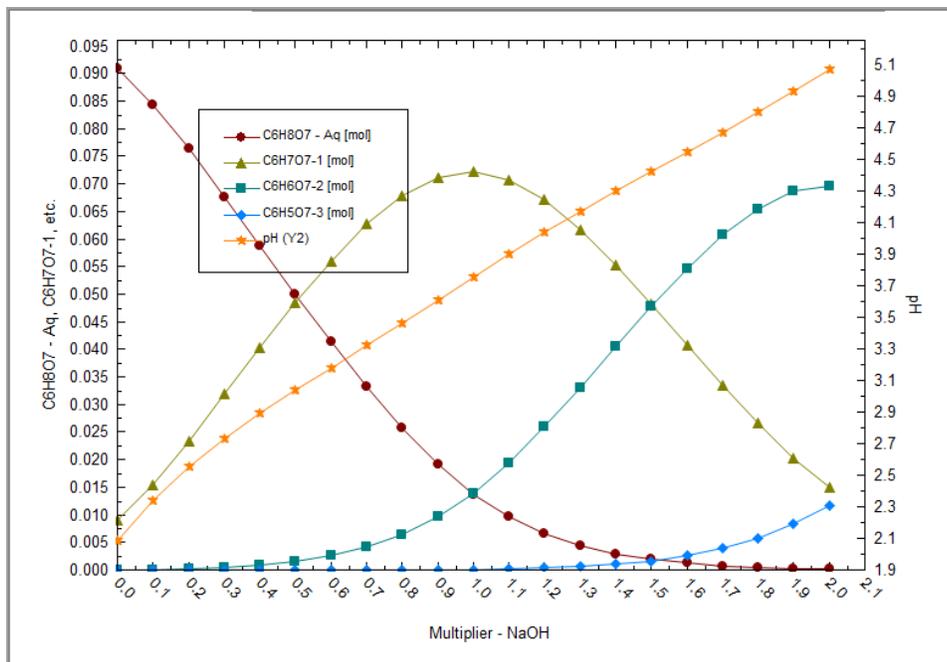


Figure 0-20 Updated plot with Y2 axis variable

Plotting two separate graphs at the same time

Frequently it is necessary to see two plots of two different systems at the same time. This is useful when comparing similar results between calculations. In this example, we have the results of a mixer calculation where we are absorbing chlorine into two different caustic (sodium hydroxide) solutions. Each caustic solution is at different concentrations.

You can download a copy of the example file from this location:

http://wiki.olisystems.com/wiki/images/5/5a/Chapter_38_-_2-Plots.zip

We will now open the file:

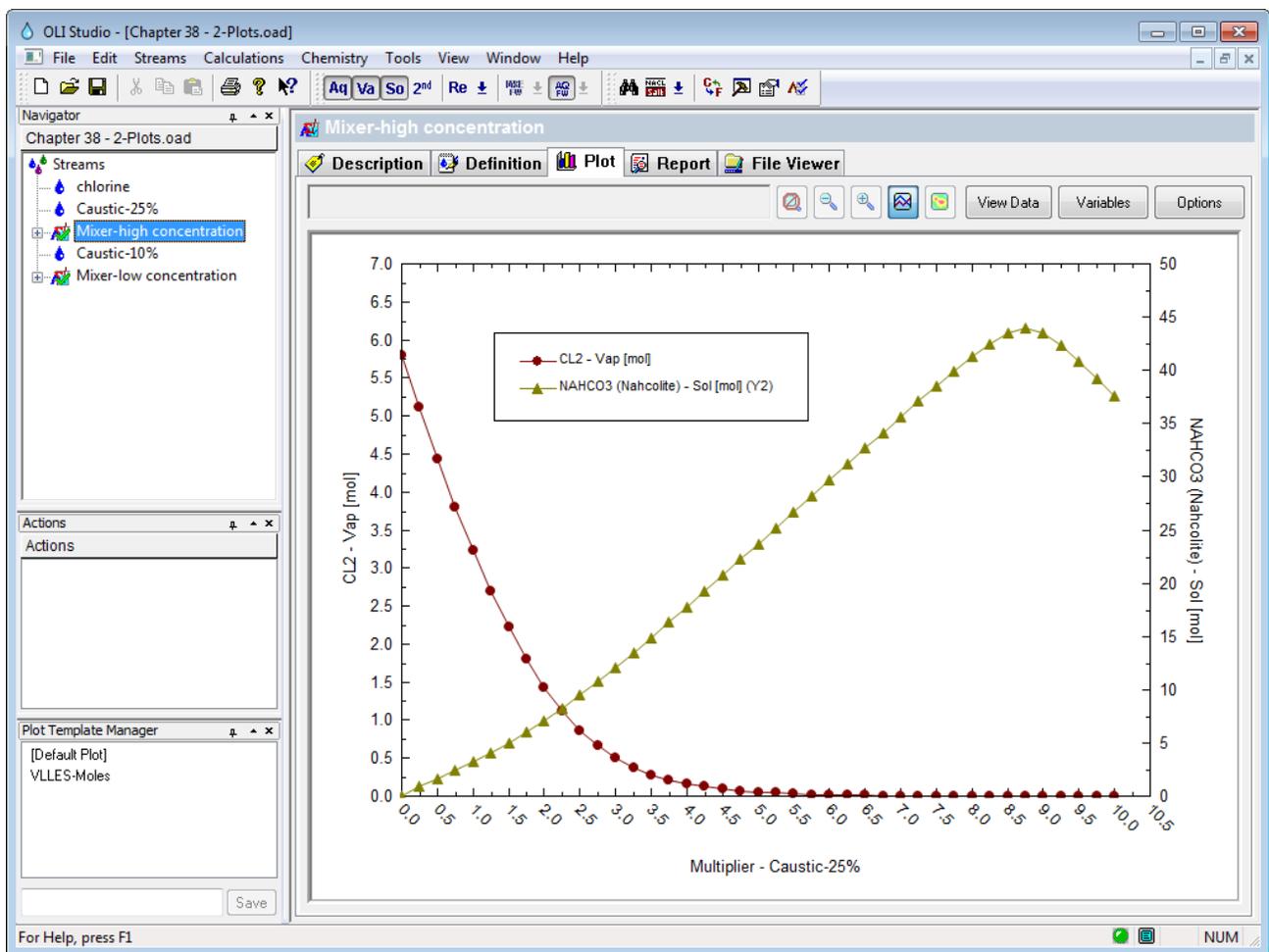


Figure 0-21 Our sample file

We have already set up our plot to display our variables. In this case, we have a 25 weight % caustic solution. It is beyond the scope of this tutorial to explain the chemistry and analysis of this case. We would like to simultaneously see the low concentration case.

To do this select **Window** from the menu line and then select **New Window**.

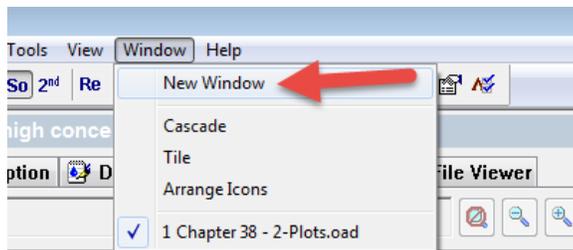


Figure 0-22 Creating a new window

This will create an exact reproduction of the same file. Notice that we have appended a window identifier for each file (the colon :1 or :2 in this case).

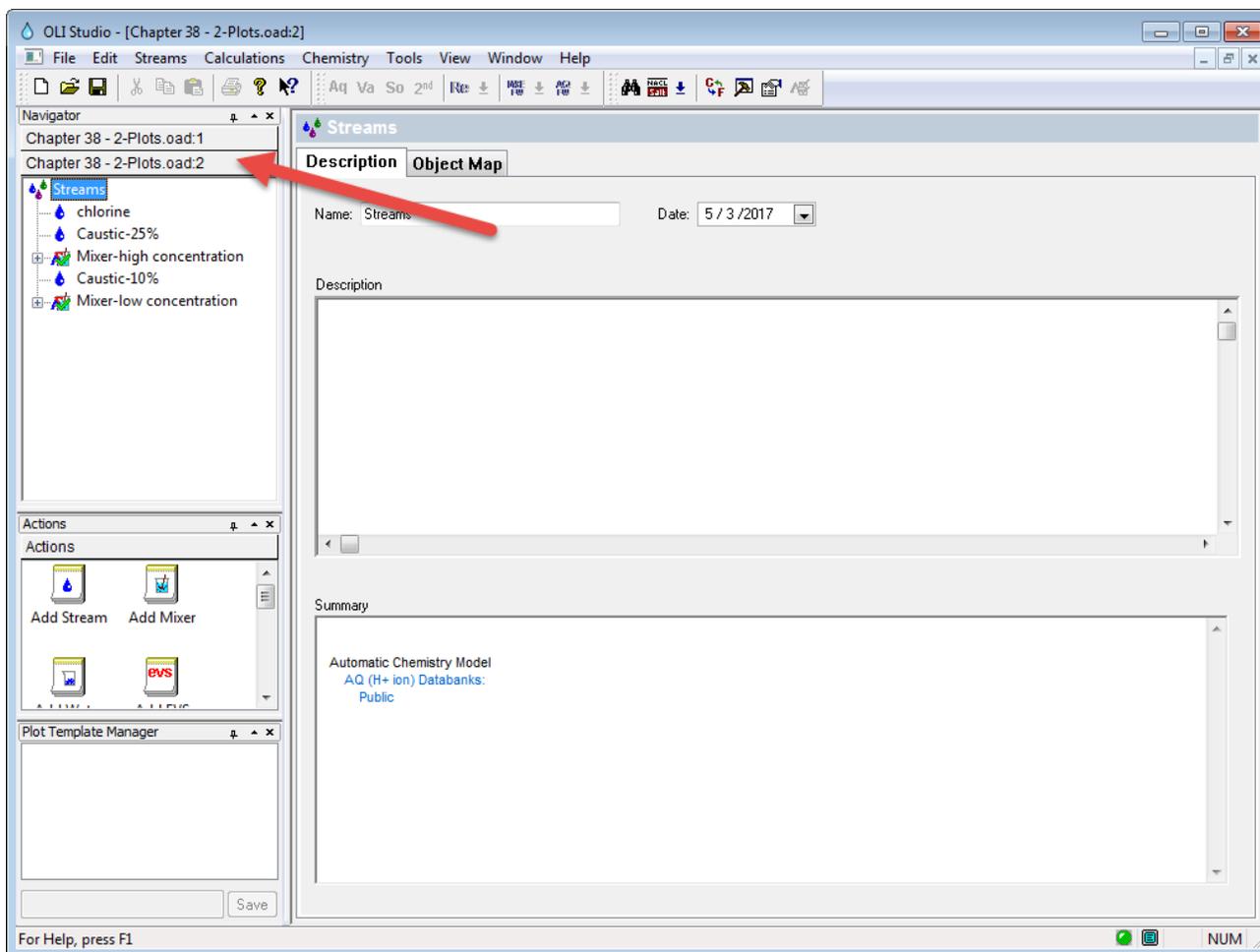


Figure 0-23 The new window

Now we select the other mixer and set up the plot with the same variables as the first plot:

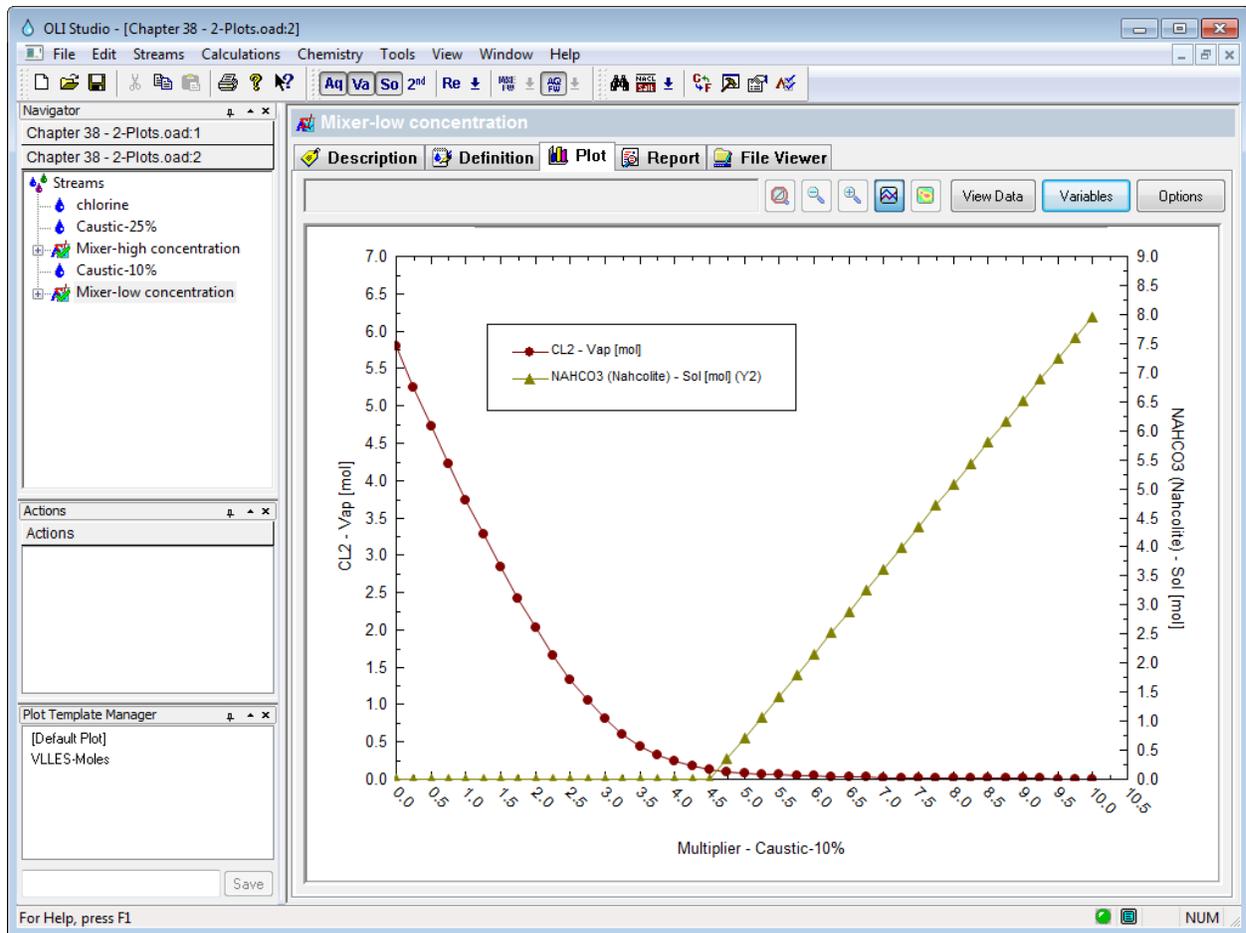


Figure 0-24 Plotting the low concentration case

Now we begin the process of putting both plots on the same display. Reselect **Window** and this time select **Tile**

