

# ProMax

## Foundations



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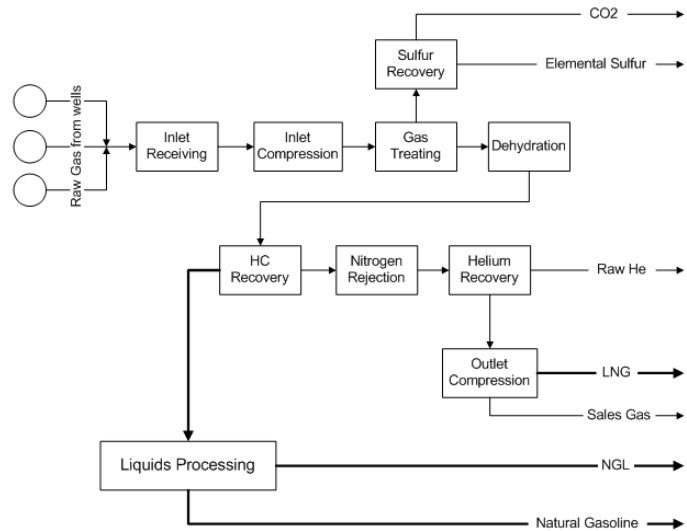
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# PROCESSES & PROCESS SIMULATION

NATURAL GAS PROCESSING  
CRUDE OIL REFINING  
PROCESS SIMULATION

## OVERVIEW OF NATURAL GAS PROCESSING

The general purpose of processing natural gas is to change the gas that leaves the well into a product that can be stored, transported, and sold. This process can be separated into 3 main areas: collection and pre-processing, gas treating, and gas processing. ProMax can be used to model most of the systems used in these three areas. The figure on the right shows a general gas processing flow diagram; however, the processing steps might vary depending on the raw gas composition and requirements. In addition, field processing, such as dehydration and sweetening, may be required before the gas can be sent to the processing facility.



## COLLECTION AND PRE-PROCESSING

Natural gas wells produce gas of various composition, temperature, and pressure. The gas leaving the well, however, may not be of sufficient quality or quantity to be economically treated on site. Thus, gathering pipelines that combine the output of several wells, as well as separation tanks to remove any associated liquids, are utilized to prepare the natural gas leaving the wells for transport to a gas processing plant. ProMax has a pipeline block that can be used to model the pressure drop, heat transfer, and flow rate of the fluids leaving the well and traveling through various sized pipes over different terrain. More information on how to use the pipeline block can be found in Exercise 9 “Pipeline Simulation” on page 49.

ProMax can also be used to model and size the separators used to remove the entrained and condensed liquid as the gas is transferred from the well to the processing plant. ProMax can model and size 2-phase and 3-phase separators in both horizontal and vertical positions. Exercise 17 “Separator Sizing” on page 57 demonstrates this ability.

## GAS TREATING

Once the natural gas has been gathered, it is treated to remove various contaminants. The contaminants of interest are usually compounds that are responsible for solids formation (e.g. hydrates, dry ice, water ice, etc.) or contribute to pipeline corrosion. The most common compounds removed at this point are acid gases, water, sulfur-containing compounds like mercaptans, and trace elements like mercury that can cause issues for equipment downstream.

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## ACID GAS REMOVAL

The removal of acid gases, specifically hydrogen sulfide (H<sub>2</sub>S) and carbon dioxide (CO<sub>2</sub>), can be achieved through several methods, including the use of: solid scavengers (e.g. iron sponges, etc.), chemical solvents (e.g. MEA, DGA, MDEA, caustic, potassium carbonate, etc.), physical solvents (e.g. MeOH, DEPG, NMP, etc.), and membranes. Some recently developed processes reduce the H<sub>2</sub>S in the natural gas directly to solid sulfur using liquid catalysts or biological pathways. The chosen method depends on the temperature, pressure and inlet gas composition.

ProMax can model the three common approaches. An example of a chemical solvent process can be found in Exercise 3 “Simple MDEA Sweetening Unit” on page 43, and an example of a physical solvent process can be found in Exercise 21 “Physical Solvent Acid Gas Removal” on page 61. Further examples of chemical and physical solvent processes can be found in the example projects located at Files->Open Example ProMax Project. The chemical solvent examples are contained in the Amine Sweetening directory and the physical solvent examples can be found in the Gas Processing directory. See the ProMax Help topic for information on modeling membranes.

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## CHEMICAL SOLVENTS

Chemical solvents usually consist of one or more amine compound mixed with water. The solvent is brought into intimate contact with the gas in an absorption column that typically has 20 trays, or equivalent packing. In the absorber, the acid gases react with the amine (a weak base) and are absorbed into the solvent. This process is rate-limited by the hydrolysis of the acid gases and subsequent neutralization. Primary amines (e.g. monoethanolamine (MEA), diglycolamine (DGA), etc.) have the fastest kinetics, secondary amines (e.g. diethanolamine (DEA), diisopropanolamine (DIPA), etc.) and tertiary amines (e.g. methyl-diethanolamine (MDEA)) have respectively slower kinetics. ProMax accounts for kinetic effects with a rigorous rate-based kinetic model.

While primary and secondary amines can absorb H<sub>2</sub>S and CO<sub>2</sub> quickly, they are typically used at lower concentrations and with a reclaimer to reduce the amount of amine loss and degradation. Tertiary amines can be used at higher concentrations and the reaction kinetics favor selective absorption of H<sub>2</sub>S over CO<sub>2</sub>. Typically, these tertiary amines have no reclaimer since their degradation and loss is much lower.

If the absorber is run at high pressure the rich amine is sent through a flash tank to reduce the amount of hydrocarbons present in the rich amine before it reaches the regenerator. A lean/rich heat exchanger is also commonly used to reduce reboiler duty.

The regenerator is a distillation tower that typically has 20 trays or equivalent packing. It is operated at the lowest pressure feasible for downstream processing of the acid gas (typically ~15 psig). The reboiler typically uses saturated steam at 50 psig and a flow rate equivalent to 1 lb steam/gal of circulating solvent. A condenser is also present to reduce the amount of amine loss and to reduce the amount of water sent down-stream.

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## PHYSICAL SOLVENTS

There are several solvents that are used in the industry that are not amine based. These solvents typically use DEPG, NMP, or chilled methanol which absorb the acid gases and some of the water, based on the partial pressures. There is no acid/base neutralization reaction that is necessary, so ProMax models these towers as equilibrium. Physical solvents work very well for high pressure systems and can provide some savings in utilities since it is possible to use pressure swings to regenerate the solvent. Examples for each kind of physical solvent can be found in the ProMax Example Projects in the Gas Processing directory.

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## GLYCOL DEHYDRATION

After the acid gases are removed from the stream, the water content is to be adjusted to meet specifications for transmission pipelines, storage, or further processing. There are two methods currently employed in most dehydration systems: injection or contacting tower. Ethylene glycol (EG) and methanol are typically used in the injection method, and triethylene glycol (TEG) is typically used with the contacting tower.

In the injection method, the glycol or alcohol is first mixed with the gas. The gas is then cooled to condense the water and any other condensable species before further processing, with the glycol or alcohol acting as a hydrate or ice suppressor and minimizing the potential of solids forming. Once the liquids have condensed, a two or three phase separator is used to remove the liquids from the gas stream.

The second method uses a tower with packing or trays to allow intimate contact between the vapor and glycol. These towers typically have 2-3 ideal stages. Lean (low water content) TEG is fed to the top of the tower and contacts the vapor stream coming up from the bottom. The TEG absorbs water and some of the heavier hydrocarbons from the gas stream. This rich (high water content) TEG can then be regenerated by boiling the water and hydrocarbons out at a regenerating column. The regenerating column will typically have 3-4 ideal stages.

To increase the amount of water removed, a stripping gas may be introduced in the reboiler or in a Stahl column. You can see an example of this type of unit with our ProMax Example File, "High Performance Dehydration Unit".

In general, the flow rate of TEG through the system is roughly three times the amount of water in the incoming gas. The reboiler temperature should not exceed the glycol degradation temperature (approximately 400°F for TEG systems). It is also common practice to maintain the temperature of the lean glycol entering the contactor at 10°F above the inlet gas temperature to reduce the amount of hydrocarbons absorbed in the glycol. Aromatic hydrocarbons are absorbed readily by glycols and may pose emissions problems. You can find an exercise on modeling a simple dehydration unit on page 46, Exercise 6 "Glycol Dehydration Unit".

Injection and glycol contacting work well to produce pipeline grade gas. However, processes that require products with ppm levels of water will use a molecular sieve. Mol-sieves are used in a semi-batch mode, with one (or more) being regenerated with hot, dry gas, and one (or more) in service adsorbing the water onto a solid substrate.

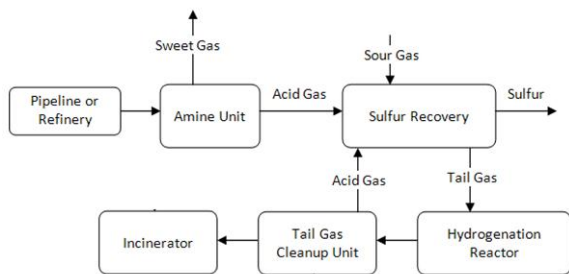
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## SULFUR RECOVERY

Most refineries and gas plants now process sour enough material to require sulfur recovery units. These units take the hydrogen sulfide captured from the process and convert it to liquid and solid sulfur for sale and transport. Claus units are the most common sulfur recovery process and entail burning the acid gases in a burner, then passing the gas over a specialized catalyst to convert the gaseous sulfur species into elemental sulfur. When the gas is then cooled in sulfur condensers, the sulfur is removed from the stream. A typical Claus unit repeats this process several times to continue removing sulfur, taking advantage of the equilibrium shift each time the sulfur is removed via the sulfur condenser.

There are several variations on the typical Claus plant, including sub-dewpoint Claus beds, direct oxidation reaction beds, and partial oxidation reaction beds (e.g. SuperClaus), any of which can be modeled in ProMax. ProMax models these reactors using Gibbs minimization, so an extensive knowledge of the reactions that occur in these units is not necessary. For a simple exercise modeling a Claus unit, please refer to page 47, "Three Bed Claus Unit".

In many cases, after the acid gases have been passed through the catalysts the tail gas still contains too much sulfur to incinerate. The most common method of alleviating this concern is to pass the tailgas through a hydrogenation reactor, with either hydrogen or a hydrogen producer added, thereby converting most remaining



sulfuric species into hydrogen sulfide. See Exercise 8 “Hydrogenation Reactor” on page 48 for an exercise on modeling a hydrogenation reactor. This H<sub>2</sub>S is then fed back to an amine system for the amine to remove the H<sub>2</sub>S. The off gas from this tail-gas clean up unit can then be incinerated. The H<sub>2</sub>S recovered in the tail-gas clean up unit is then recycled back through the sulfur recovery unit. This entire process can be modeled in ProMax by combining the various parts.

## GAS PROCESSING

Raw natural gas coming from the well will contain varying amounts of ethane, propane, n-butane, isobutane, and pentanes. These compounds comprise what is called natural gas liquids (NGLs). These NGLs need to be removed from the methane, which is sold as “natural gas.”

The NGLs are removed before the natural gas is introduced to the transmission pipelines. This helps to maintain the quality of the natural gas within regulations and minimize liquids formation in the pipeline. The NGLs, once removed, can be used as raw material, in enhanced oil recovery, and as a fuel source.

The NGLs are removed in a demethanizer column. The methane, at pipeline purity, is recovered at the top of the distillation column. All others are removed in the liquid stream. Demethanizers are operated at very low temperatures, -150°F (-100°C) at the top is common, and at moderate pressures. The temperatures and reboiler requirements for the demethanizer often result in the use of a “cold box” exchanger. This is often a compact exchanger with multiple streams exchanging energy (often 4-5 different streams). ProMax has the ability to both model and rate these exchangers.