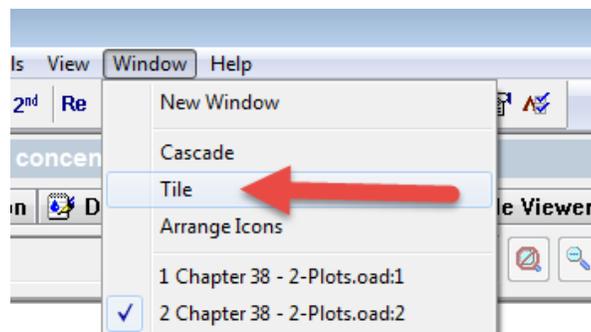


Figure 0-25 Tiling the images

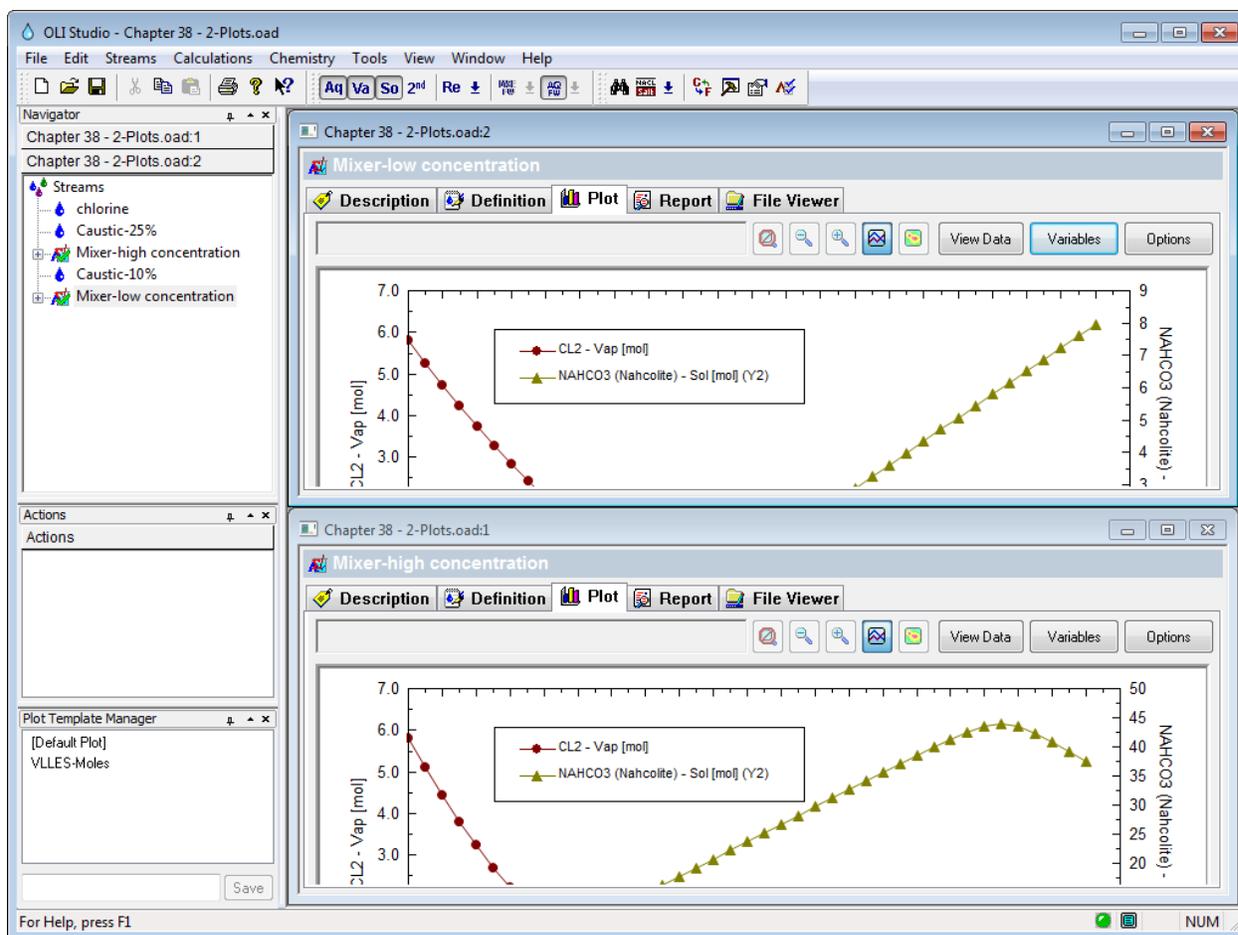


Figure 0-26 The tiled images

One of the limitations of a program such as Microsoft Word is that we are usually constrained by page width. To limit the amount of space we have artificially decreased the width of the Stream Analyzer window to make it fit on our page. What the user will have to do is resize the images so both fit at the same time.

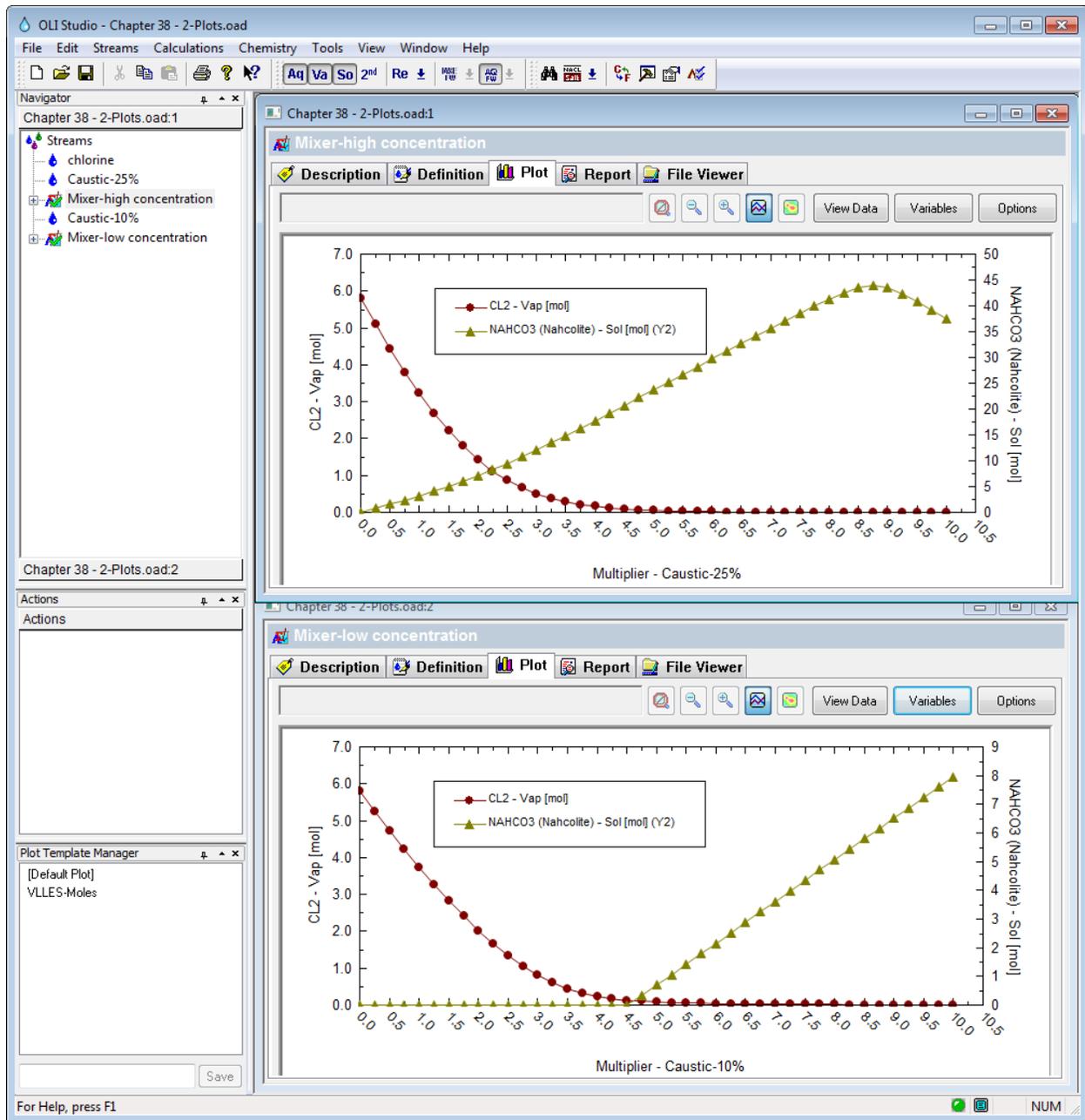


Figure 0-27 Resized Pictures

You will notice that the top window slightly overlaps the bottom window. This was done to make the image fit into Microsoft Word. You will get different results depending on the size of your monitor.

To complete the analysis here the top image is using a more concentrated solution of sodium hydroxide than the other and the formation of the solid sodium bicarbonate appears earlier than in the bottom (lower concentration) display. This may be important if you are designing multi-stage scrubbers.

You can download all the examples for this chapter from the [OLI Wiki Page](#)

Displaying Transport Properties and Extra Thermodynamic Parameters

Single Point Calculations

The OLI Analyzer program generates a lot of data. The program has attempted to sort out the most important data for you, but some values are still hidden.

Other values, such as the Gibb's Free Energy of a species are not automatically calculated since it can impart a large time burden on the calculation. To enable these types of calculations (Gibb's, Entropy and Heat Capacity) you need to enable them prior to starting the calculation.

For our example we have taken a simple chemistry and created a **SinglePoint** calculation. See Chapter 2

Open the Mixer example that we used for determining the pH of FeCl₃ solutions

Click the **Specs...** button to enable the extra thermodynamic calculations.

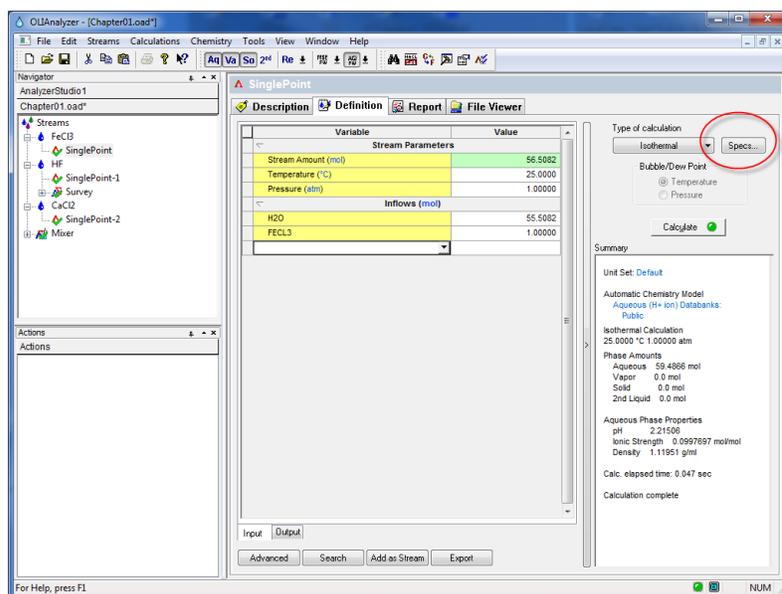


Figure 0-28

This will display the Calculation Options dialog. You will notice that we have left unchecked those calculations which take extra time to complete. You can enable any or all of them by checking the box.

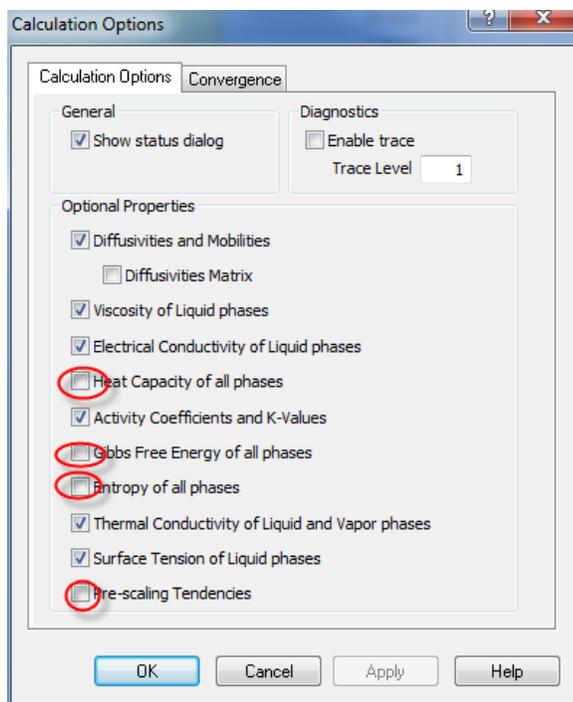


Figure 0-29

Here we have enabled all the extra calculations.

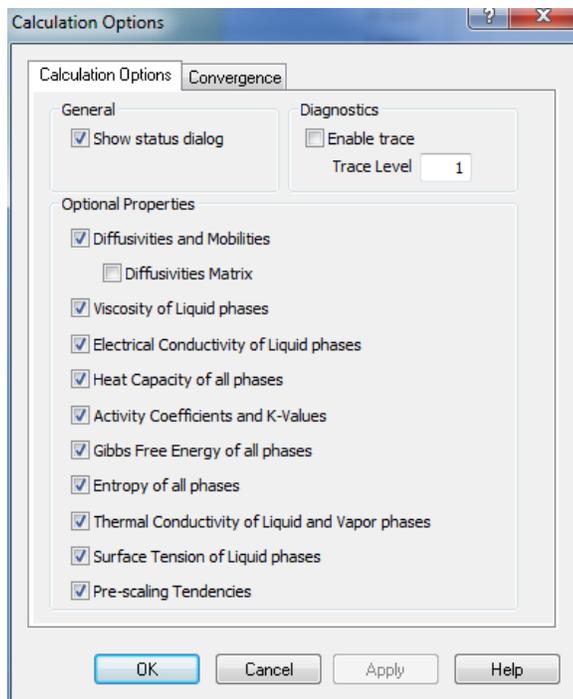


Figure 0-30

Click the **OK** button to continue

Click the **Calculate** button to continue. When the program finishes click on the **Report** tab and then the **Customize** button to enable the new values to be displayed.

Survey Calculations

To specify the extra thermodynamic values in a survey you need to follow similar steps as with the single point calculation. Here we have added a temperature survey. Click the **Specs...** button to add the additional calculations.

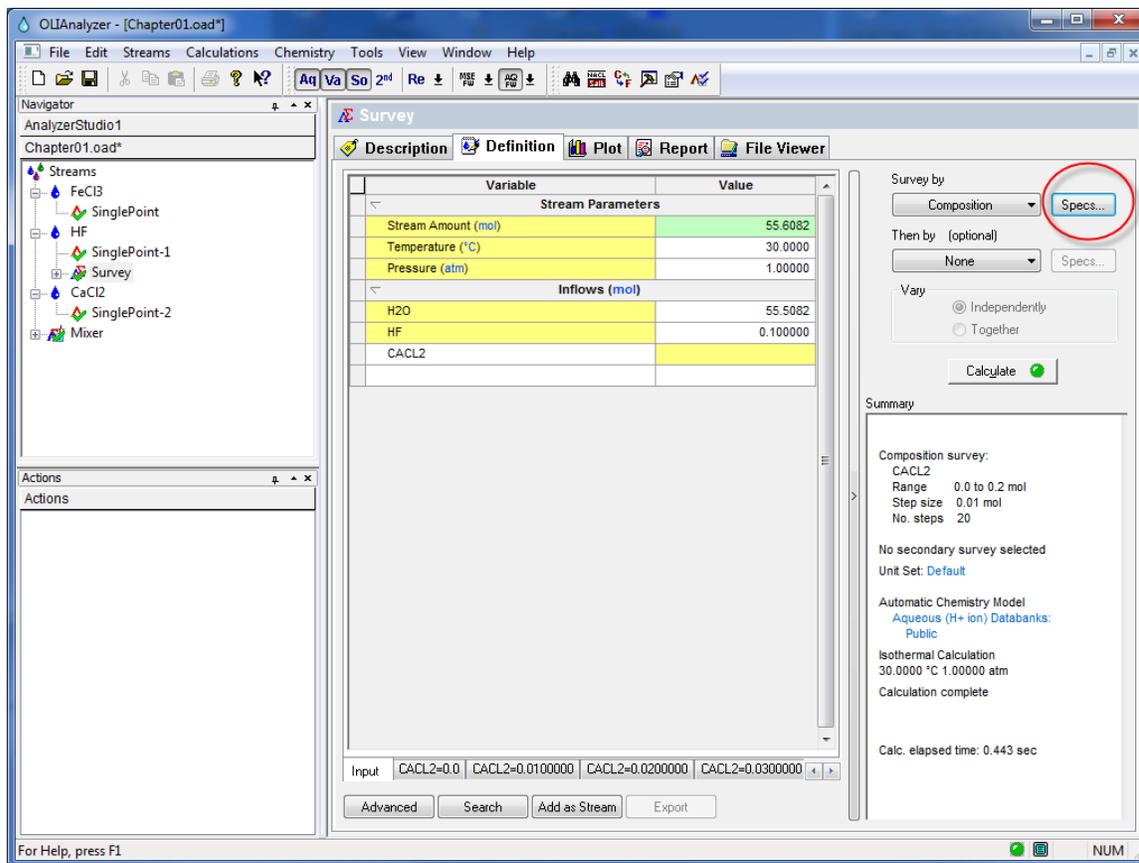


Figure 0-31

The Survey Options dialog is different from the single point dialog. You now must select **Calculation Options** to select the new calculations.

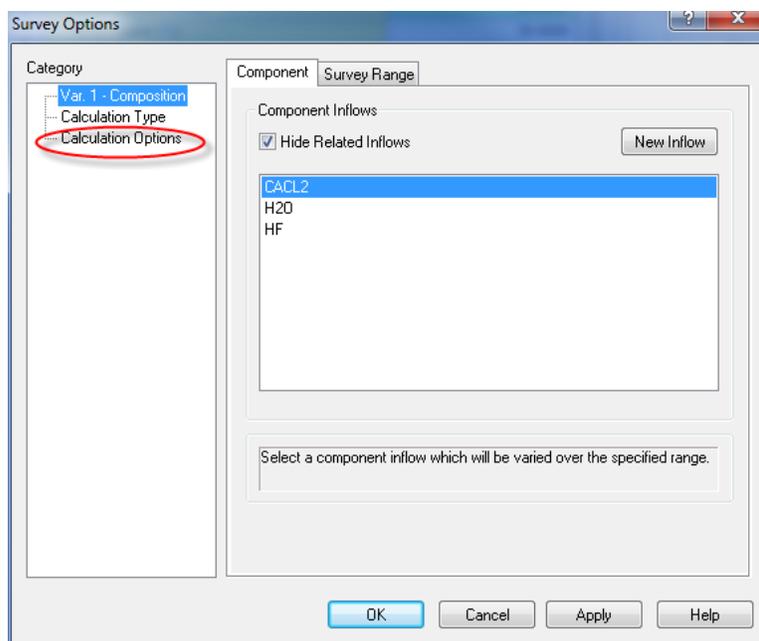


Figure 0-32

Once selected, the Calculation Options dialog is very similar to the single point dialog. Select the desired values. You will need to calculate (or recalculate) the survey when you are done.

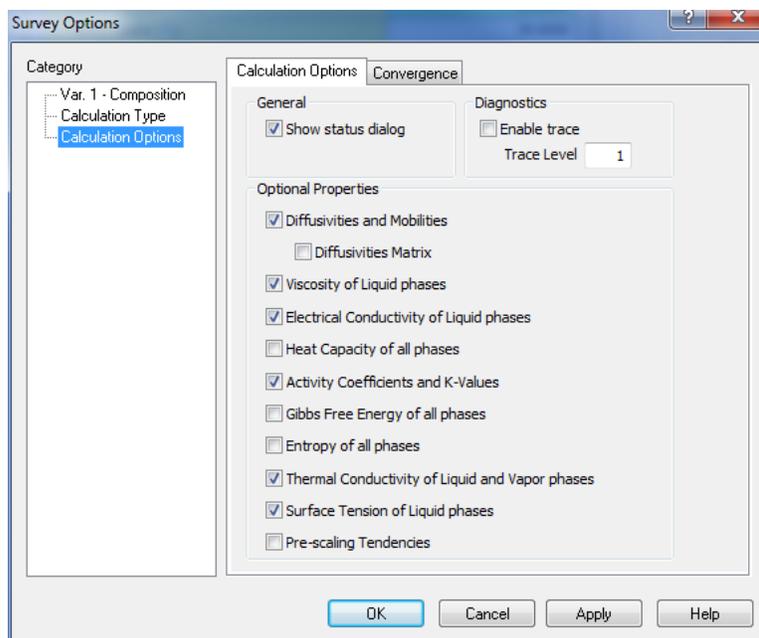


Figure 0-33

Displaying Transport Properties and Extra Thermodynamic Parameters Modifying the plot

Switching Variables between plots

Occasionally it is necessary to quickly switch variables between the Y1 axis and the Y2 axis. This is frequently necessary because the range of the variables plotted is vastly different. In this example, we are using the files created in Chapter 8. See: http://wiki.olisystems.com/wiki/images/5/53/Chapter_08.zip for the latest version of the worked file or

Hiding Curves

One nice feature of the OLI Analyzers is that you can generate a lot of points to plot many variables. You can also perform multiple series of plots such as plotting temperature curves as a function of pressure. This is what we are showing below. This is a pre-run temperature survey with pressure selected as the secondary (*then by...*) survey.

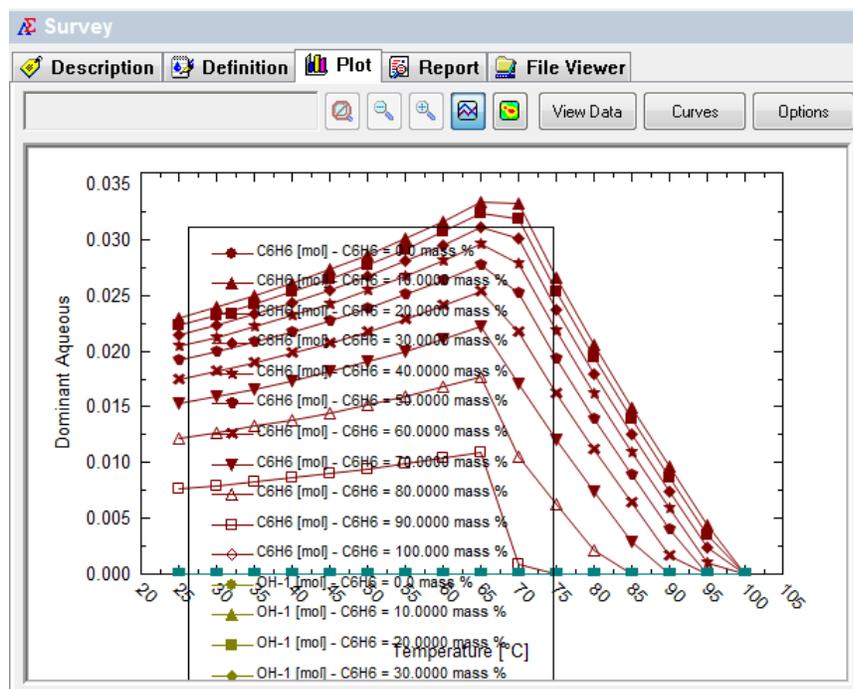


Figure 0-34

As you can see there is a lot of data, the plot is very hard to read. Fortunately, we have created a tool to clean up the plot. Click the **Options** button in the upper right-hand corner.

This will display the **Customize Plot** dialog. Select the **Curves** category.

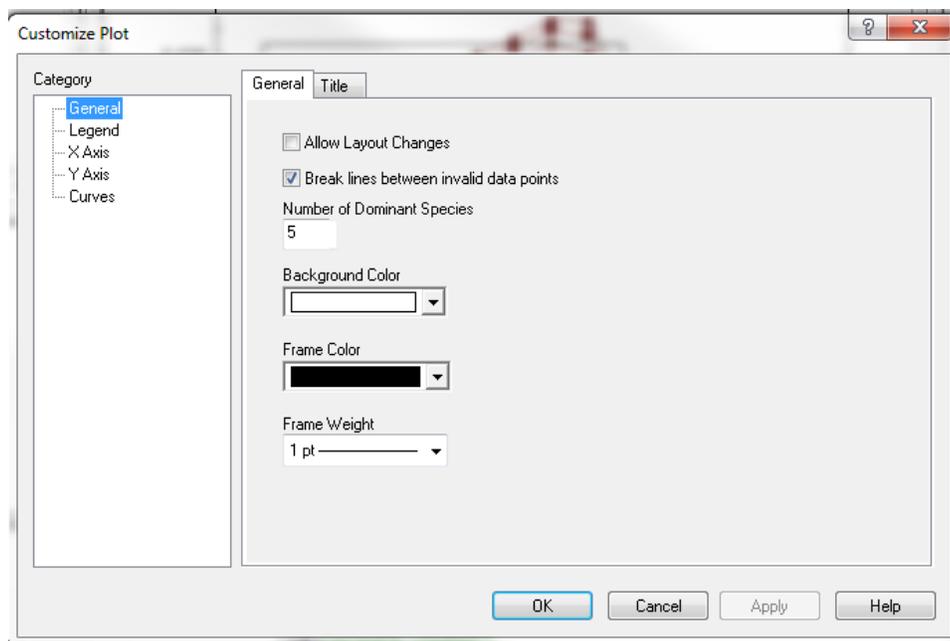


Figure 0-35

Each data series in the current plot is displayed. As you can see in the dialog below there are many series currently displayed. You could hide each one individually or select groups to hide. We are first going to hide all the curves. Select the first item in the list and hold the **Shift Key**.

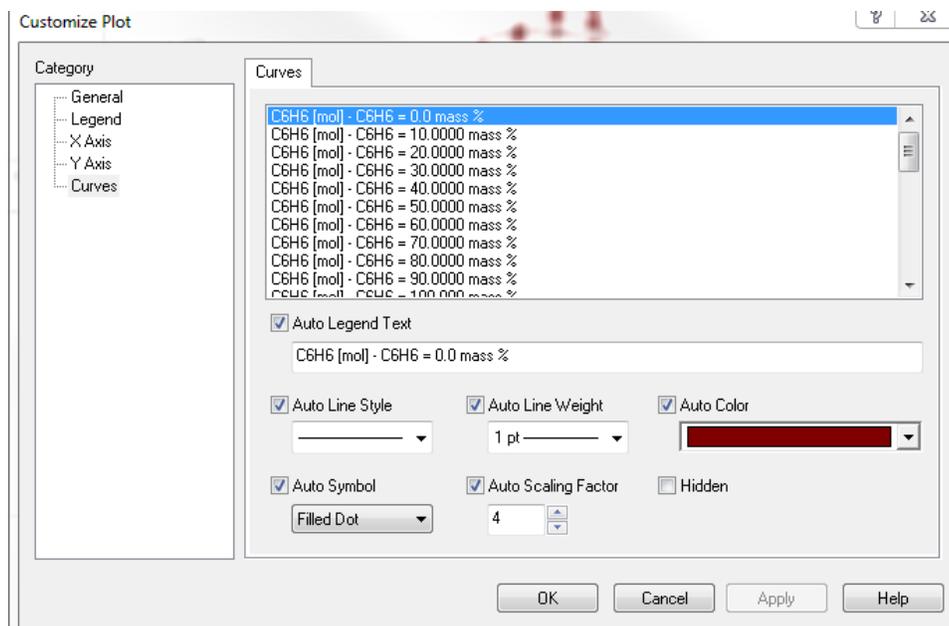


Figure 0-36

Scroll down to the last item in the list

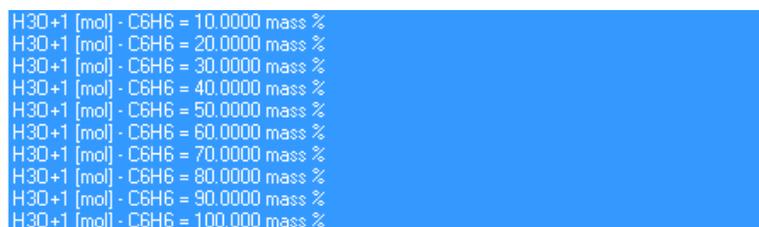


Figure 0-37

We have now selected all the items. Click the **Hidden** check box to hide these curves.