This NGL stream is then further fractionated. First, the ethane is removed from the NGLs via a deethanizer. After this is a depropanizer to remove the propane and a debutanizer to remove n-butane and isobutane. Each column operates at a higher temperature than the previous, and the pressure is roughly held the same. If there is sufficient butane recovered, the butane stream may be split by a butane-splitter to remove the n-butane from the more valuable isobutane. What is removed and recovered in pure form depends on the composition of the raw natural gas and what can be economically recovered. Examples of each type of column can be found in the ProMax Examples in the Gas Processing directory. A relevant exercise is also available on page 64, titled “Fractionation Train”.

It is not always possible to store and transport natural gas in its gaseous form. Large volumes are required and it is difficult to transport large quantities to areas without a pipeline infrastructure. Liquefied natural gas (LNG) is transported at a temperature of -260°F and 3.6 psig. Thus, the methane stream recovered in the fractionation process discussed above can be liquefied if it is not introduced to a pipeline. LNG is produced using a cryogenic expansion process. Because of the low temperatures, it is necessary to have a high purity methane feed, or the impurities may freeze and block the cryogenic portion of the process.

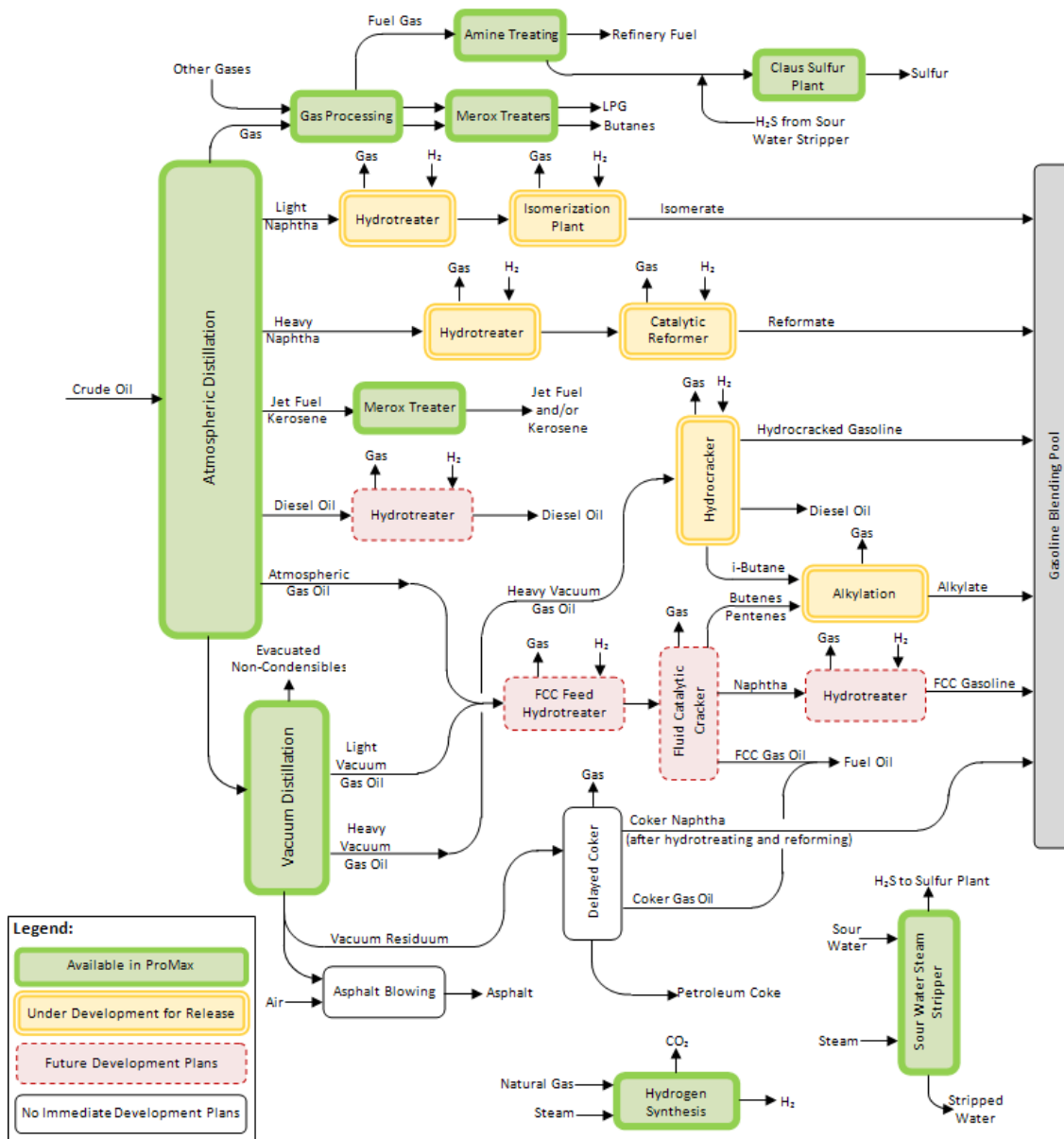


# OVERVIEW OF CRUDE OIL REFINING

## CRUDE OIL CHARACTERIZATION

Crude processing is complicated by the component mixtures found in crude oils. As opposed to gas processing where a generally well-defined composition of 10-20 components is being treated and processed, a crude oil tends to consist of hundreds or thousands of components.

Before you can model the process of the refinery, the oil must be defined. ProMax can utilize information from several assay types to create this curve oil model. Please see page 18, "Defining an Oil", for further information on how to define your crude oil in ProMax.



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## CRUDE DISTILLATION

The crude oil, or blend of crude oils, is separated into various fractions, then each cut further treated and refined. The atmospheric distillation column and any associated side-columns are used to separate light gases from naphtha, kerosene, diesels, atmospheric gas oil and the heavier atmospheric bottoms. This last cut is taken to a vacuum distillation column to obtain additional cuts to be cracked or put to a coker unit. An example of a crude distillation column can be found on page 50: "Crude Distillation with Side Strippers". Additional examples can be found under "Refining" from the Examples folder available in ProMax.

## CRUDE TREATING & UPGRADING UNITS

After separating the crude into several fractions, each fraction is further treated to increase the value of the cuts. Some of the common processes are:

### ALKYLATION

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This process is the reverse of cracking. Low molecular weight isoparaffins and olefins combine to form higher molecular weight isoparaffins in the presence of a strong acid catalyst. The acid protonates the olefins, which then attack the isoparaffins to form a high octane alkylate product.

### CATALYTIC REFORMING

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This is used to upgrade the octane rating of the heavy naphtha stream, having components approximately C7-C11. Lighter feed tends to crack into  $\leq C4$  species, which are not useful for gasoline blending, or into aromatics that are tightly regulated. During this process, hydrogen is produced, as well as some lighter species such as C1-C4, in addition to the primary products. If you would like some more information on how ProMax can help you model your catalytic reformer, please contact our support group.

### FLUID CATALYTIC CRACKER (FCC)

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The FCC is used to break higher molecular weight components into lighter components. Newer designs incorporate zeolite-based catalysts in short contact time at high temperatures (1250-1400F). The feed is vaporized by the hot catalyst, which then breaks down the oil into lighter components including gasoline and diesel. Cyclones separate the catalyst from the mixture, and the hydrocarbons are then fractionated into desired boiling ranges. Spent catalyst is regenerated in a fluidized-bed regenerator.

### HYDROCRACKER

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This unit is designed to break larger hydrocarbons down into smaller more uniform products. Hydrogen is added to this catalytic cracking process, which will produce saturated hydrocarbons. The reaction conditions determine the product range, from ethane and LPG to heavier hydrocarbons comprised mostly of isoparaffins. The major products are jet fuel and diesel, especially in Europe and India, and often high octane gasoline fractions in the United States. These products have low contaminants such as sulfur because of the hydrogen added, which acts similarly as in the hydrotreating unit.

## HYDROTREATING

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This is essentially the addition of hydrogen to the crude at elevated temperatures. A catalyst is used to promote the reactions, and may be specialized towards denitrification (HDN), desulfurization (HDS) or even aromatic saturation (HDA) reactions. These processes are used to remove contaminants such as nitrogen, sulfur, condensed ring aromatics, or metals from the oils.

## ISOMERIZATION

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This unit is designed to convert light naphtha straight chain hydrocarbons into higher octane branched hydrocarbons. It should also minimize the production of benzene.

## MEROX TREATING

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The name “Merox” stands for mercaptan oxidation. This catalytic process requires an alkaline environment, often using NaOH, and removes mercaptans from many types of crude distillation products by converting them into liquid hydrocarbon disulfides. This method is often more economical than using hydrotreating.

## REFINERY AUXILIARY UNITS

The Refinery utilizes several auxiliary units to meet required environmental concerns, and to provide it with necessary reactants for many processes. Some of the most common are:

### HYDROGEN PLANT

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For many refineries, the amount of hydrogen required is high. Therefore, many choose to have a hydrogen plant on-site instead of purchasing it. The most common source of hydrogen is through Steam Methane Reforming. Steam and methane are reacted to form hydrogen and carbon monoxide, and then a shift reaction is utilized to create more hydrogen and carbon dioxide from the carbon monoxide. Please review the ProMax help topic and example files for more information on modeling hydrogen plants in ProMax.

### SOUR WATER TREATING

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Water and steam is used in most refining processes, including the atmospheric crude column, vacuum crude tower, HDS units, steam crackers, and FCC units. These processes often contaminate the water with hydrogen sulfide, ammonia, phenol, and cyanide, which must then be removed. H<sub>2</sub>S and NH<sub>3</sub> tend to be highest in waters from the HDS and FCC units. A sour water stripper uses a reboiler and condenser to remove the contaminants from the water. An example of this can be seen on page 42 with our Exercise 2 “Simple Sour Water Stripper”.

### SULFUR RECOVERY UNITS

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This unit is used to remove the captured sulfur for environmental reasons. This process is explained more on page 7. Also available is “Three Bed Claus Unit” on page 47.

### SWEETENING UNITS

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These processes are used to sweeten products to remove acid gases. Please read page 6 for more information on sweetening. Also, Exercise 3 “Simple MDEA Sweetening Unit” on page 43, Exercise 19 “Mixed Amines” on page 61, Exercise 20 “Activated MDEA for Acid Gas Removal” on page 61, and Exercise 21 “Physical Solvent Acid Gas Removal” on page 61 all refer to sweetening processes.

# PROMAX OVERVIEW

OVERVIEW  
USER INTERFACE  
SOLVERS & SPECIFIERS  
ADDITIONAL TOOLS

## OVERVIEW

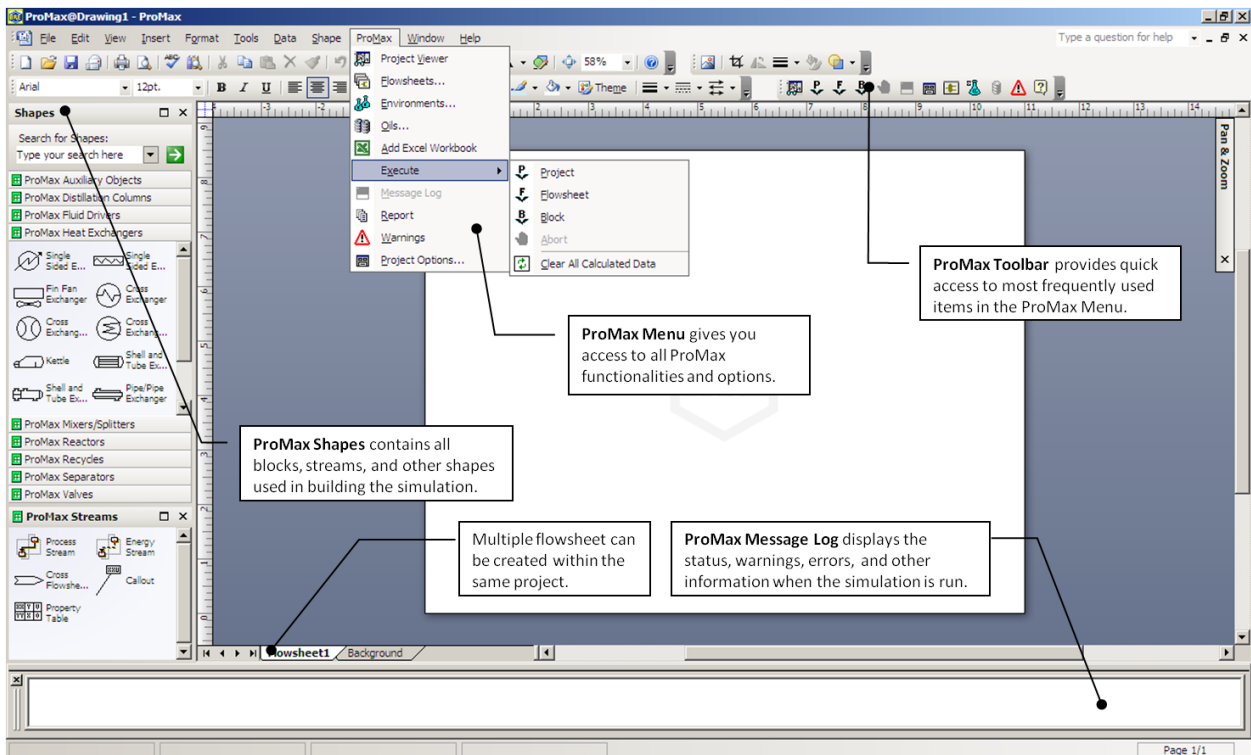
ProMax is a flexible, stream-based process simulation package used for the design and optimization of gas processing, refining, and chemical facilities. ProMax provides flexibility through its thermodynamic packages and components, which cover most of the systems encountered in the oil and gas industry. ProMax users have access to over 50 thermodynamic package combinations, over 2300 components, and crude oil characterization. For unit operations, the user has access to pipelines, fluid drivers (compressors and pumps), heat exchangers, vessels, distillation columns, reactors, membranes, and valves.