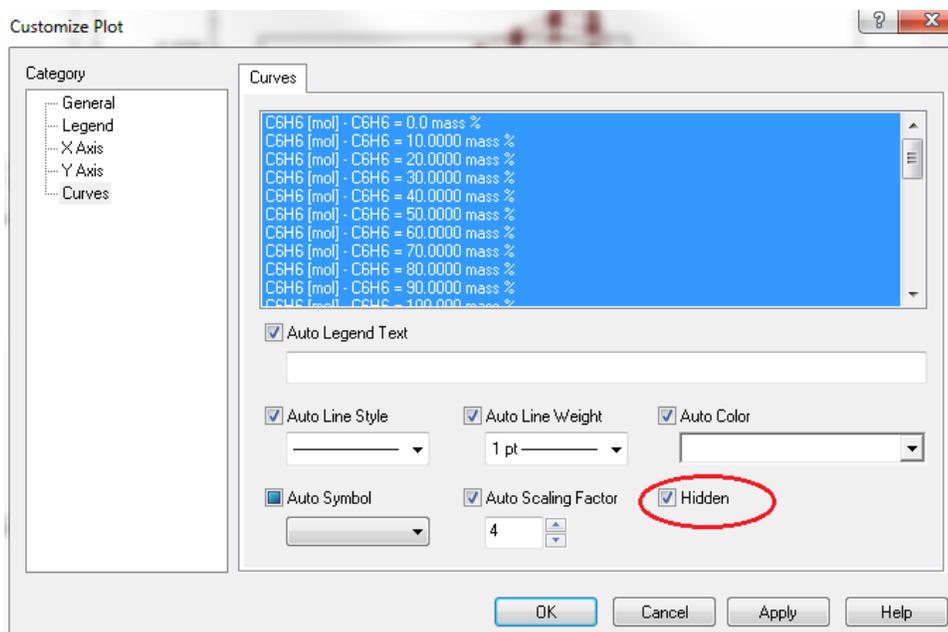


Figure 0-38

Click the **Apply** and then **OK** buttons to see the plot.

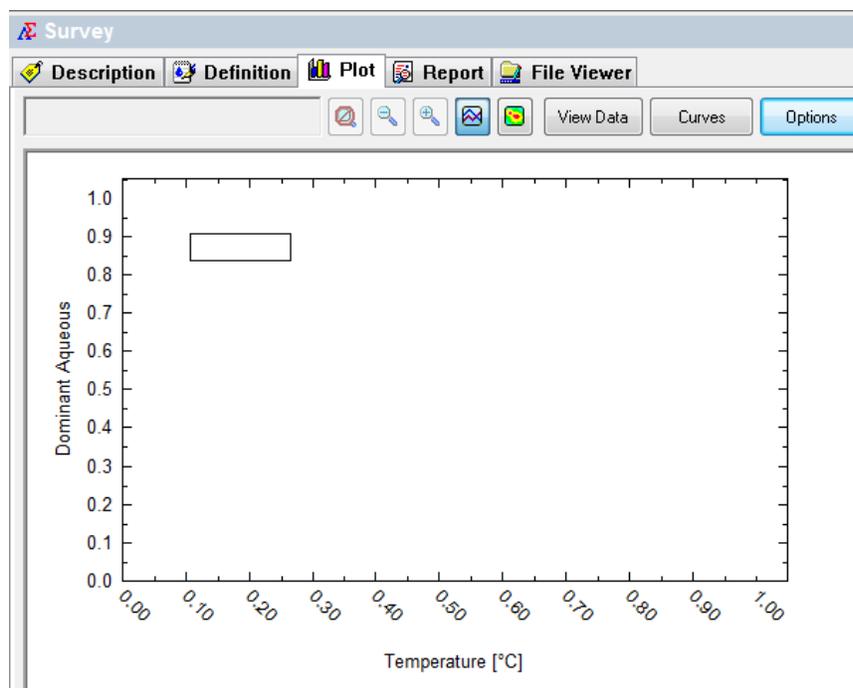


Figure 0-39

This is not very helpful. We need to "Unhide" some curves. Once again, click the **Options** button and then reselect the **Curves** category.

For this example, we want to see the highest pressure for this dual survey. Scroll to the bottom of the list and then uncheck the **Hidden** box.

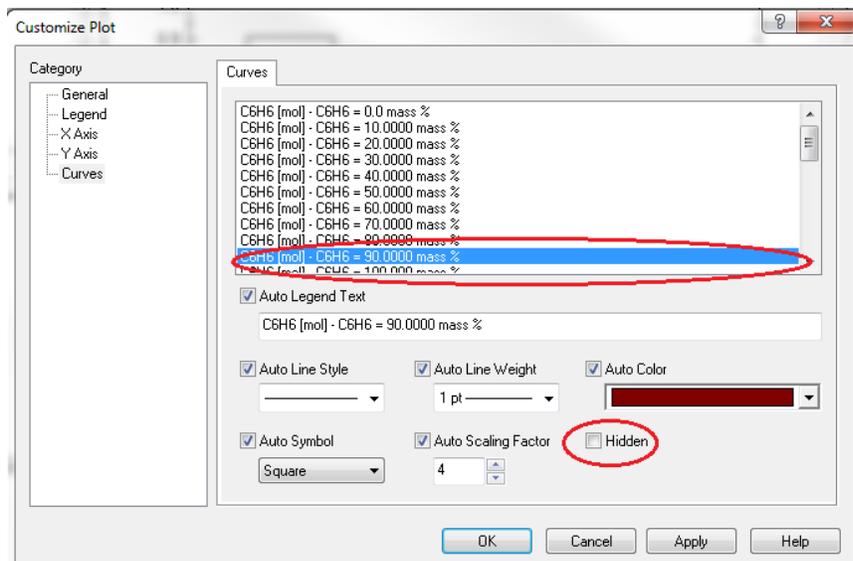


Figure 0-40

Click the **Apply** and **OK** buttons to display the plot.

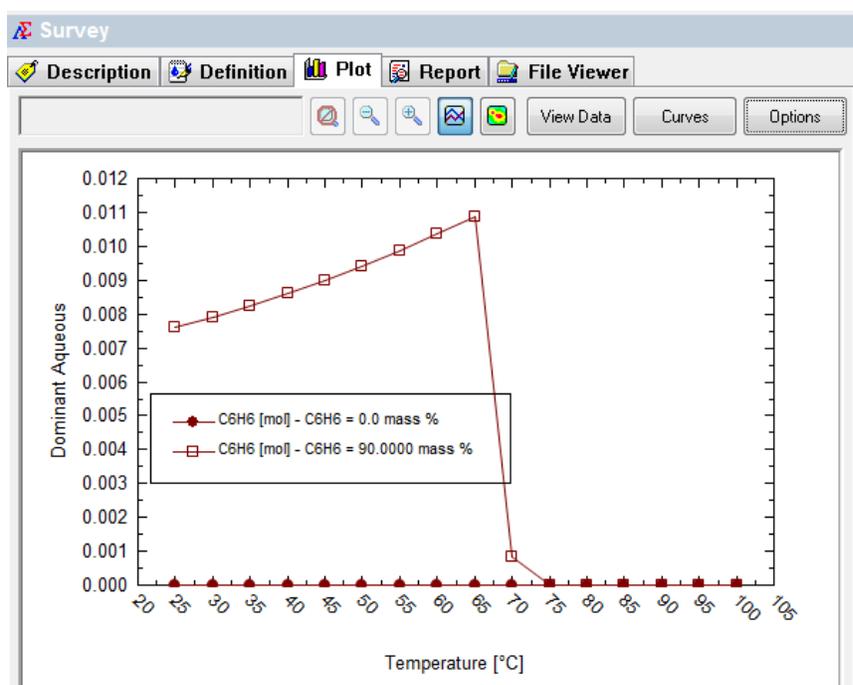


Figure 0-41

We now have our plot without all the clutter of extra points. We can now go back and add (or unhide) additional curves. Once again, click the **Options** button and then reselect the **Curves** category.

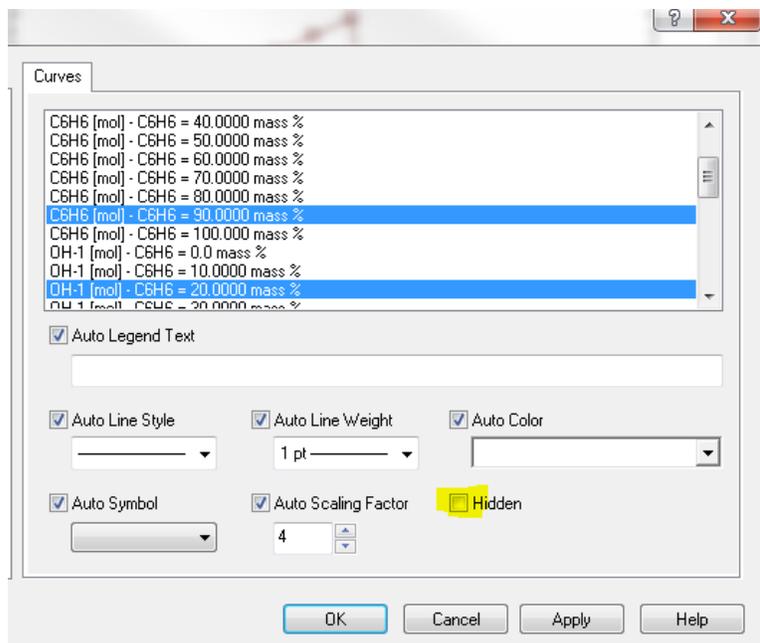


Figure 0-42

Locate a curve midway in the list (here we have chosen a different variable also at the highest pressure). Uncheck the **Hidden** check box. Click the **Apply** and **OK** buttons to display the plot.

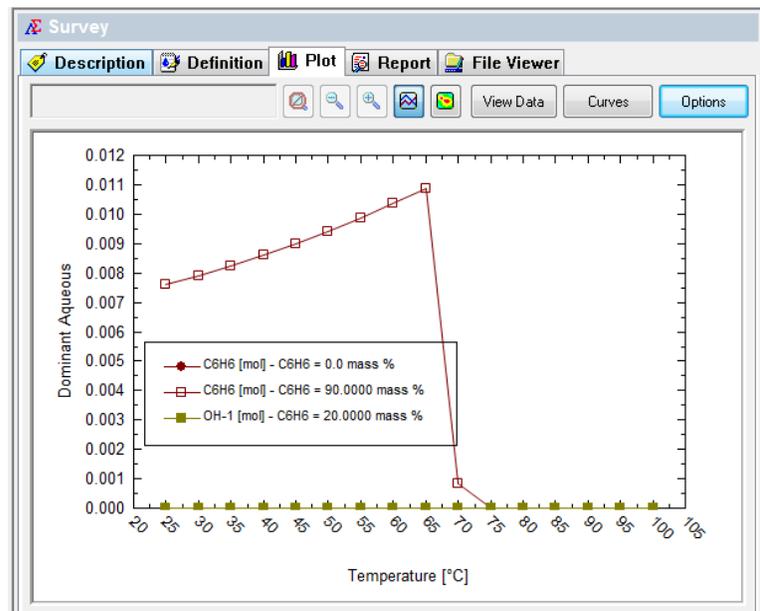


Figure 0-43

We now have two curves displayed. It is helpful to note that all the other curves are still present in the diagram. If you export this plot to a spreadsheet, all the data, not just the displayed values, will be used.

We can modify the plot directly without the use of the Options button. **Right-click** any displayed curve. We have chosen the upper curve.

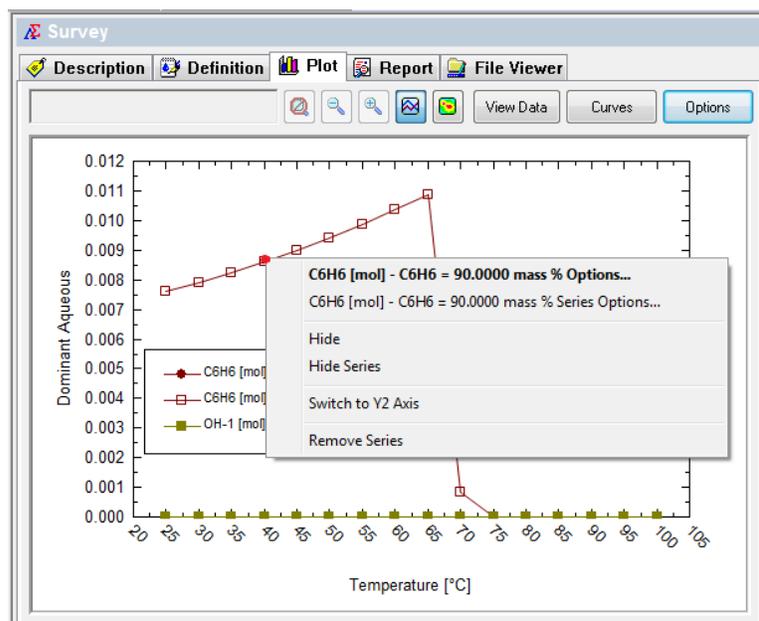


Figure 0-44

This will display a pop-up menu. The name of the series is displayed. Select **Hide Series**.



Figure 0-45

This removed the series from display. Unfortunately, the only method to "Unhide" the series is to use the Options button as we did above.

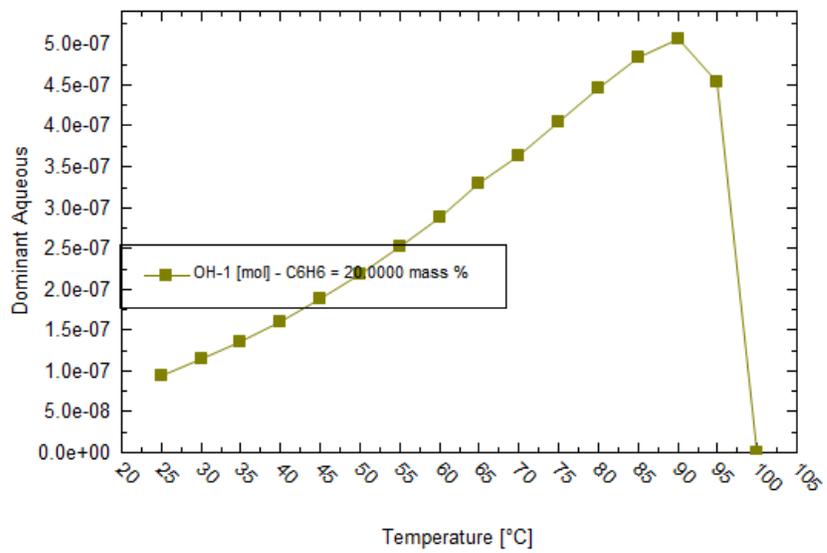


Figure 0-46

Plotting two separate graphs at the same time

Frequently it is necessary to see two plots of two different systems at the same time. This is useful when comparing similar results between calculations. In this example, we have the results of a mixer calculation where we are absorbing chlorine into two different caustic (sodium hydroxide) solutions. Each caustic solution is at different concentrations.

You can download a copy of the example file from this location:

http://wiki.olisystems.com/wiki/images/5/5a/Chapter_38_-_2-Plots.zip

We will now open the file:

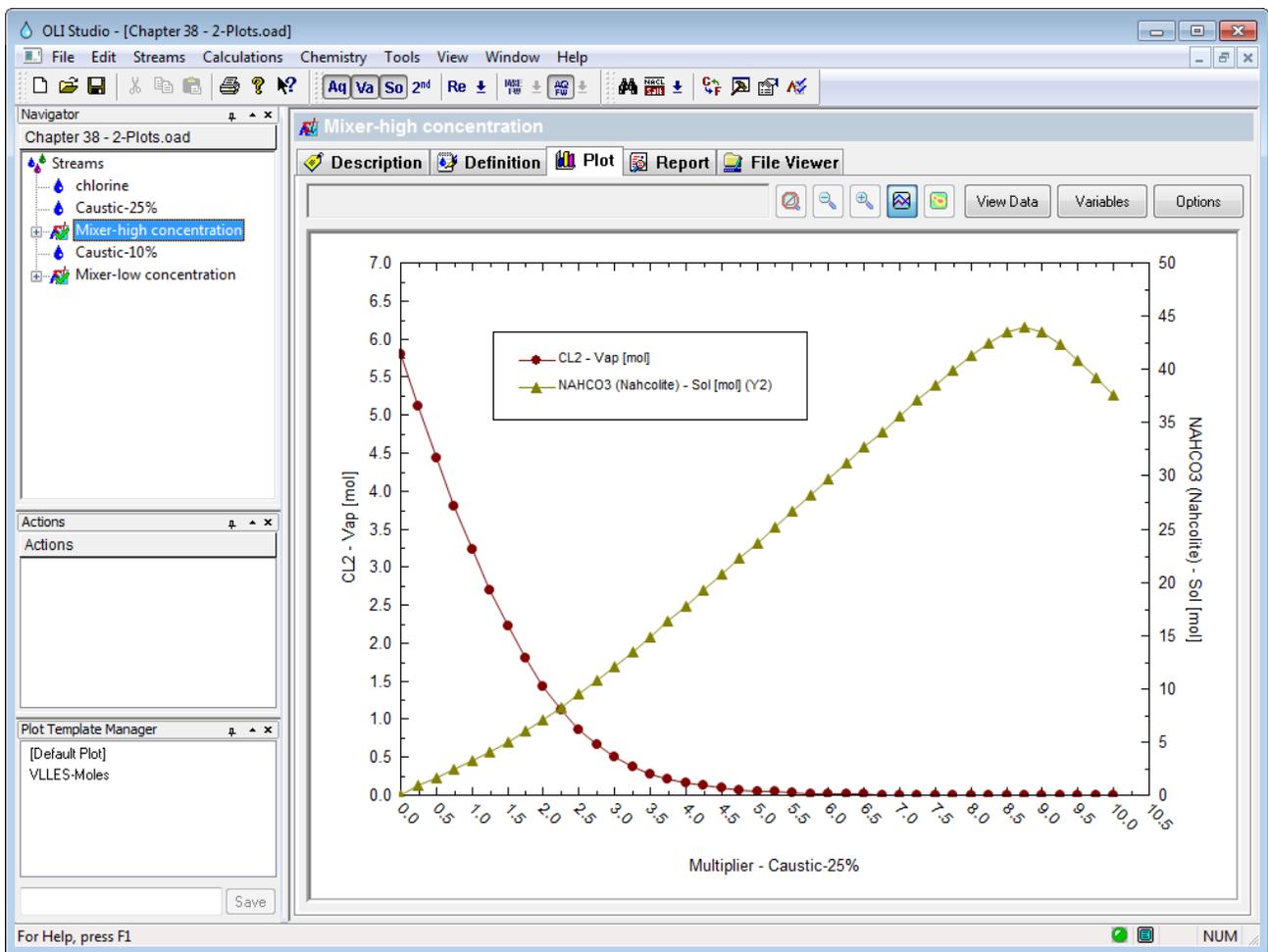


Figure 0-47 Our sample file

We have already set up our plot to display our variables. In this case, we have a 25 weight % caustic solution. It is beyond the scope of this tutorial to explain the chemistry and analysis of this case. We would like to simultaneously see the low concentration case.

To do this select **Window** from the menu line and then select **New Window**.

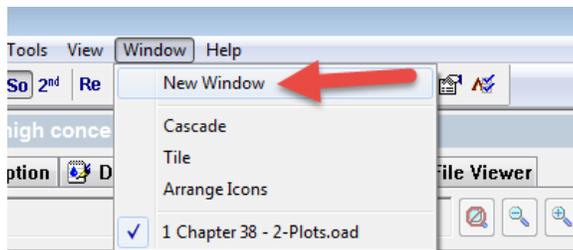


Figure 0-48 Creating a new window

This will create an exact reproduction of the same file. Notice that we have appended a window identifier for each file (the colon :1 or :2 in this case).

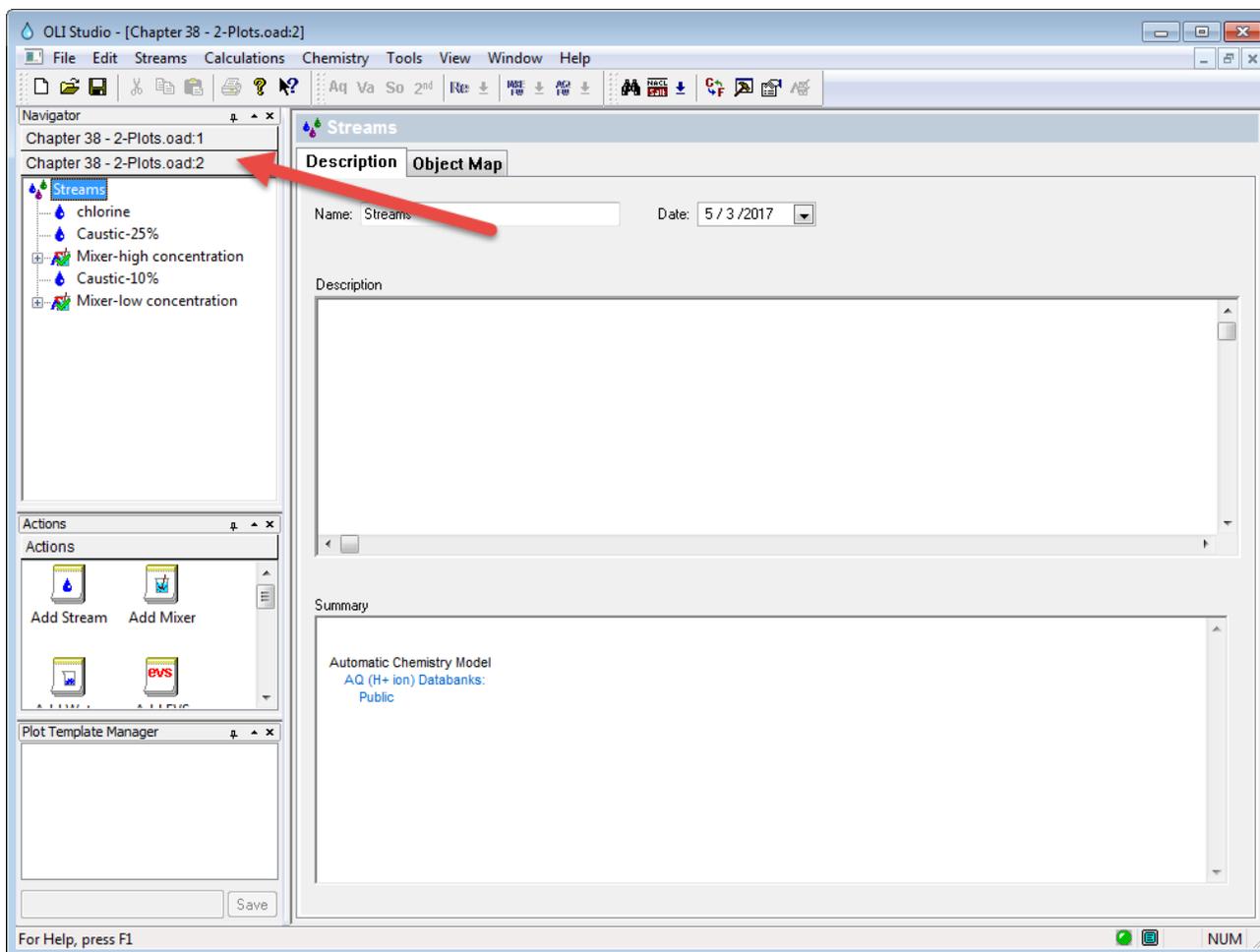


Figure 0-49 The new window

Now we select the other mixer and set up the plot with the same variables as the first plot:

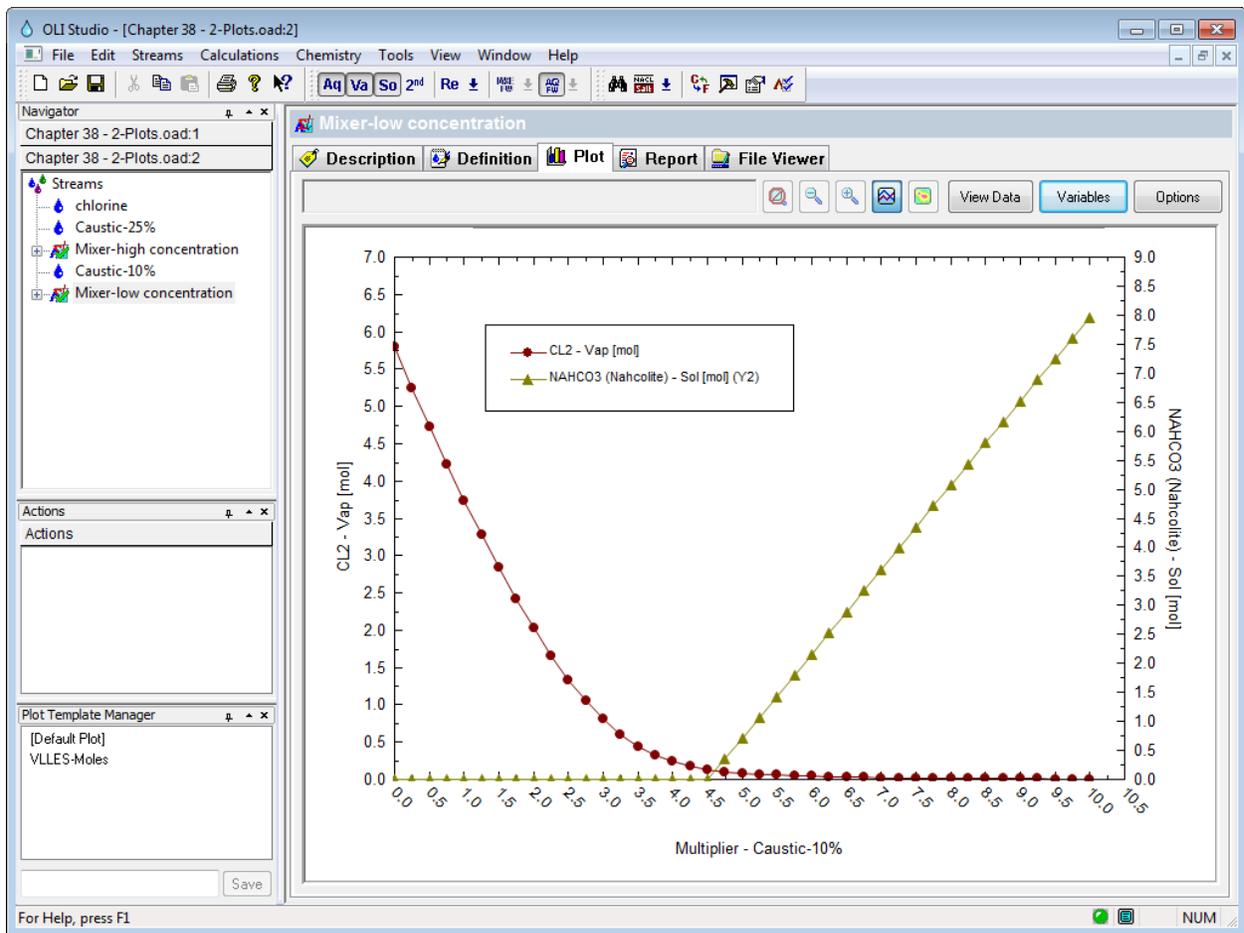


Figure 0-50 Plotting the low concentration case

Now we begin the process of putting both plots on the same display. Reselect **Window** and this time select **Tile**