In addition, ProMax provides OLE automation tie-ins, specifiers, solvers, and Microsoft Excel® spreadsheet embedding, which give the user full access and control of all the information within any stream or block.

Being a stream-based simulation program allows ProMax to execute in both the upstream and downstream directions without complicated specifications, as is the case with block-based simulators. ProMax has the freedom for specifications to be made in any process or energy stream giving the user complete control.

## INTERFACE

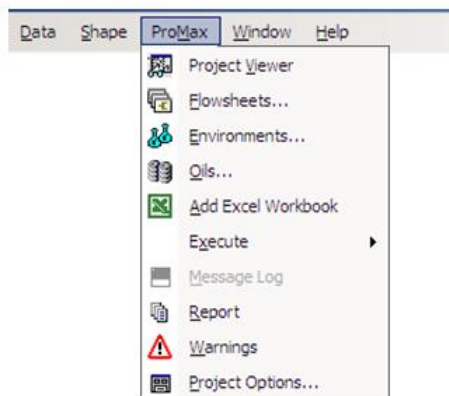
The ProMax interface is built around the Microsoft Visio® package. Therefore, it inherits many of the benefits of this package (e.g., shape sizing, transformation, placement, text annotations, etc.). Starting ProMax will automatically start Visio. The interface is basically the same as that of Visio with a few additions, as indicated in the following screenshot. This screenshot is from Visio 2007; each version is different, and Visio 2010 has added the “ribbon” bar, giving the version some new capabilities which ProMax can take advantage of.



## PROMAX MENU

The ProMax menu gives access to all the available functions and options in ProMax. The menu contains 10 items as follows:

1. **Project Viewer:** Opens the ProMax Project Viewer, which contains all project information. More details on the Project Viewer can be found on page 15.
2. **Flowsheets:** Displays and manages all available flowsheets within the current project.
3. **Enviroments:** Displays and manages all available thermodynamic enviroments defined in the project.
4. **Oils:** Displays and manages all defined oils in the project, including both single and curve oils.
5. **Excel Workbook:** Embeds an Excel workbook to the current project. Once a workbook is added, data can be exchanged between ProMax and Excel.
6. **Execute:** Provides options to “run” the model in the current project, abort any running calculations, and clear all the stored calculated data. Three options are provided for executing the simulation: “Project” executes all flowsheets, “Flowsheet” executes the current flowsheet, and “Block” executes selected blocks.
7. **Message Log:** Displays a log window showing the output of ProMax during execution.
8. **Report:** Opens the report window to publish the results for the project into a document or worksheet.
9. **Warnings:** Displays all warnings produced by ProMax.
10. **Project Options:** Displays options to customize units, property displays, tolerances, and other items.



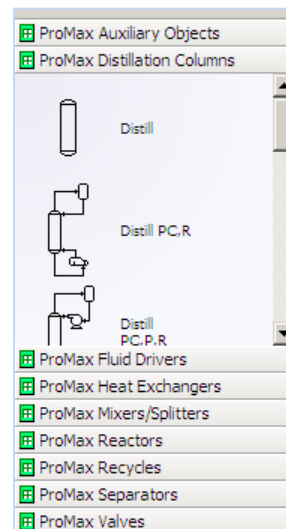
## PROMAX SHAPES

ProMax Shapes are a collection of blocks, streams, and other items used in building the flowsheet. Those shapes are categorized into 10 main groups. Shape functions in ProMax can be divided into the following:

1. Unit operations: heat exchanger, pump, column, etc...
2. Streams: process or energy
3. Simulation specific blocks: recycle, makeup, etc...
4. Data presentation blocks: callouts and tables

These blocks or shapes interact with ProMax through the Project Viewer. Only ProMax Shapes are loaded when ProMax starts. Standard and other Visio shapes can be loaded if needed, but will not interact with ProMax.

Shape groups can be opened and closed as needed. To close a group, just right click on the group title and choose Close. To open a group, go to File>Shapes> then choose the desired group to open.



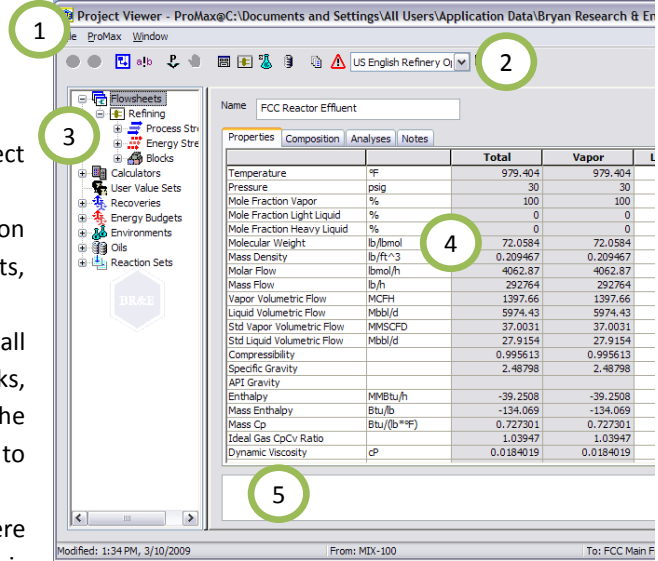
## PROJECT VIEWER

The Project Viewer is the primary graphical interface to input and retrieve information within ProMax. The Viewer provides access to the majority of Project information, and provides additional shortcuts to running ProMax.

### CONTENT

The Project Viewer contains five different elements:

1. Menu: contains options for the ProMax Project and others specific to the Project Viewer.
2. Toolbar: providing easy access to common ProMax operations (e.g., Execute, Environments, Report) and navigational buttons.
3. Navigation tree: includes a detailed list of all Flowsheets, Process and Energy Streams, Blocks, Calculators, and other objects contained in the Project and provides the user easy access to manage these.
4. Data display: The information displayed here depends on the selection. If a process stream is selected, the Viewer will have a "Properties" tab showing the stream properties, a "Composition" tab showing the composition of that stream, an "Analysis" tab, showing any analyses requested for that stream, and a "Notes" tab for user-added notes. An energy stream will have only a "Specifications" tab for the energy rate and a "Notes" tab. Similarly, a different set of information is displayed for the different blocks.
5. Message log: similar to the ProMax Message Log but displays messages related to the selected item only.



### COLOR CONVENTION

The data displayed in the Project Viewer cells are color-coded for easy identification as follows:

Project Viewer Cell "Convention"		Explanation
White Cell Background with No Text	<input type="text"/>	Available parameter, can be user-specified
White Cell Background with Blue Text	100	User-specified parameter
White Cell Background with Black Text	100	Calculated parameter, can be user-specified
Gray Cell Background	100	Calculated parameter, unavailable for specification
Blue Cell Background	100	Value from a solver, specifier, or import from Excel
Red Cell Background	100	Parameter not applicable, calculation failed
Yellow Cell Background	100	Parameter value extrapolated or approximated

## BUILDING YOUR SIMULATION

ProMax gives you freedom when building a simulation. You can start by defining the environment and adding components or by drawing the flowsheet. During this process, you can make changes on any item as required.

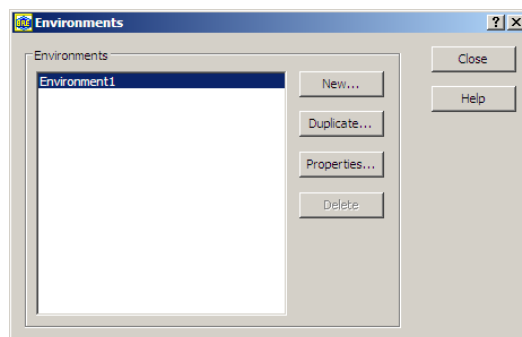
When a new project is created, ProMax will automatically create a blank flowsheet (Flowsheet 1) and assign an empty environment (Environment 1) to that flowsheet. As discussed below, you can add and delete flowsheets or change the assigned environment and its properties at any point.

### DEFINING ENVIRONMENTS

In ProMax, the term Environment is used to refer to the thermodynamic package, components, reaction sets, oils, and other parameters specific to the simulation. The Environment dialog provides access to all these properties and more. Flowsheets can share the same environment or each may have a unique environment.

To define an Environment, choose the Environments item from the ProMax menu. This will open a dialog window containing all available Environments. The dialog window allows you to create

a new Environment from scratch, duplicate an existing Environment, or edit a pre-defined Environment.



#### Tip

Use the ProMax toolbar to get quick access to the Environment used in the current Flowsheet.

The Environment dialog has several tabs. The most commonly used tabs are the “Property Package” and “Components” tabs. The Property Package tab provides a list of predefined thermodynamic models that can be selected directly. Alternatively, you can create your own combination by selecting the “Use Custom Package” option. In this case, you have the freedom to assign the desired thermodynamic model for each physical property.

Choosing the correct Property Package is critical in obtaining reliable results. Use the following table as a guideline; refer to ProMax help for more information (“Applicable Property Packages for Common Processes”).

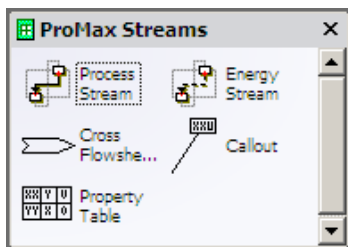
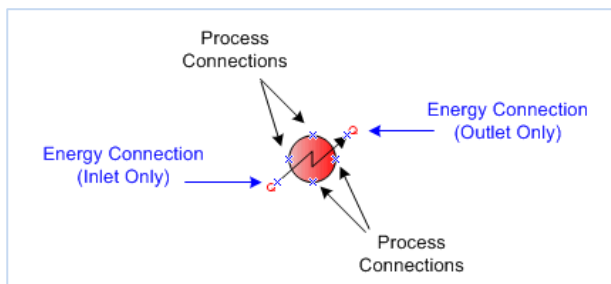
<b><u>SRK/Peng-Robinson</u></b> <ul style="list-style-type: none"><li>• HC Dew Pt Control w/ DEPG</li><li>• Physical Solvent Acid Gas Removal (E.g. DEPG, PC)</li><li>• Gas Processing</li><li>• Refrigerant Systems</li><li>• Acid Gas Injection Systems</li><li>• Fractionation</li><li>• Lean Oil Absorption</li><li>• Glycol Dehydration</li><li>• Crude Oil Distillation</li><li>• Air Separation</li></ul>	<b><u>Amine Sweetening/Electrolytic ELR</u></b> <ul style="list-style-type: none"><li>• Amine Sweetening</li><li>• Sour Water Stripping</li></ul> <b><u>SRK Polar/Peng-Robinson Polar</u></b> <ul style="list-style-type: none"><li>• Physical Solvent Acid Gas Removal (e.g. NMP, MeOH)</li><li>• Gas Processing with Methanol</li></ul> <b><u>Non-Electrolytic Gibbs Excess/Activity Coefficient Model (e.g. TK Wilson, UNIQUAC, etc.)</u></b> <ul style="list-style-type: none"><li>• Chemicals</li></ul>	<b><u>NBS Steam Tables</u></b> <ul style="list-style-type: none"><li>• Steam Systems: Turbines, Condensers, Superheaters</li></ul> <b><u>Heat Transfer Fluid</u></b> <ul style="list-style-type: none"><li>• Hot Oil System</li></ul> <b><u>Sulfur</u></b> <ul style="list-style-type: none"><li>• Sulfur Recovery</li></ul> <b><u>Caustic Treating</u></b> <ul style="list-style-type: none"><li>• Caustic Treating</li></ul> <b><u>Tillner-Roth and Friend NH3+H2O</u></b> <ul style="list-style-type: none"><li>• Ammonia Absorption Refrigeration</li></ul>
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Once a Property Package is set, components can be added to the Environment under the Components tab. You can either manually search for it in the components list, or use any of the filtering options provided. For example, to add methane to the components list, type in “methane” in the Name filtering box and hit the Enter key on your keyboard. You can also type ch4, c1, carbane, or r-50 – each being a different alias for methane.