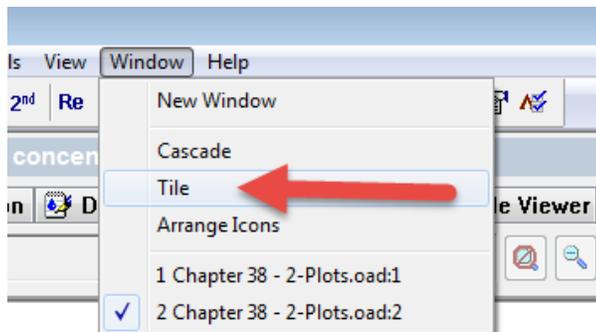


Figure 0-51 Tiling the images

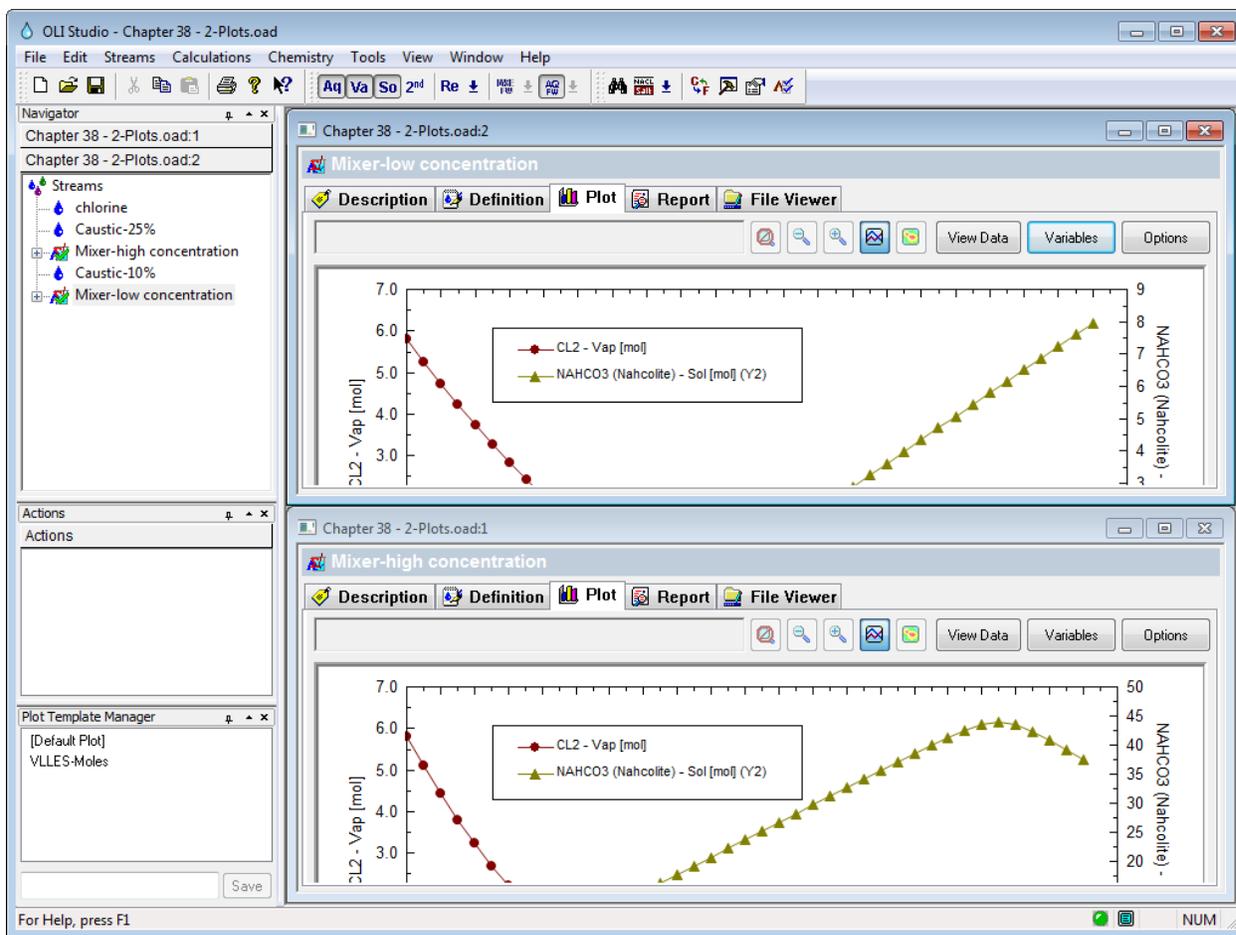


Figure 0-52 The tiled images

One of the limitations of a program such as Microsoft Word is that we are usually constrained by page width. To limit the amount of space we have artificially decreased the width of the Stream Analyzer window to make it fit on our page. What the user will have to do is resize the images so both fit at the same time.

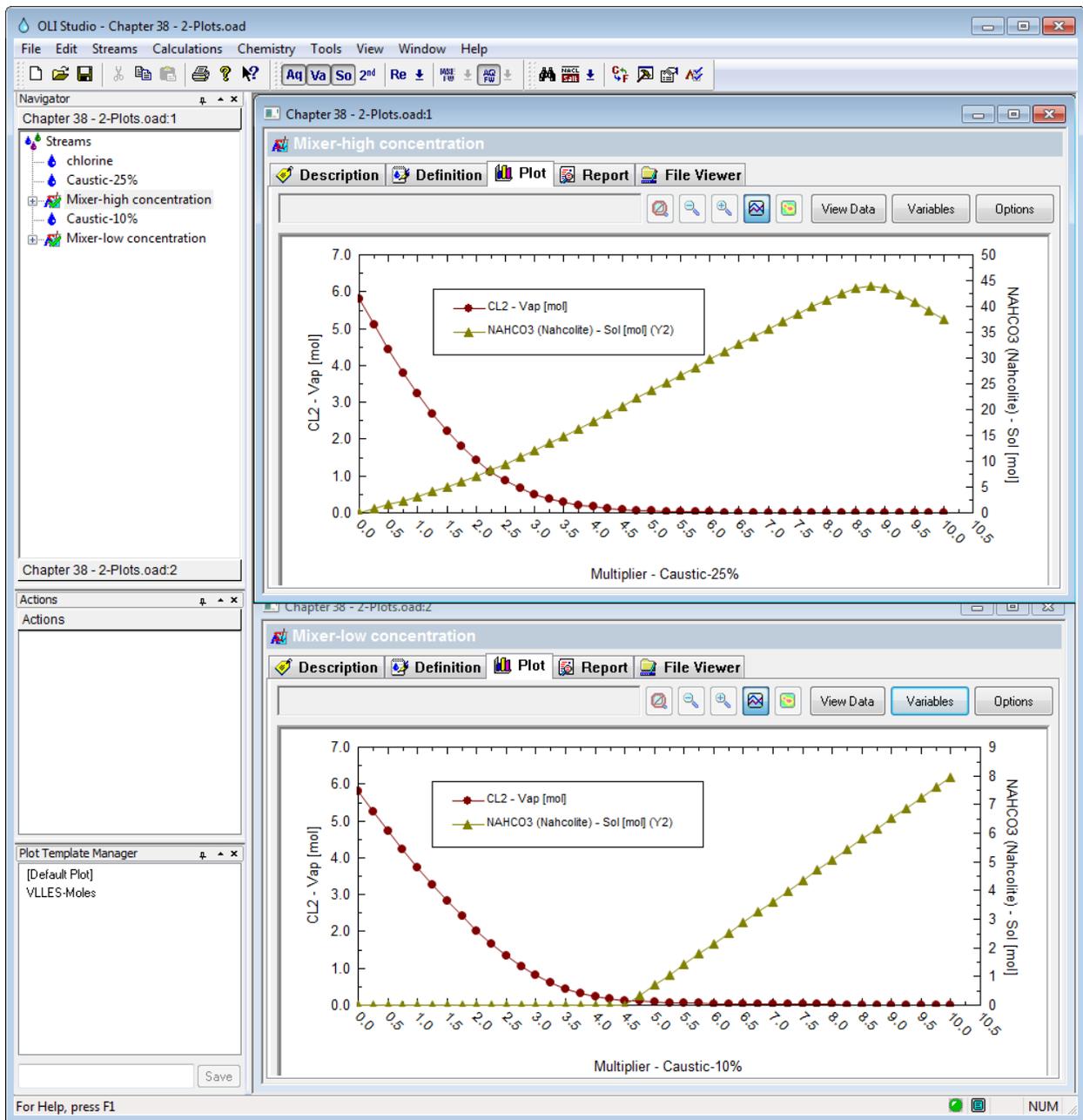


Figure 0-53 Resized Pictures

You will notice that the top window slightly overlaps the bottom window. This was done to make the image fit into Microsoft Word. You will get different results depending on the size of your monitor.

To complete the analysis here the top image is using a more concentrated solution of sodium hydroxide than the other and the formation of the solid sodium bicarbonate appears earlier than in the bottom (lower concentration) display. This may be important if you are designing multi-stage scrubbers.

You can download all the examples for this chapter from the [OLI Wiki Page](#)

Appendix

Definitions

Electrolyte: A molecular or atomic species (gaseous, liquid, or solid) which has some solubility in water and reacts in water, to some significant extent, to one or more ionic (charged) species. $\text{CO}_2(\text{g})$ and $\text{NaCl}(\text{s})$ are examples of electrolytes.

Nonelectrolyte: A molecular or atomic species (gaseous, liquid, or solid) which has some solubility in water and remains nearly or totally in the molecular form (uncharged) when dissolved in water. $\text{Ar}(\text{g})$ and $\text{C}_6\text{H}_{14}(\text{l})$ are examples of non-electrolytes.

Complex, ion pair: A species composed of both cationic and anionic portions. Complexes can be charged or uncharged. $\text{FeCl}_2^+(\text{aq})$ and $\text{FeCl}_3(\text{aq})$ are examples of complexes.

Strong Electrolyte: A molecular or atomic species which completely dissociates to its constituent base ions, leaving virtually no uncharged molecular forms of the species in water. $\text{KCl}(\text{s})$ and $\text{NaCl}(\text{s})$ at room temperature are examples of electrolytes.

Weak Electrolyte: A molecular or atomic species which partially dissociates in water to its constituent ions, leaving a significant concentration of the molecular forms and/or other complexes. Acetic acid and sulfuric acid are examples of weak electrolytes

Liquid-1:

True Species

Molecular Species

TDS

pH

Proration

Makeup ion

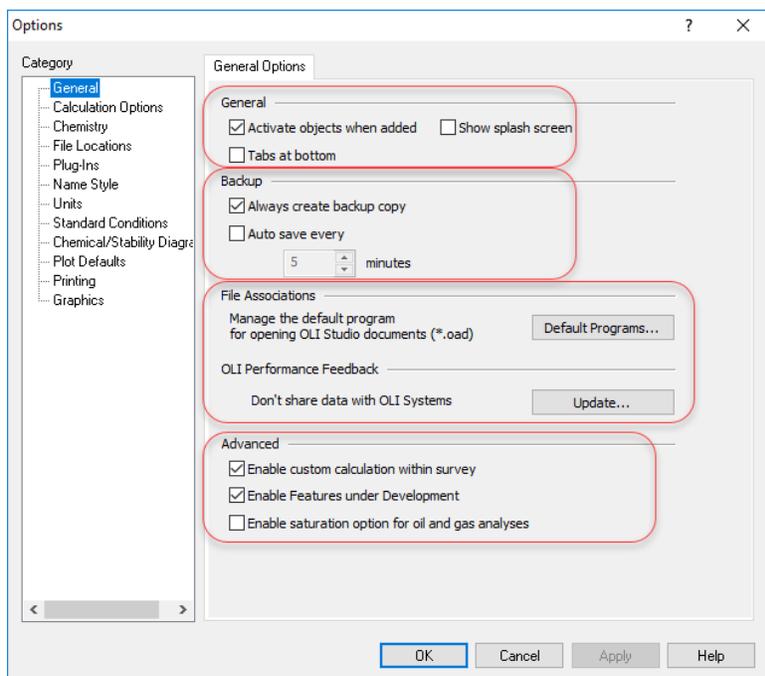
S, ST – Saturation, Scale Tendency: The ratio of the concentration (activity) to its solubility ($S=1$).

SI – Scale Index = $\text{Log}(S)$

Contact Surface

General Options

You can access the **General Options** from the Menu Bar: **Tools > Options...** or via the quick access from the Tool Bar . This will open a new window where you can change default setting in the software.



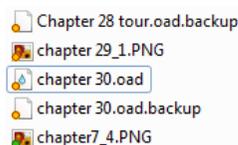
Even though modern computers are very reliable, some software packages were written without full consideration of what else may be running. This may cause system crashes and you may lose your work.

OLI has provided a method to help recover lost data. By default, OLI will back up any file you open with the OLI Analyzers so that you have the previous version saved. OLI will also automatically save your file every 5 minutes. You can change these settings.

By default, the OLI Analyzers will create a backup copy of the file (if it was previously saved). If this was a large file you may want to disable this feature but unchecking the **Always create backup copy** check box.

Also, by default, the OLI Analyzers will save your file every 5 minutes. You can decrease or increase this time as you require.

If you need to recover a file that you accidentally saved (or it got corrupted) OLI creates a file with essentially the same name except the extension "backup" is appended. You should copy or rename this file and then open it as you would any other OLI Analyzer file.



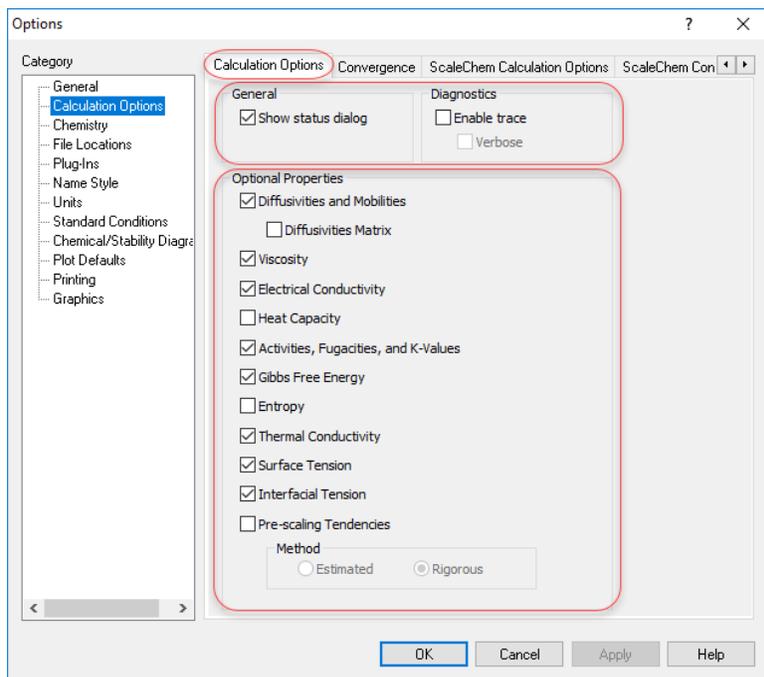
- Chapter 28 tour.oad.backup
- chapter 29_1.PNG
- chapter 30.oad
- chapter 30.oad.backup
- chapter7_4.PNG

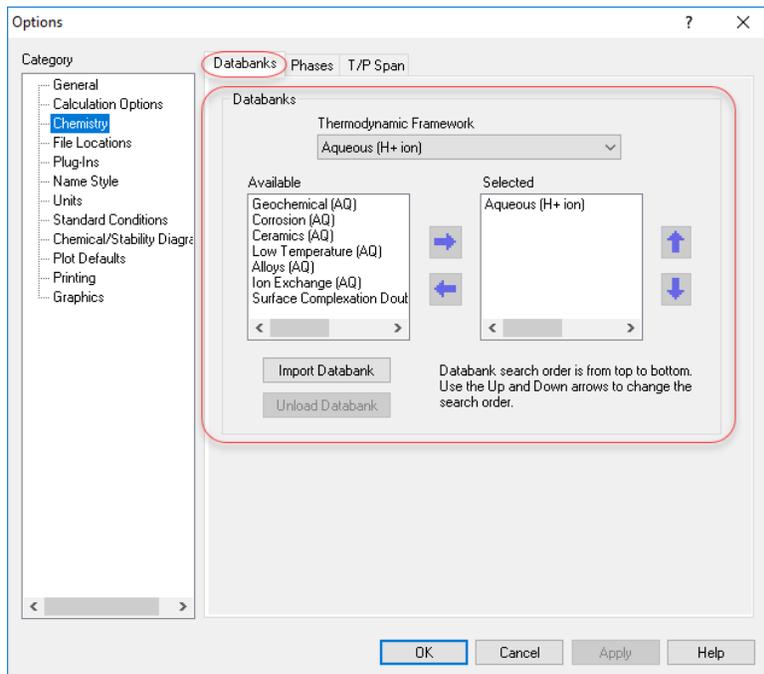
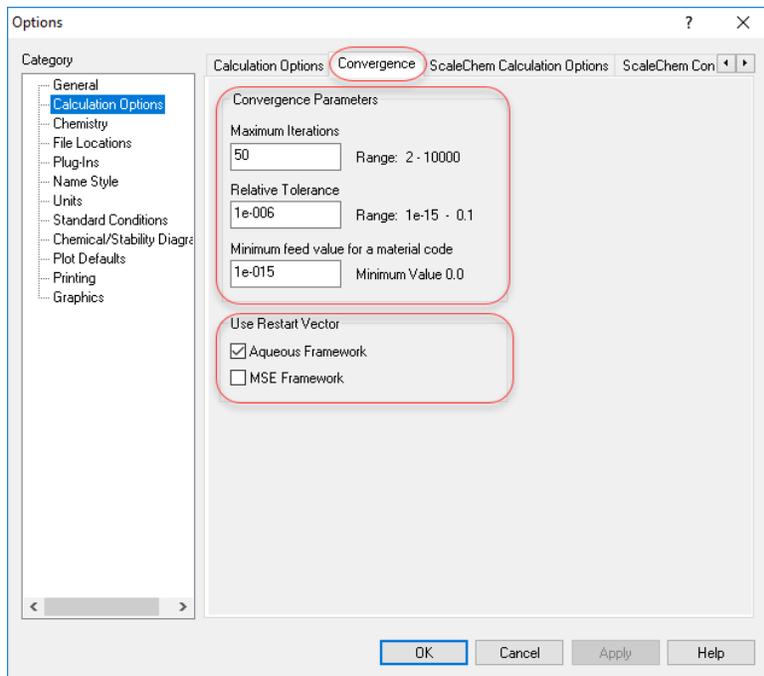
Changing the default file locations

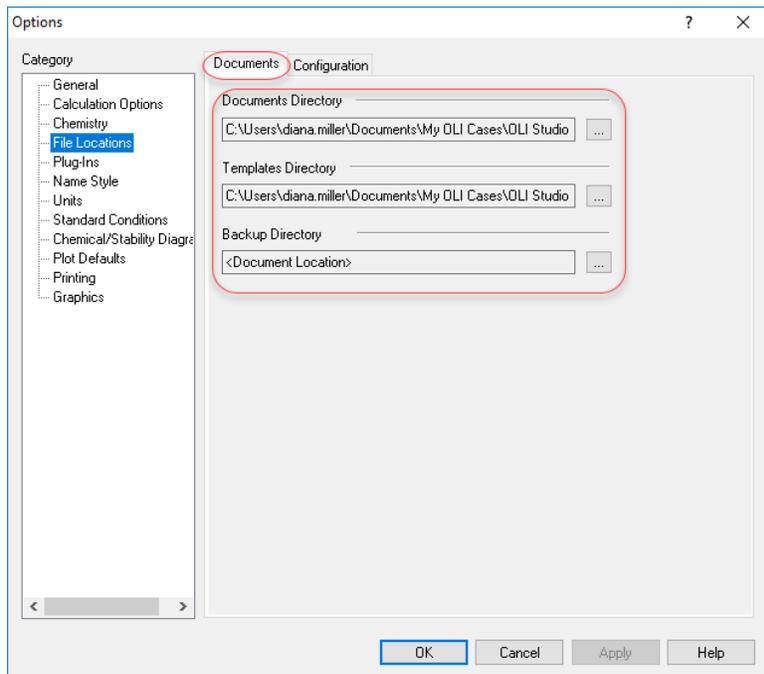
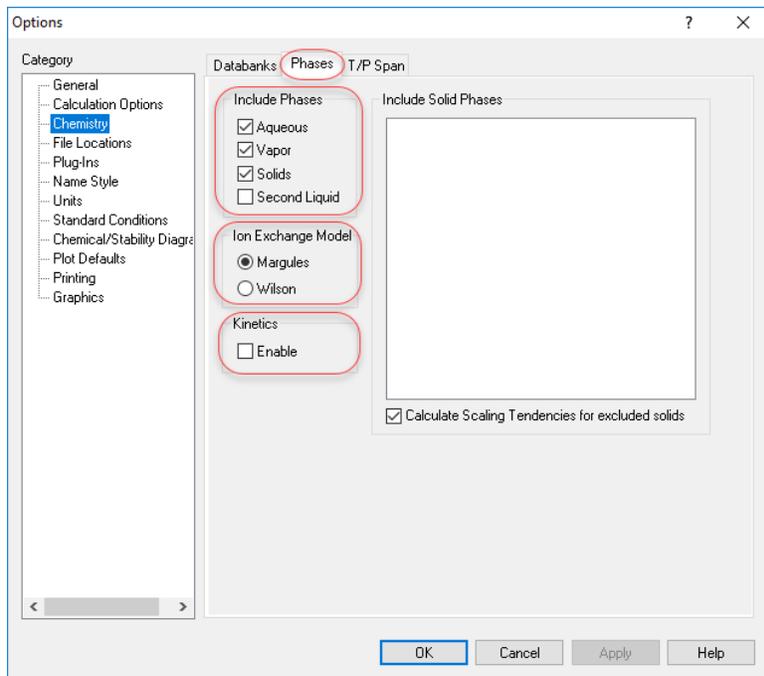
Sometime a user will need to change the default file locations for the OLI Analyzers. There are many reasons to do this but frequently it is because the user is on a multi-user system with multiple user logins. To change or verify the file locations the user needs to select the **Tools** menu item:

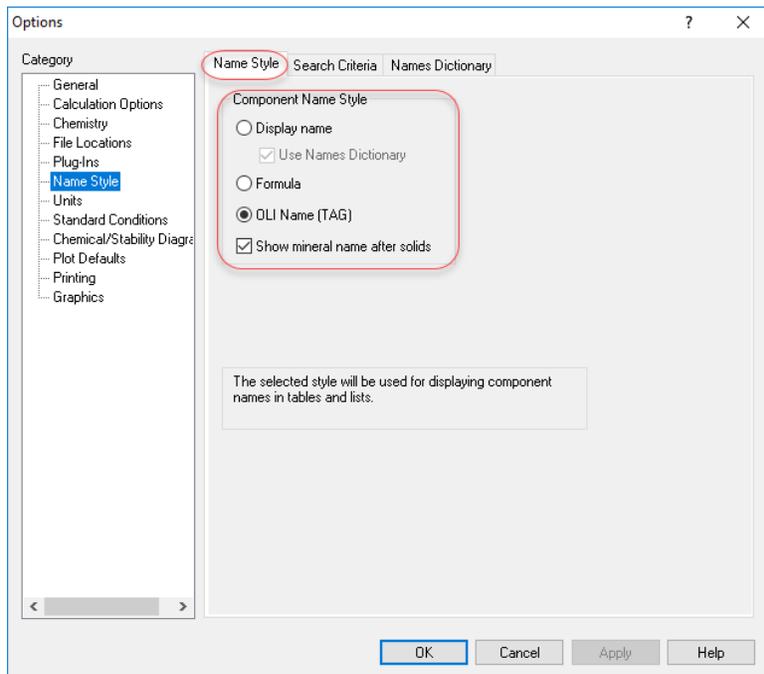
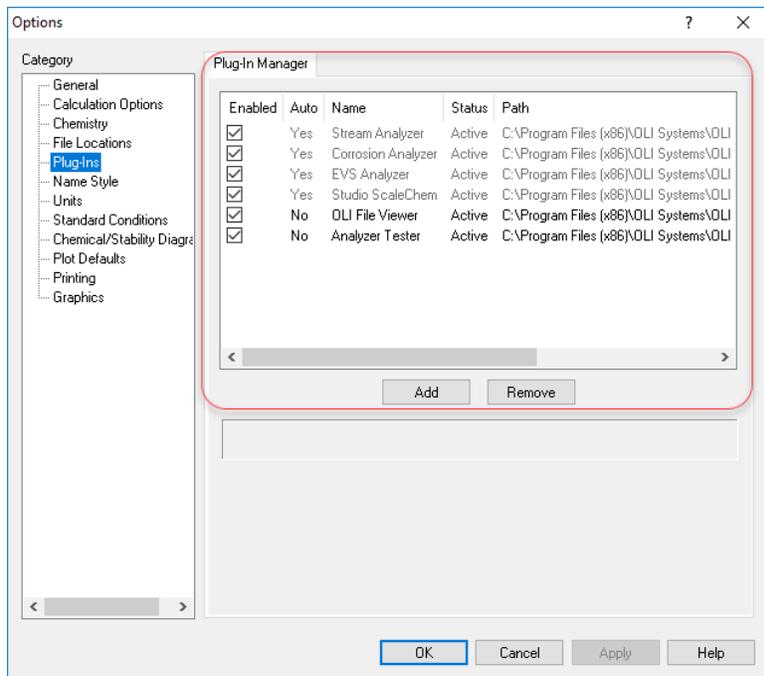
This will display the current file locations. You may want to verify these locations (some OLI programs will inadvertently modify these locations).

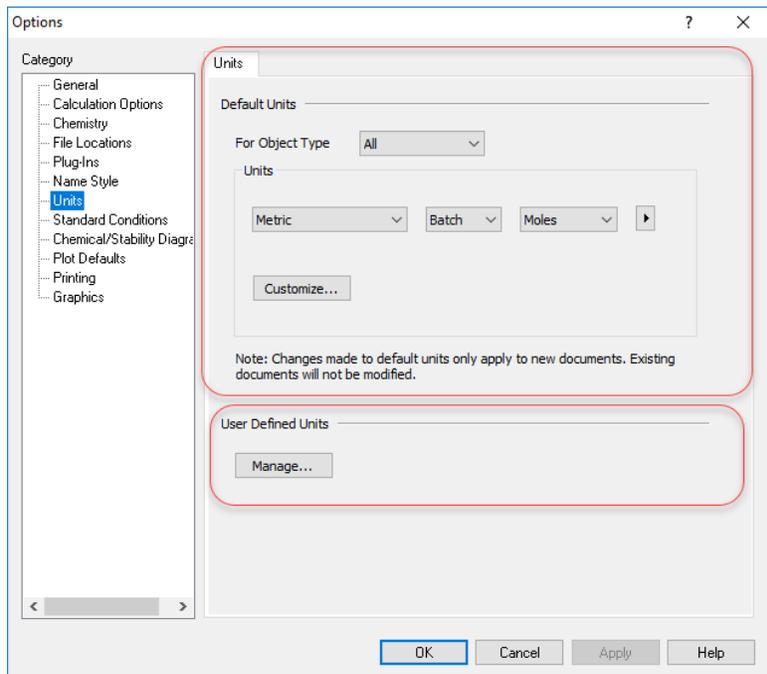
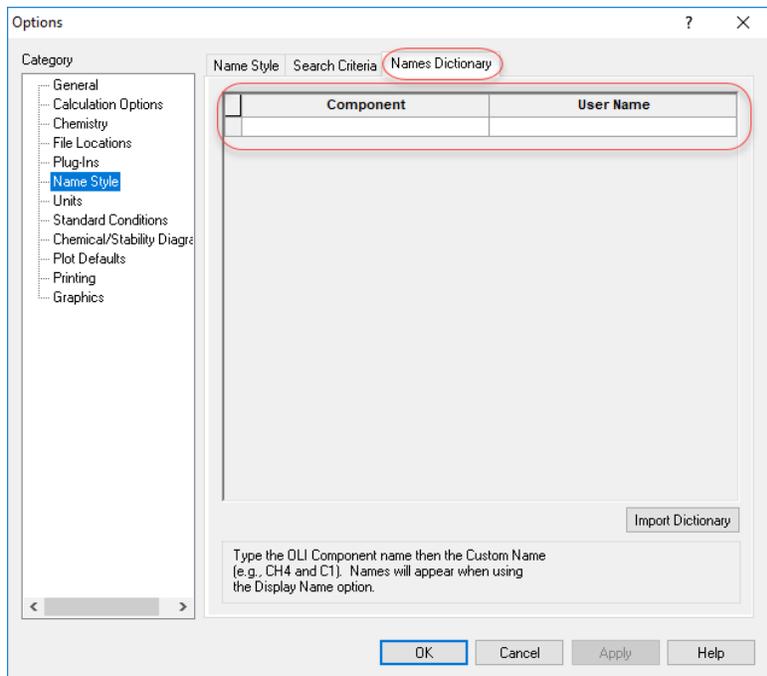
If you need to change the file location, click on the "..." to open the dialog.