## DRAWING THE FLOWSHEET

To draw the flowsheet, click and drag any shape from the Shapes Stencil and place it on the page. Repeat this process to add all the desired shapes. Shapes can then be connected with process or energy streams, at the Connections Points. Connections Points in the shape are indicated by a small x as shown in the figure. These can either be process connections or energy connections, which are not interchangeable. The number and type of connections for each shape can be viewed in the Project Viewer.

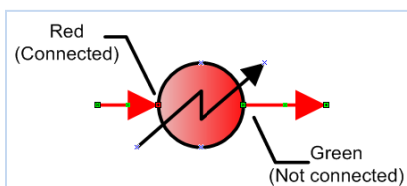


Process and energy streams can be added by either clicking and dragging them from the ProMax Streams Stencil, or using the Connector tool in the Standard

Visio toolbar (  ). Once a stream is present on the flowsheet, it can be manipulated using standard Visio connection techniques. After a block or stream is created, its parameters can be defined using the Project Viewer by double clicking on the item to be defined.

### Tips

Using the Visio Connector Tool provides a more convenient way if you want to draw several connections.



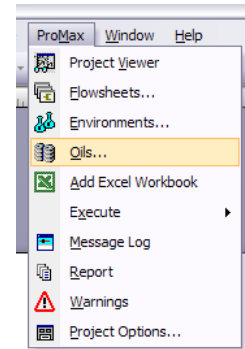
In Visio, a connection is made *only* when a red square appears at the end of the connection. Any end of the connection with a green square indicates a free (not connected) end. Visio 2010 has changed this convention and all streams have a blue and white end point, whether connected or not.

The Project Viewer provides a convenient way to navigate through the successive streams and blocks using its Upstream/Downstream navigational buttons located at the upper-right corner.



## DEFINING AN OIL

ProMax has two oil classifications: single oil and curve oil. These can be created from the ProMax menu, under the “Oils...” option. The description for creating the oils can be found below. A single oil is treated as a single component and can be used to model a single hypothetical component, such as a C<sub>6</sub>+ fraction. A curve oil is treated as a collection of several cuts” and is used to model a crude oil with a large boiling range, typically defined by a TBP curve or D86 curve. Unlike a single oil, a curve oil may be fractionated in a distillation column.



After creating an oil, it must still be added to any environment you would like to use it in from the environment dialog, under the components tab.

## SINGLE OIL

To define a single oil, you must provide one of the following combinations at a minimum:

- Volume Average Boiling Point
- Molecular Weight AND Specific Gravity
- Molecular Weight AND API Gravity

Every additional piece of information provided will improve the prediction accuracy as the correlations are updated.

The single oil, once added to the environment, is found in the component list as a single component, with the properties specified by you in the single oil definition.

Single Oil Correlations Notes

Name: Single Oil 1

Bulk Property Data

Volume Average Boiling Point		°F
Molecular Weight		lb/lbmol
Specific Gravity		
API Gravity		
Critical Temperature		°F
Critical Pressure		psig
Critical Volume		ft <sup>3</sup> /lbmol
Acentric Factor		
Carbon to Hydrogen Ratio		
Refractive Index		
Temperature of Low T Viscosity	100	°F
Low Temperature Viscosity		cP
Temperature of High T Viscosity	210	°F
High Temperature Viscosity		cP
Watson K		
ASTM D86 10-90% Slope	0	°F/%
ASTM D93 Flash Point		°F
Pour Point		°F
Paraffinic Fraction		%
Naphthenic Fraction		%
Aromatic Fraction		%
Ideal Gas Heat Capacity		Btu/(lbmol*°F)

Viscosity Type  
 Dynamic  
 Kinematic

## CURVE OIL

Assay Cut Points Light Ends Correlations Plots Notes

General

Oil Name: HCGO

Assay Fraction Basis: Std. Liquid Volumetric Fraction

Bulk Properties

Bulk Specific Gravity: 0.9569

API Gravity: 16.3734

Bulk Molecular Weight: 267.202 lb/lbmol

Viscosity Type:  Dynamic  Kinematic

Curve Data

Assay Type: ASTM D86

Test Pressure: 14.6959 psia

Volume Fraction Distilled	Temperature
%	°F
0	365
10	648
20	670
30	690
40	705
50	724
60	743
70	769
80	804
90	850
100	910

Edit...

To define a curve oil, you must provide a boiling point curve to ProMax. This curve can be on several bases, but the most common are D86 and TBP curves. If it is available, the TBP curve is preferable because ProMax will first convert other curves into an estimated TBP curve within the program.

You may also provide independent curve data for Specific Gravity, Molecular Weight, and High and Low Temperature Viscosity to better define your oil, if available.






Once the curve data is entered, you may select



## DEFINING STREAMS/BLOCKS

To run any part of the simulation, you must provide all information needed by ProMax to perform the required calculations. The information is entered as parameters for process streams, energy streams, or blocks. Keep in mind that the properties of the streams and blocks are interrelated, which gives the option to either specify the property of a stream directly, or to specify how the block affects the process stream. For example, the temperature at the outlet of a heat exchanger may be placed in the outlet stream, or calculated from a change in temperature from the inlet stream.

ProMax helps you keep track of this process using color coding for streams and blocks. The following table summarizes the color conventions used within the flowsheet:

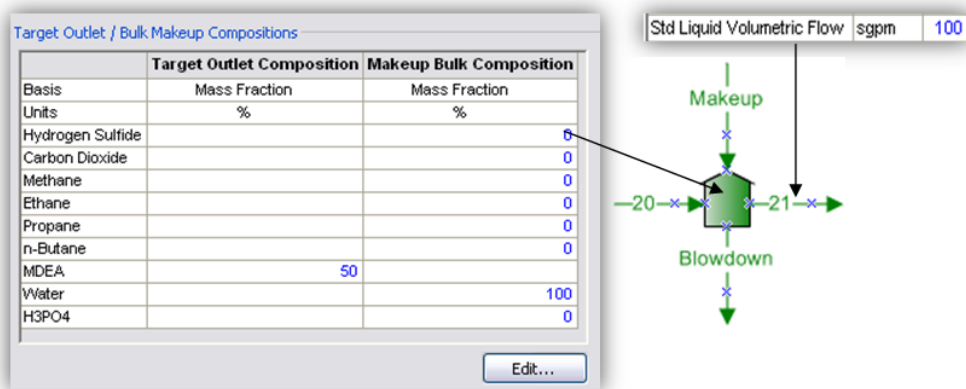
Color	Block Status	Stream Status	Comments
RED	 Unconnected	Not ready	Stream: specification(s) missing Block: stream connection(s) missing
BLUE	 Unsolved	N/A	Block has all required connections
BROWN	 N/A	Unsolved	Stream is defined and ready for execution
ORANGE	 Approximate Solution	Approximate Solution	With few exceptions, approximate solution indicates a calculation outside the correlation range
GREEN	 Solved	Solved	

ProMax also allows for specifications to be made both upstream and downstream of most blocks, as all stream properties are propagated as far as possible in both directions. Hence, the user has the flexibility to specify properties in the most convenient fashion while maintaining the user's approach. Refer to the guide below for specification recommendations.

## AUXILIARY OBJECTS

- **Divider** – this block can be used to split any percentage of any specific components from the main process stream. This is often useful in cases where you do not wish to set up a full simulation, such as a dehydration unit that does not need a rigorous simulation. There must be one inlet and at least one outlet, although typically two are used. An energy stream must also be connected to keep the simulation in both heat and material balance. The desired split must be set in the block as a percent of each component being split to a specified outlet stream.
- **Pipeline** – the pipeline block can rigorously solve for many properties of single- or multi-phase flow in a pipe of any alignment. Ambient losses can be calculated based on pipe and ground material if an energy stream is connected to the pipeline block. Multiple pipe and fitting segments can be modeled in a single pipeline block.
- **Saturator** – This block can saturate to any level and with any component. The block will add the material at a necessary temperature and pressure such that the outlet temperature and pressure are equal to the dry basis stream. The heat of mixing is incorporated into the saturant temperature. Multi-phase streams should be separated before feeding to the saturator block. Please see the Help for additional information.

- **Make-up/Blow-down** – If there are losses in the process, material must be made up to keep a steady circulation rate. Over time, an analysis and tank level indicator will give the necessary information for the plant operators to know what and how much to add to restore the desired concentration. ProMax is a steady-state simulator and must do the same calculation on an ongoing basis. The make-up/blow-down block allows you to set a desired outlet concentration (what weight percent the amine should be leaving the make-up/blow down block), and the flow rate (set in the outlet stream).



## DISTILLATION COLUMNS

There are predefined distillation columns available from the stencil set; however, these are *not* the only options available. You can configure a column with draws and pump-around loops, or more complex reflux/reboil circuits.

Most applications will use an “Equilibrium” Column Type. The exceptions to this are for amine sweetening: amine absorbers will use the “TSWEET Kinetics” model, and amine regenerators will use the “TSWEET Alternate Stripper” model. The kinetics model requires that the user provide tray and column information so that the residence time on a tray can be calculated to fully model the reaction kinetics. Typical initial design input values are 70% flooding, a Real/Ideal Stage Ratio of 3, a system factor of 0.8, tray spacing of 2 ft and weir height of 3 in. These values are input in the Hardware grouping on the Stage Data tab of the absorber column. Please see our Help for additional information on tower hardware specifications.

All columns must have a pressure profile set (i.e., pressure drop, or top and bottom pressure, etc...). In addition, each condenser, reboiler, draw or pump-around adds a degree of freedom. Each degree of freedom requires a specification, chosen from the following options.

### Tips

Setting a tolerance for specifications is discouraged since the program will choose a tolerance to optimize convergence speed; changing this tolerance can decrease column stability.

- **Boiling Curve Gap** – the difference between boiling curve temperatures at specified fractions for selected stage(s) and phase(s). For example, you can specify that the bottoms liquid from a crude distillation tower should have a 200°F gap between the 10% and 90% boiling curve temperatures for an ASTM D86 test.
- **Boil-up Ratio** – the flow of vapor returned to the column from the reboiler divided by the flow of liquid and vapor product in the bottoms leaving the reboiler.

- **Component Flow/Composition** – the flow rate or fraction of one or more of the available components in one of the streams exiting the distillation column.
- **Component Ratio** – the ratio determined by specifying a numerator, the flow of one or more components; and a denominator, the flow of one or more other components.
- **Component Recovery** – the ratio of the flow rate or fraction of one or more of the available components in one of the streams exiting the column to the flow rate of the same selection in the total feed to the column.

If a *flow* unit is chosen, this is designating the fraction of the selected components from all feeds that will be sent to the specified stream.

If a *fractional* unit is chosen, the value is a dimensionless ratio of the *fraction* of the components in the specified stream to the *fraction* of the components from all feeds. For example, if the feed to a deethanizer contains 7.28 mol% ethane and the bottoms contains 14.45% ethane, then the ethane fraction recovery in the bottoms is  $14.45/7.28 = 1.985$ .