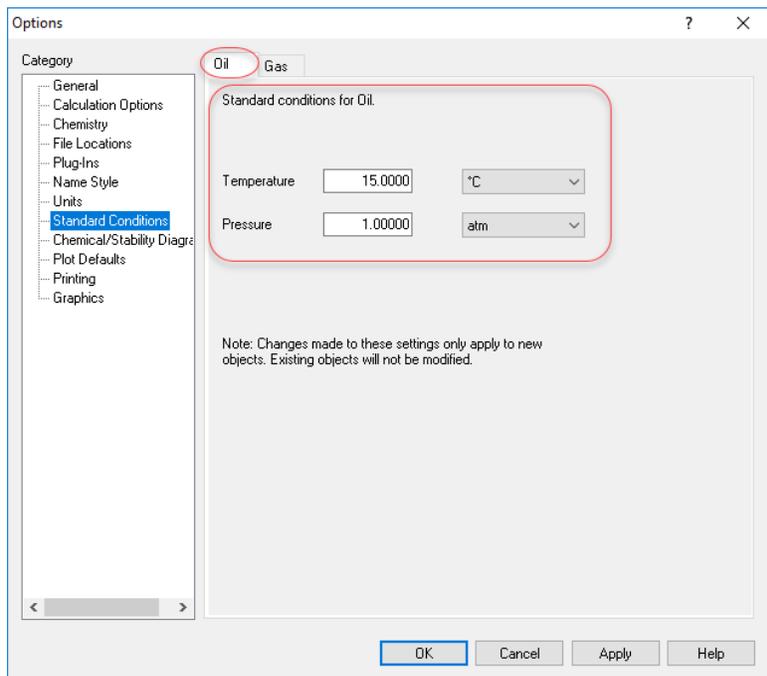
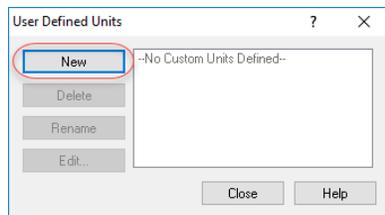


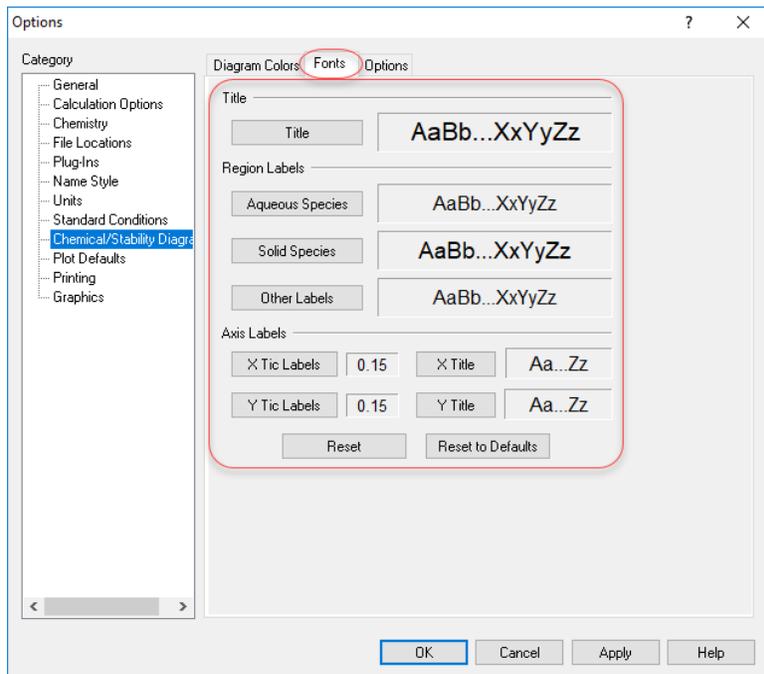
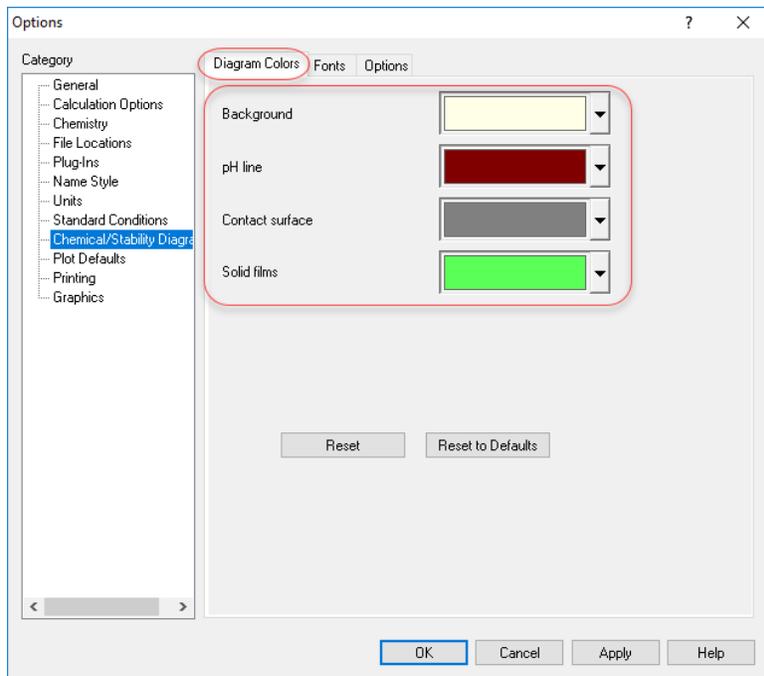


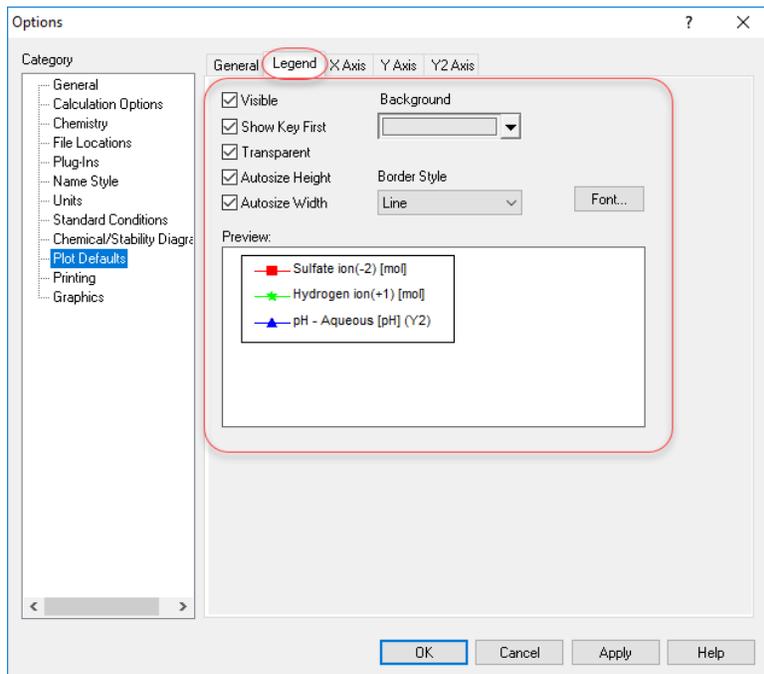
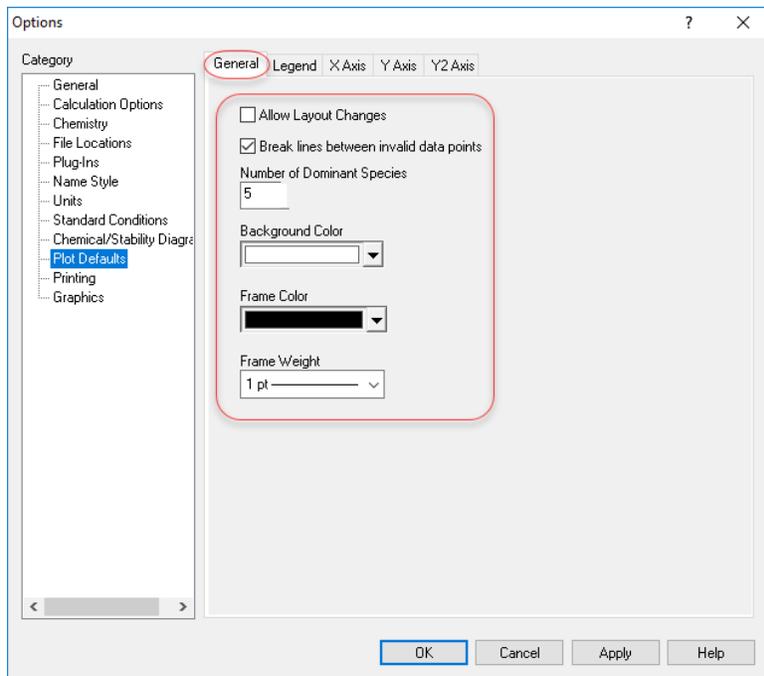


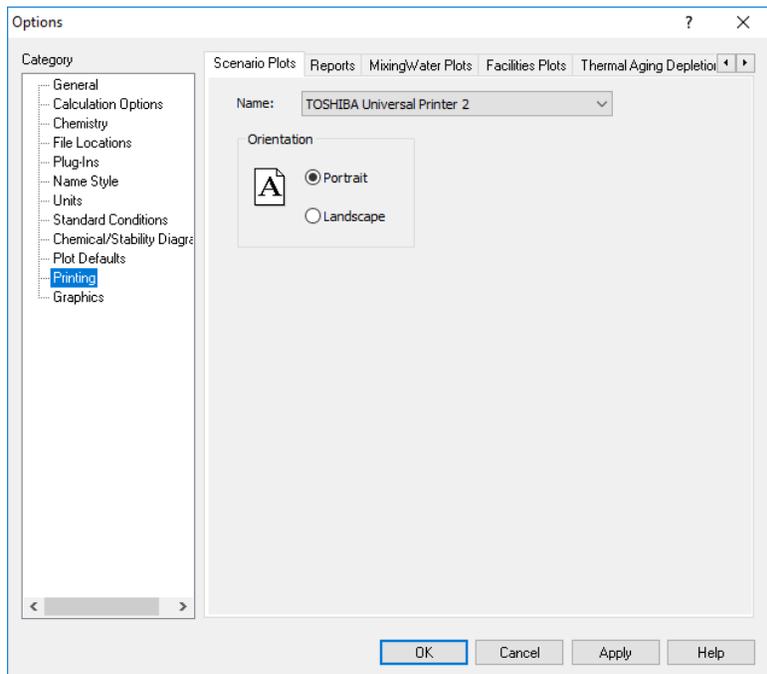
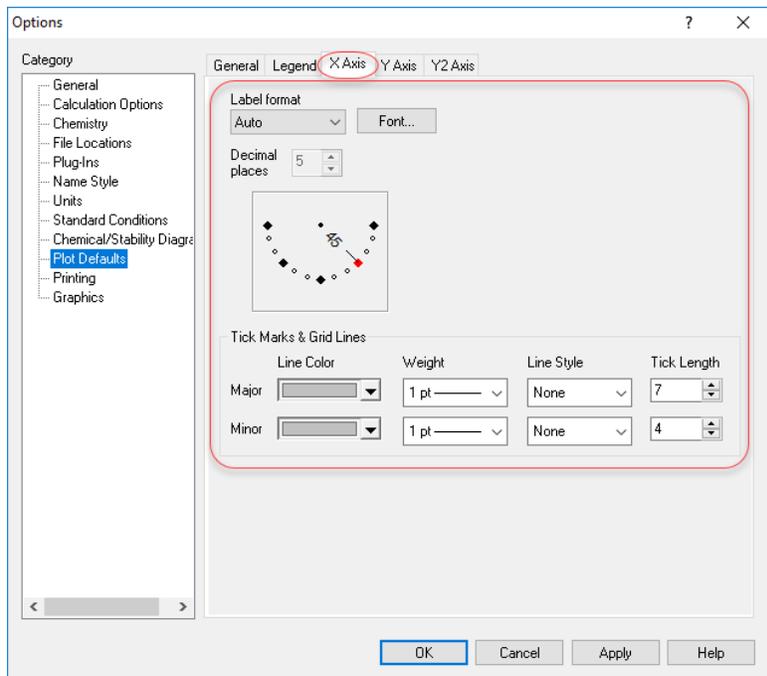


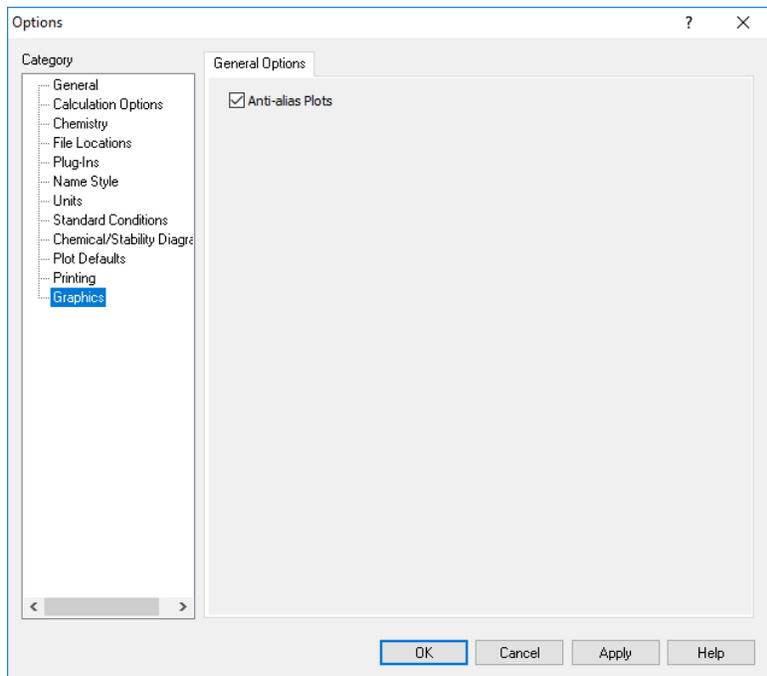












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