- **Cut Point** – the boiling temperature of the oil at a certain percentage distilled for the specified stage and phase. All distillation curves are calculated on a dry basis.
- **Draw Rate** – the amount of flow in one of the draw streams from the column.
- **Draw Recovery** – the ratio of the flow rate of one of the streams exiting the distillation column to the flow rate of the total feed to the column.
- **Duty** – the duty associated with an unspecified energy stream attached to the distillation column. The value should be positive for heat injected into the column (and the energy stream arrow points *towards* the column) and negative for heat removed from the column (and the energy stream arrow points *away* from the column).
- **Flow Ratio** – the ratio given with the numerator as the flow in a draw stream or on a stage and the denominator as the flow in another draw stream or on another stage.
- **Fraction Vapor** – the percentage of vapor in the total distillate or bottoms product. This specification is intended to be used for a column with a partial condenser including a liquid draw from the reflux, or a reboiler with a vapor draw from the vapor return stream. The column automatically calculates the liquid draw rate for the condenser or vapor draw rate for the reboiler to meet the specified value. Note that this specification does NOT decrease the degrees of freedom for the column; instead it sets the percent split in the splitter involved.
- **Fuel Property** – fuel properties are calculated on a dry basis, and are available for any phase on any stage in the column. Available fuel properties are:

Cetane Index	Research Octane Number
ASTM D93 Flash Point	ASTM D97 Pour Point
ASTM D611 Aniline Point	Refractive Index
Absolute Viscosity at 100F	Kinematic Viscosity at 40C
Absolute Viscosity at 210F	C:H Weight Ratio
Specific Gravity 60F/60F	ASTM D86 10% Cut Point
API Gravity 60F/60F	ASTM D86 50% Cut Point
Paraffinic Mole Percent	ASTM D86 90% Cut Point
Naphthenic Mole Percent	ASTM D1322 Smoke Point
Aromatic Mole Percent	ASTM D2500 Cloud Point

- **Phase Property** – a number of phase properties are available for any stage in the distillation column. Select the desired property from the drop-down list which includes all properties available for a stream (e.g. Temperature or Flow Rate) and Reid Vapor Pressure and True Vapor Pressure.
- **Reflux Ratio** – the reflux ratio, or flow of liquid from the condenser returned to the column divided by the flow of vapor and liquid product overhead from the column.

The following items are available through the specifications tab of the column, but will not fulfill a degree of freedom. These items are used as either an initial estimate for iteration purposes, or to report back information about the column.

- **Lean Approach** – the equilibrium composition of the selected component for the specified stage and phase divided by the calculated composition of the selected component for the same stage and phase. This specification is useful for determining "Lean End Pinch" for amine sweetening absorbers, and also for determining the approach to equilibrium water content in glycol dehydration contactors.
- **Pump-around Estimate** – an estimate may be requested for some pump-arounds. Options are:

*Fraction Feed Entering Column* – If the pump-around path contains a mixer followed by a splitter, the fraction of added material that reaches the column should be given as the estimate. For example, 10 mol/hr of material is added to a 90 mol/hr pump-around via a mixer, and 5 total mol/hr of material is subsequently removed from the pump-around via a splitter. The "Fraction Feed Entering Column" would be 95% since 9.5 mol/hr of the 10 mol/hr feed reach the column. (0.5 mol/hr or 10% of the 5 mol/hr removed via the splitter is attributable to the feed). If the splitter has a % split specified instead of an outlet flow rate, this estimate is not required.

*Fraction Draw Returned* – If any stream between the draw and the return contains a splitter, the fraction not drawn off should be given as an estimate. For example, if the pump-around draw is 100 mol/hr and 15 mol/hr is removed from the pump-around via a splitter, then the "Fraction Draw Returned" is 85%.

*Pump-around Duty* – If duty is added to a pump-around by a heat exchanger or pump, an estimate should be given for the total pump-around duty amount (positive if energy is added to the system). This estimate is not required if *duty* or *power* is set in all heat exchangers and pumps found in the pump-around.

- **Rich Approach** – the calculated concentration of a selected component in the liquid exiting a specified stage divided by the equilibrium concentration based on the specified lean feed. Select either: "Maximum Loading", which reports the rich approach as a percentage of the highest loading attainable (equilibrium), or "Excess Solvent", which reports the rich approach as the percentage solvent flow in excess of the flow required for max load. This specification is most useful for determining "Rich End Pinch" for amine sweetening contactors.
- **Side Column Estimate** – for side columns, estimates may be required in some cases. Estimate options are:

*Fraction Feed Entering Column* - If either path between the main and side columns contains a mixer followed by a splitter, the fraction of added material that reaches the column should be given as the estimate. For example, if 10 moles of material are added to the path from the main column to the side column via a mixer, and 4 moles of material are subsequently removed from the same path to the side column via a splitter, the "Fraction Feed Entering Column" would be 60%.

*Fraction Draw Entering Column* - If any stream between the main and side column contains a splitter, the fraction that is not drawn off should be given as the estimate. For example, if the draw from the main column to the side column is 100 moles and 15 moles are removed from the path to the side column via a splitter, then the "Fraction Draw Entering Column" is 85%.

*Side Column Duty* – If duty is added to the path from the main column to the side column, or from the side column to the main column via a heat exchanger, the amount should be given as an estimate (positive if energy is added to the system).

## FLUID DRIVERS

All fluid drivers (blowers, compressors, expanders, and pumps) should have either an efficiency or performance curve designated. An outlet pressure or change in pressure should also be defined. We recommend setting the pressure in the outlet stream, as doing so will maintain the set pressure even if the upstream pressure is changed. While ProMax will allow different specifications for the outlet stream, we generally discourage this practice as impossible efficiencies in the pump may likely be calculated causing the execution to stop.

## HEAT EXCHANGERS

We recommend specifying a pressure drop for every side of the exchanger. While an outlet pressure *can* be set, this has a consequence of dictating process stream pressures downstream of the exchanger, even if upstream conditions change.

Any other degrees of freedom should be specified based on outlet stream temperatures, exchanger duty, UA, or approach temperatures. All but one side may be specified, as the last side will be calculated by ProMax based on heat balance.

In exchangers with a non-linear heat transfer curve, as often demonstrated in exchangers with phase changes, the heat release curve increments should be increased from the default value of five.

## MIXERS/SPLITTERS

Mixers and splitters have a default pressure drop of zero, but this may be changed if necessary. In splitters, you may designate the percent splits in the block or the flow rates in the outlet streams. Mixers may have an unlimited number of streams mix together into one outlet stream, and splitters may have as many outlet streams as needed from a single inlet. Mixer/Splitter blocks may have as many inlets and outlets as desired. The outlet pressure of a mixer is equal to its lowest inlet stream pressure minus any pressure drop designated in the mixer.

## REACTORS

There are several options for reactors in ProMax, including Conversion, Equilibrium, Gibbs Minimization, Plug Flow, and Stirred Tank. The reactors we will discuss in this training are generally designed for sulfur recovery units, so we will focus on the Gibbs Minimization option. The others require reaction sets to be defined and used; for more information on these reactors and reaction sets, please see our Help topics, call our Support team, or attend one of our Advanced Simulations courses.

Within the Gibbs Minimization choice there are “Gibbs Sets” options, explained below. Each step of the sulfur recovery process has a corresponding option, with many constraints and reactive species predefined.

- **General** – this option can be used for any general reactor type for which you wish to use the Gibbs Minimization option. This does not include any constraints and all species are reactive.
- **Acid Gas Burner** – this set includes constraints on COS and CS<sub>2</sub> production during the burning of acid gases, and should be used when modeling a burner that has either H<sub>2</sub>S or CO<sub>2</sub> in the feed.
- **Claus Bed** – for all typical Claus beds, this choice is best. All species involved in the Claus reaction are reactive. Note: COS and CS<sub>2</sub> are *not* reactive at typical conditions for the Claus reactors.



- **Equilibrium Hydrolyzing Claus Bed** – as opposed to the “Claus Bed” option, the “Hydrolyzing Claus Bed” allows the COS and CS<sub>2</sub> to react, as this bed is designed to be operated at higher temperatures and with a specialized catalyst to destroy these species.
- **GPSA Hydrolyzing Claus Bed** – this option adds constraints to the destruction of COS and CS<sub>2</sub> to follow with the correlations from Section 22 of the GPSA Data Book.
- **Sub-Dewpoint Claus Bed** – this choice best models those Claus beds that are operated where sulfur condenses directly on the catalyst and the bed undergoes a regeneration cycle.
- **Sulfur Condenser** – the Sulfur Condenser allows further reactions for sulfur redistribution at the cooling temperatures, but no other reactions.
- **Sulfur Direct Oxidation** – this selection is for sulfur recovery units that utilize direct oxidation methods typically used where the H<sub>2</sub>S concentration is too low for combustion, even with a split flow configuration.
- **Sulfur Hydrogenation** – the hydrogenation option models the reactions of the tail gas with an oxidizing stream to recreate H<sub>2</sub>S as the stream is passed on to an amine tail-gas treating unit.
- **Sulfur Partial Oxidation** – the "Sulfur Partial Oxidation" or SUPERCLAUS® type Reactor uses a special catalyst for "selective oxidation" that converts almost all of the H<sub>2</sub>S directly to sulfur and is usually the final bed in a Claus unit. In ProMax, Sulfur Direct Oxidation mainly converts H<sub>2</sub>S to SO<sub>2</sub>, whereas Sulfur Partial Oxidation converts the H<sub>2</sub>S to elemental sulfur.
- **Sulfur Redistribution** – this option is used to represent the second pass of the waste-heat boiler in a typical Claus burner-WHB setup. The only reactions allowed in this Gibbs set are for the redistribution of the sulfur species; no other species are allowed to react. This can also be used to model reheaters more accurately.
- **Sulfur Thermal Reaction Zone** – this is used to model the first pass of the waste-heat boiler. Constraints are added to a few components that cease reacting once the temperature has cooled below a set temperature.

## RECYCLES

- **Process Recycle** – this block is used when any material is recycled from somewhere downstream back into the process upstream. Analyzing the flowsheet to reduce the number of recycles necessary by combining as many as possible is typically encouraged, as this will reduce the execution time.  
The stream exiting the recycle block must be fully user-defined, including temperature, pressure, composition, and flow rate. This is a guess and provides ProMax a place to begin its execution. Your guess is overwritten each time the recycle begins a new iteration. This block is considered “solved” when the stream entering into the recycle block is the same, within tolerances, as the stream exiting.  
In some cases, the recycle guess stream can be disconnected from its downstream connection point and have a good guess provided by solving through the simulation once.  
Priorities must be set for recycle blocks. All default to a priority of 1, but should be adjusted to match your analysis of the necessary solve order. Higher priority numbers solve first and can be any integer number.
- **Q-Recycle** – this block is used when energy is taken from somewhere downstream and applied to an upstream location. Often this occurs with a glycol reflux coil, as the amount of cooling that occurs in the coil is generally dependent upon the specification of the distillation column, and the outlet temperature of the rich glycol is not directly controlled, even though it is upstream of the column. This case is demonstrated in Exercise 6 “Glycol Dehydration Unit”.  
The initial guess for a Q-Recycle is provided in the block itself, unlike with the Process Recycle. This guess is provided as the “Calculated Value” on the Process Data tab. Priority, zero by default, should be adjusted to match your analysis of the necessary solve order. Higher priority numbers solve first. Bounds and step size are optional, and typically not recommended.

- **Propagation Terminal** – the propagation terminal is a specialized recycle block designed to be used in closed-loop systems where no material enters or leaves the loop, such as is found in refrigeration loops, hot oil loops and similar systems.

The terminal allows chosen properties to propagate through the block, unlike a recycle block that will break all propagation. Two properties should be selected, typically pressure and temperature, but this depends on how the loop is specified. Please contact our support team, read our Help topics and review our example files for more information on how to use a propagation terminal.

## SEPARATORS

- **Two Phase Separator** – this block allows the separation of liquid and vapor phases of a process stream. There may be multiple streams as inlets attached to the separator, but only two outlets: one vapor and one liquid. A pressure drop must be specified, and may be zero if a valve has already given the operating pressure of the vessel. Energy streams may also be attached. If this is done, an additional degree of freedom is given, and should be specified as a temperature or fraction vapor in the separator.
- **Three Phase Separator** – this block works essentially the same as the two-phase separator. The primary difference in specifications is that the three-phase separator allows an additional outlet stream, so there are vapor, light-liquid, and heavy-liquid outlets. On the Process Data tab, there is an option for the “Main Liquid Phase”. This allows you to specify whether the liquid phase should use the light- or heavy-liquid outlet if there is only one liquid phase predicted by ProMax.

## VALVES

- **JT Valve** – the valve has several icons available, but all are identical in their operation. Typically, a pressure drop across the valve or an outlet pressure is specified. In some rare cases, an outlet temperature or fraction vapor may be specified.

## STREAMS

- **Process Stream** – ProMax is a stream-based simulator; process streams typically contain most of the specifications. For a stream to be fully specified, two “flash variables” (these include temperature, pressure, mole fraction vapor, and enthalpy), a flow rate, and a composition should be known or propagated from upstream or downstream.
- **Q-Stream** – these are energy streams that are connected to compressors, pumps, some heat exchangers and separators, and various other blocks.
- **Cross Flow Sheet Connector** – these allow stream information to cross from one flow sheet to another. If a process stream is connected, then pressure, enthalpy, and molar fractions are transferred. You have the ability to set warnings for any variation in these values from one flow sheet to another, and also the ability to choose not to transfer components that are below a specified mole fraction in the stream. This gives the ability to limit the number of components in the new environment to speed the execution time.

## MULTIPLE FLOWSHEETS

ProMax allows you to have as many flowsheets in a project as you like. Each flowsheet may have a separate environment to allow multiple processes to be modeled in the same project. Additional flowsheets can be added using the ProMax “Flowsheets” menu option, or by right-clicking on the flowsheet tabs area at the bottom of the screen.

When creating a new flowsheet, the environment can be an existing environment, a duplicate of an existing environment that you can then modify, or a new environment to be fully defined.

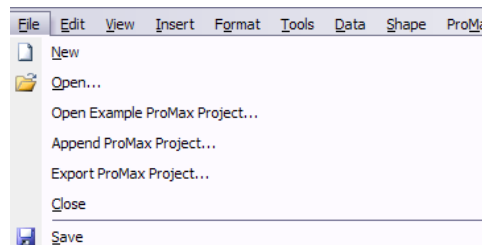
Once the flowsheet is created, a cross-flowsheet connector may be used to have a process or energy stream flow from one flowsheet to another. This block will appear on both of the two connected flowsheets and is arrow-shaped, to indicate the process or energy flow direction. The process or energy flow directions must agree on both sides of the connector (e.g. an input on one sheet must be an output on the other). These allow some flexibility to disregard certain irrelevant material in a stream, such as the tiny amount of amine in a gas stream after sweetening. Excluding unnecessary components can speed the execution time for the project.

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## EXPORTING/APPENDING FLOWSHEETS

Starting with version 3.0, ProMax has the ability to export entire projects to be appended to other ProMax projects. This is a simple two-step process that will import all streams, blocks, specifications, calculators, environments, user value sets, and other information from one project into another project.

1. With the project you wish to export open, select the “File” menu -> “Export ProMax Project”. Save the file as a “.pmxexp” file type.
2. With the destination project open, select the “File” menu -> “Append ProMax Project” and browse for the desired “.pmxexp” file.



This process will import the entire project to the new project.

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### Tip

If you wish to use this option often for specific processes, we recommend having single flowsheets for each process, so they can easily be combined into your new project.

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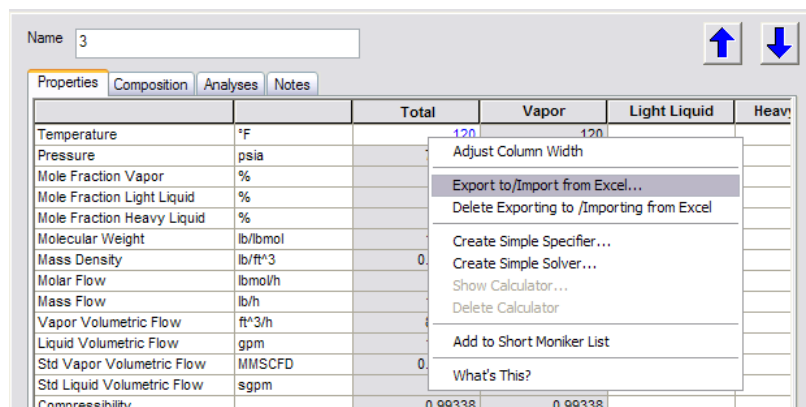
## EXCEL INTERACTIONS

ProMax has several methods to interact with outside programs, most notably Microsoft Excel. The next few pages will outline how to use two of the most popular methods.

- **Import/Export:** The simplest method is an import/export functionality that is available between ProMax and an embedded Excel workbook.

To embed a workbook, select “Add Excel Workbook” from the ProMax menu. This workbook is embedded within ProMax and will open, close, and save with the project. It is not available outside of the ProMax project except as a saved copy of the file that will remove all ties with ProMax, but allows you to share the results with any colleagues.

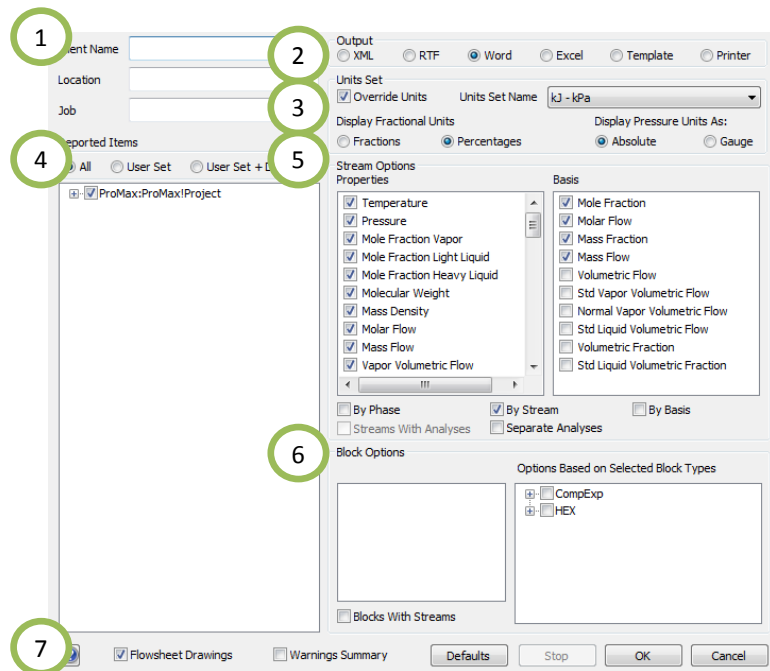
Once an Excel workbook is embedded, right-clicking on most properties in ProMax will now give an option for “Export to/Import from Excel”. Selecting this then allows you to choose what unit set you would like to transfer with the value, and to which cell in Excel you would like to connect the property. If a value is already in the ProMax field, only exporting is allowed; if there is no value in the ProMax field, either exporting or importing is allowed.



- **Scenario Tool:** A second option for Excel interactivity is our Scenario Tool. This tool can be accessed by both embedded Excel workbooks, or by external workbooks. This tool is useful for running many different cases of the same project to find many different types of trends in the operation of the unit. Refer to the notes on page 30 for more information on how to run the Scenario Tool.

## PROMAX REPORTS

ProMax provides several options for generating a report after your project has been completed.



1. Optionally supply a Client Name, Location and Job. This will be added to the first page of the report.

2. Choose the output file type. The most common are Word and Excel format. The “Template” option allows you to choose a custom report, formatted in Excel, that looks exactly as you want. More information on this can be found in the Help topic, or by contacting BR&E Support.

3. Unit Set configuration should be set here. By default ProMax will override any unit changes that have been made throughout the report. If this is unselected, changes made for individual streams or blocks will stay as the selected values for the report. Custom Unit sets can be created through the Options.xml file if none of the

selections available apply. Please see the Help or contact BR&E Support for additional information. This section also allows for the report to be displayed based on Fraction or Percentage and Absolute or Gauge pressures, regardless of how the project was created.



4. The tree control diagram allows you to select which pieces of information are included in the report. For the entire project, check the top-most box. You may select individual flowsheets, selected flowsheets, selected process streams, environments, user value sets, or almost any combination that you wish to be included in the reports.
5. The stream options selected may be rearranged if the order is not what you would like. Selected options are “checked” and found at the top of the list. The composition bases available are listed to the right.
6. Block options are available below the stream options. The selections here will vary depending on your project, but can include various plots or analyses that you may want included in your report based on the blocks in the project. Heat exchanger specification sheets can be created from the options, and are available if the Word report format is selected and a rated exchanger is included in the simulation.
7. If you would like either the drawing of the flowsheets or the warnings summary included with the report, select the corresponding option here.

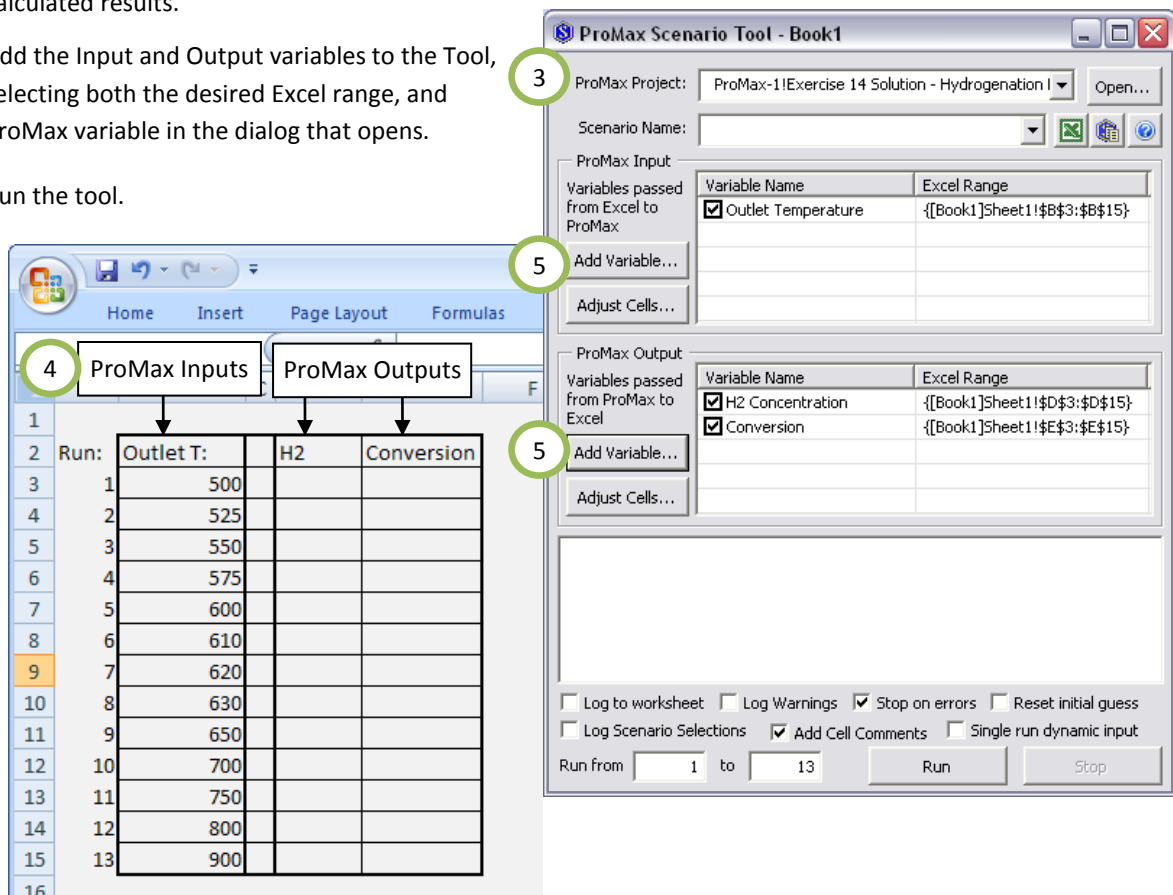
Select “OK” when the selections are complete. ProMax will then open a dialog asking for your choice of file save location, and create the report afterwards.

If ProMax is installed on the computer the report is opened at, a “Report Navigator” appears, and can assist in finding information from a generated report. This navigator does not use a license, but is only available on computers with ProMax installed.

## USING THE SCENARIO TOOL IN PROMAX



ProMax includes an Excel Add-in that allows you to create a case study for any unit you have created. The Scenario Tool may be used in either an embedded or external Excel workbook, depending on your needs. Since this is an Excel add-in, you have access to all of the functionality of Excel. For example, you may use any plotting tools or “in-house” worksheet formulas for manipulating and interpreting your data.

1. Open a blank Excel sheet and then add-in the *ProMax Scenario Tool.xla* file. This file can be found in the installed ProMax folder, under the option of “AddOns” and “Excel”. By default, this location is C:\Program Files\Bryan Research & Engineering Inc\ProMax3\AddOns\Excel. Double-click on the .xla file to add it in.
2. Start the tool in Excel. In Excel 2003 and earlier: double-click on the  that appears in a new toolbar. In Excel 2007: click on the  that appears in the “Add-Ins” tab.
3. Select from the drop-down list the appropriate ProMax file to be used.
4. Create in Excel the input parameters to be supplied to ProMax and the output locations to display the calculated results.
5. Add the Input and Output variables to the Tool, selecting both the desired Excel range, and ProMax variable in the dialog that opens.
6. Run the tool.



Run	Outlet T	H2	Conversion
1	500		
2	525		
3	550		
4	575		
5	600		
6	610		
7	620		
8	630		
9	650		
10	700		
11	750		
12	800		
13	900		

### Tip

For embedded Excel sheets there are two additional tools:  allows for easily setting a grid with two input variables and one output variable;  is a *wizard* available to help set up a scenario step-by-step.

## AVAILABLE ANALYSES IN PROMAX

Analyses can be added to any stream in ProMax. This is accomplished by clicking on the “Analyses” tab from the Project Viewer and selecting “Add Analysis...” towards the bottom of the screen. The options are:

**Amine Analysis** – This analysis gives information on amine loading for carbon dioxide, hydrogen sulfide, and total acid gas loading. It also shows the pH and Molarity of the stream.

**Combustion Analysis** – This will calculate the required combustion oxygen for a stream, as well as various heating values and the Wobbe Index.

**Distillation Curves** – This will calculate a table and generate a plot of a distillation curve based on TMP, ASTM D86, ASTM D1160, ASTM D2887/SD, or EFV on either a wet or dry basis of the selected stream.

**Freeze Out, Hydrate, H2O Dew Point** – For any stream phase, including total, this analysis will calculate the solids formation temperature, water content, and water dew point. It can calculate multiple hydrate points, structures and regions. This is particularly useful if you are operating in a condition that is below the highest hydrate point but you are not operating in the hydrate region.

**Fuel Properties** – Fuel properties of the stream can be calculated, including the Flash Point, high- and low-temperature viscosity, API gravity, various ASTM cut points, and the smoke or cloud point.

**Ionic Information** – Information on the ions present in the stream can be calculated using this analysis if an electrolytic environment is being used.

**Line Sizing** – ProMax can calculate the required nominal pipe size based on a limited gas velocity, pressure drop, or both. This rigorous calculation can include the inclination angle, pipe schedule, pipe roughness, material of construction, corrosion allowance, and other variables.

**Phase Envelope** – This analysis can generate a plot or table from the stream on either a wet or dry basis. The Hydrate Curve, Dry Ice Curve, or Ice Curve can all be included if desired. Beginning with ProMax v3.1, the required information (minimum and maximum mole fraction vapor and number of steps) is provided to give a default bubble/dew point curve. ProMax automatically matches the bubble-point curve if you request the dew-point curve, and similarly will match the 90% curve with the 10% curve, etc...

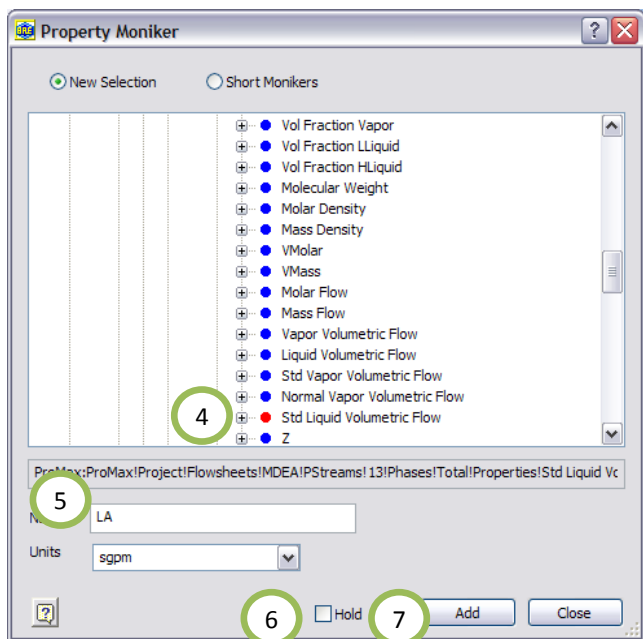
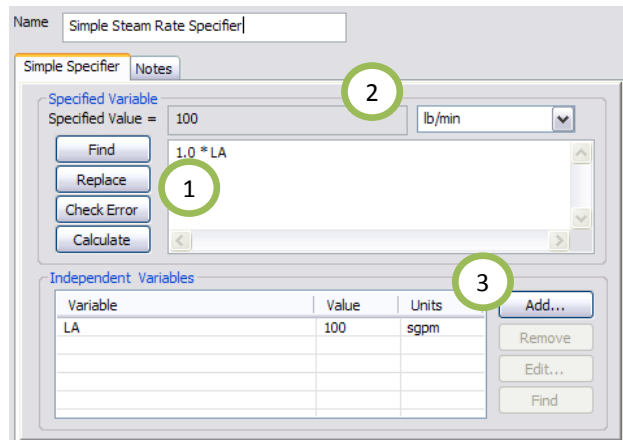
**Relief Valve Sizing** – This sizing analysis can be performed on various standards, with the default being the ASME API RP520 standard. Relief Temperature and Pressure, Set Pressure, Over Pressure, Back Pressure, Flow Rates, Coefficients, and Corrections are all available for specification. The stream Latent Heat can also be found on this analysis as defined in the standard.

**Vapor Pressure, Dew, Bubble Point** – The Bubble Point and Dew Point pressures and temperatures can be calculated from this analysis on a wet or dry basis. The True Vapor Pressure (TVP) and Reid Vapor Pressure (RVP) can also be calculated.

## USING A SIMPLE SPECIFIER IN PROMAX

A specifier is used to set the value of a property based on the value of other known variables or constants. To set a specifier, right-click on the property you wish to have calculated, then select Create Simple Specifier. The independent variable must be known and calculated by ProMax prior to the Specified Variable being used.

1. Write the expression that defines your specified variable. This must be a single-line expression, but can have multiple independent variables.
2. A unit selection must also be made. ProMax will maintain the units even if project units are altered.
3. Select the Add button to add the Independent Variable to be used in your specifier. The Property Moniker dialog box, as shown below, will appear.
4. From the variable selection dialogue, begin expanding the tree control through the project, flowsheets, stream or block, down to the desired independent variable. When a valid selection is picked, the gray box below the tree will fill in with a moniker string.
5. Upon selecting the variable, type a unique name to briefly identify the value. This name must not include any special characters, with the exception of the underscore (\_); a space will be replaced with an underscore; the name must not start with a number.
6. If you have multiple variables to select, the Hold button will keep the dialog open after adding the current variable.
7. Select Add when finished, and repeat for as many variables as required for your specifier.

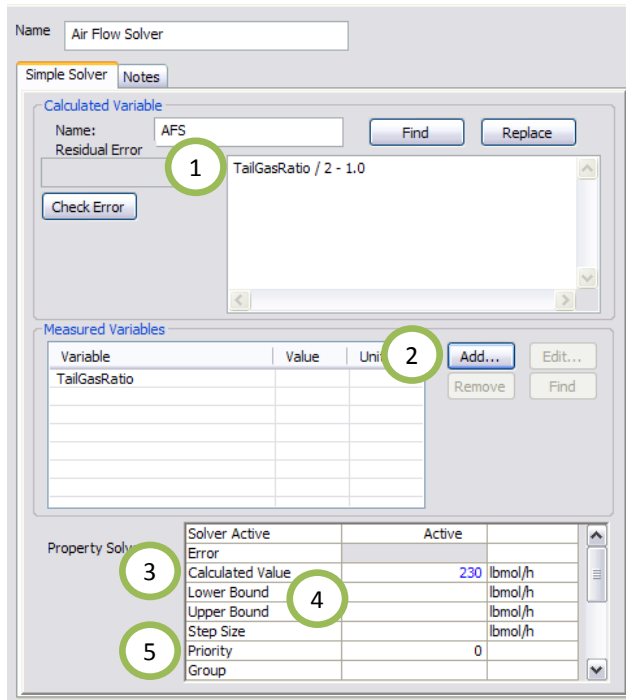




## USING A SIMPLE SOLVER IN PROMAX

A solver must be used if ProMax will need to iterate to find the solution to your goal. To create a solver, right click on the property that the Solver is to adjust and select Create Simple Solver.

For example, if you want to adjust the flow rate of air fed to a Claus unit to achieve a set tail gas ratio of H<sub>2</sub>S to SO<sub>2</sub>, you might place the Solver in the inlet air flow rate field. ProMax will use the Solver criteria to iterate on the air flow rate until it achieves the desired tail gas ratio.



1. ProMax will iterate your Calculated Variable until the equation written here is equal to zero, so the equation must be written with this in mind.

2. Select the Add button to add the Measured Variable to be used. This is the value ProMax will measure to see if it meets your goal (in our case, the tail gas ratio).

This opens a tree dialog as shown in the Specifier example on the previous page.

3. A guess for the “Calculated Value” must also be supplied to give the Solver a starting point.

4. Upper and lower bounds may be set, though this is usually not necessary.

5. A Priority must be set if multiple Solvers are present in the simulation for acceptable execution time. It is suggested that the Solvers be prioritized to solve loops from the “inside out”.

### WRITING THE SIMPLE SOLVER EXPRESSION:

If we would like our example tail gas ratio to be 2, then a simple starting expression for our goal would be:

$$0 = \text{TailGasRatio} - 2$$

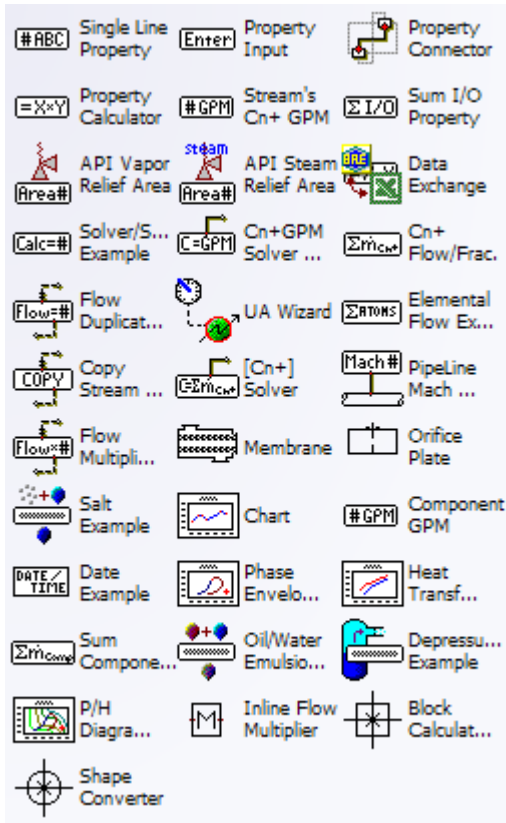
Only an expression needs to be written, as ProMax will iterate until this is equal to zero. In other words, you should not write the “0 = ” half of the equation.

While writing  $\text{TailGasRatio} - 2$  is acceptable, we highly recommend that each expression be normalized to aid in convergence. Normalizing the above expression results in the following:

$$\text{TailGasRatio}/2 - 1$$

## PROPERTY STENCIL

The ProMax Property Stencil is designed to add customizable functionality to ProMax. This self-contained stencil augments ProMax's Callout or Property Table and adds the ability to embed and share VBScript-based calculations. Many examples are available for your use and modification, as listed below. The Stencil may be found in the File menu, under "Shapes" or "Stencils" (this location is slightly different for each version of Visio).



**Single Line Property** – Displays any single piece of information from the project on the flowsheet.

**Property Input** – Displays any "input-ready" field from the project on the flowsheet. The value may be modified from the flowsheet by typing in the new value and pressing enter.

**Property Connector** – Connects to another property stencil, such as the Property Calculator, to allow the use of an offset moniker in the connected stencil. This essentially will preselect a moniker fragment up to the object the connector is connected to, simplifying and allowing quick changes to similar objects without the need to fully redefine a moniker.

**Property Calculator** – Displays the results of a script calculation on the flowsheet, and gives you the option to assign a prefix and suffix to the answer. You can define any number of variables by double-clicking in the grid area and browsing through the tree diagram. Once you have found all the necessary variables, click on "Edit Script Function" and define what you would like displayed on the flowsheet.

**Stream's Cn+ GPM** – Displays the potential Cn+ from any single stream in standard gallons per MSCF (thousand standard cubic feet). The "n" may be modified by double-clicking on the shape, selecting "edit source" and then double-clicking on the "intMinCAToms" value and replacing the number.

**Sum I/O Property** – Displays the sum of a selected property across all input streams, if an input stream is selected; sums the property across all outlet streams if an outlet stream is selected; or sums the property across all internal (non-outlet/inlet) streams if an internal stream is selected.

**API Vapor Relief Area** – Calculates the API Relief Valve Area for a vapor stream.

**API Steam Relief Area** – Calculates the API Relief Valve Area for a steam-only (vent to atmosphere) stream.

**Data Exchange** – Allows bi-directional specifications between an embedded Excel workbook and ProMax.

**Solver/Specifier Example** – This is a shell that supplies a value to a script based ProMax Calculator (Solver or Specifier) with appropriate VBScript edits.

**Cn+GPM Solver** – This stencil works identically to the [Cn+] solver on the following page except that the units solved for will be standard gallons per MSCF.

**Cn+ Flow/Frac.** – Displays the total flow rate or fraction of any single stream of all components containing the minimum carbon atoms. Can be molar, mass, Normal Vapor, Standard Liquid or Vapor or Volumetric units.

**Flow Duplicator** – Copies a reference stream's composition, and sets target stream flow rate. Pressure and temperature are not set, and must be designated by the user. Target stream MUST be connected to a block, even if it is a valve with 0 pressure drop. The flow rate will NOT update otherwise.

**UA Wizard** – Creates a solver on the variable of your choice to solve an exchanger to a desired UA, LMTD, Approach Temperature, or percent over design. Starting with ProMax 3.0, some of these may be directly specified.

**Elemental Flow Example** – Displays the total flow of a given element in a selected process stream.

**Copy Stream** – Copies a reference stream by transferring molar enthalpy (not shown by default), pressure, component mol fraction, and molar flow rate. Target stream MUST be connected to a block, even if it is a valve with 0 pressure drop. The flow rate will NOT update otherwise.

**[Cn+] Solver** – Manipulates a selected variable to achieve a desired Cn+ fraction or flow rate in a selected target stream. A blank simple solver must be created on the manipulated variable prior to placing the stencil on the flowsheet. The connector on the shape should then be placed on the target stream. The desired fraction or flow rate should be defined by double-clicking on the shape and changing the value.

**PipeLine Mach Number** – Solves for a specified Mach number through the pipe. By default it will change the flow rate of the fluid until the Mach number is 1. You should set an inlet flow rate as an initial guess for the solver. A desired Mach value can be specified by double-clicking on the shape.

**Flow Multiplier** – Copies a reference stream's molar enthalpy, pressure, and composition, then modifies the reference stream's flow rate by a multiplier. Default = 2x. Target stream MUST be connected to a block, even if it is a valve with 0 pressure drop. The flow rate will NOT update otherwise.

**Membrane** – Solves for asynchronous vapor separation in a membrane. Permeability values and available membrane area is defined in the block.

**Orifice Plate** – This can simulate either an orifice plate or a nozzle/venturi. It is capable of solving outlet pressure, inlet pressure OR mass flow, depending on what is specified in the inlet and outlet streams. Double-click on the shape to specify parameters.

**Salt Example** – Double-click on the shape to specify the stream in which you wish to have an aqueous salt. Then, select which salt you would like and the mass percent of the salt in the solution. The tool will then add the required acid and base to the environment, calculate the required amount of each in the stream, and define the composition based on this.

**Chart** – Allows the user to generate simple plots such as the column temperature profile or the temperature at each increment through a heat exchanger. These plots can be generated using the Plots tab of these blocks, but the Chart version is smaller and can be conveniently placed on the flowsheet without obstructing anything else.

**Component GPM** – Displays the standard gallons per MSCF of any single selected component.

**Date Example** – Displays the project name and the created, saved, modified, and solved dates and times. This can be modified by changing the solver scripts.

**Phase Envelope** – Displays the phase envelope of a selected stream on the flowsheet. The current stream conditions are shown on the diagram with a red "X".

**Heat Transfer** – Displays the heat transfer chart of a selected exchanger on the flowsheet.

**Sum Component Flow/Frac.** – Displays the sum of flows or fractions of components selected by the user. Sx, Amines, BTEX, and Mercaptans are pre-defined, but any selection can be made.

**Oil/Water Emulsion** – This will modify the properties of an existing single oil to create an emulsion, and save this new component into the current environment. The water volume fraction is then specified by double-clicking on the shape.

**P/H Diagram** – Displays the Pressure/Enthalpy diagram of a selected stream on the flowsheet. The current stream conditions are shown on the diagram with a red “X”.

**Inline Flow Multiplier** – Transfers a process stream’s conditions and composition from one connected stream to another. The flow specification is set from the source stream and multiplied by the Flow Multiplier parameter. The user has the ability to select which properties to transfer to the target stream.

**Depressurization Example** – This tool estimates an orifice diameter required to depressurize a vessel to a given pressure in a given amount of time. The user should set the vessel volume, vent pipe diameter, vessel initial pressure, vessel initial temperature, downstream pressure, target pressure, time to reach target pressure, heat input into the vessel, etc.

**Block Calculator** – Creates a new stencil that is based on an existing block from your flowsheet. The stencil saves user defined properties (e.g., temperature on an outlet stream) and specifiers or solvers associated with the block. The values can be changed from the dialog for each user defined property. A “Master Name” should be selected for the stencil name, and then “Store in Stencil” selected to save the shape. Once stencils have been saved, you should select the “Save” button in the top right-hand corner of the stencil set for future use. Both this saved stencil group and the ProMax property stencil set must be open to use these created stencils.

**Shape Converter** – Modifies any Visio object into a ProMax shape. Connection points can be added from the connection point tool (in the same group as the connector tool); block type and connection point assignments are made in the stencil. Once both the shape and stencil set are saved, the shape may be used in any project.

### Tips

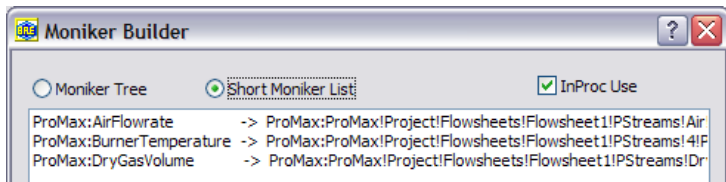
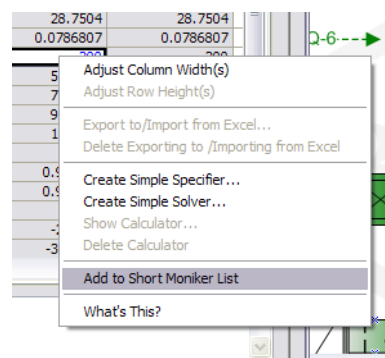
Instead of using the relief valve property stencils available, use the Relief Valve Sizing Analysis available for any stream in ProMax.

## CREATING A SHORT MONIKER IN PROMAX



A moniker in ProMax is essentially the name given to each piece of information within the project. As seen throughout the program, finding the value required in ProMax often leads you to expand through a “tree” diagram, with (+) signs opening to sub-categories.

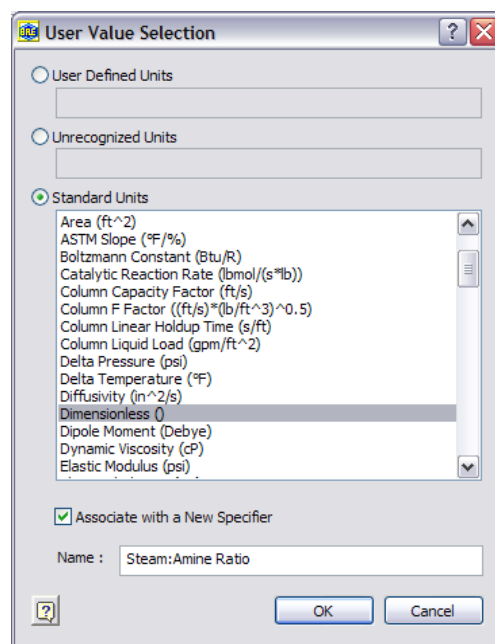
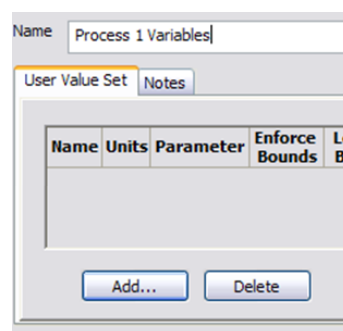
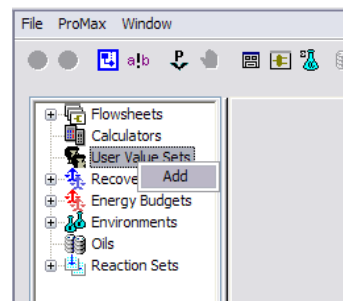
A shortcut is available to find your required variable. First, create a “short moniker” by right clicking on the value you wish to use and select “Add to Short Moniker List”. Name the variable in the dialog and add/reset the moniker. Once created, this can be accessed from any moniker location by selecting the “Short Moniker” radio button located above the tree diagram. Note: not all variables can be added as short monikers, such as compositions.



## USER DEFINED VARIABLES

ProMax provides a method to define a variable that it does not calculate otherwise. These variables are stored in User Value Sets, so they may be grouped as you would like. To add a new user-defined variable:

1. Open the Project Viewer and select (double-click) the User Value Set in which you would like to add the new variable. If you need to create a new User Value Set, right-click on the “User Value Sets” option in the tree diagram of the project viewer and select “Add”.
2. It is recommended to change the name of the User Value Set to something descriptive.
3. Select “Add...” to create the new variable.
4. From the new dialog box that appears, you must tell ProMax what type of unit this variable will have associated with it. There are three choices:
  - a. User Defined Units – you will define units based on what ProMax can understand, but in an unusual sequence, different than available in the “Standard Units” choices, (e.g. kW\*h/ft<sup>2</sup>)
  - b. Unrecognized Units – you will define units based on something ProMax cannot understand, such as monetary units (e.g. \$, £).
  - c. Standard Units – you will select from the list which set of units this variable will have.
5. Choose whether to associate this variable with a new specifier. Choose to associate with a specifier if any information must be taken from within the project to calculate what the variable will be (e.g. flow rates, compositions, horsepower, etc...). If you will be providing the value of the variable, leave this unmarked (e.g. setting an ambient temperature for use in the project).
6. Name your variable and select “OK”.
7. If you have selected to associate this with a specifier, it will create an undefined specifier. Right-click on the blue box, select “Show Calculator” and define your requirements. Please see Using a Simple Specifier in ProMax on page 32 for further details.
8. Lower and upper bounds are optional, but may be set. If the “Enforce Bounds” box is selected, a warning message will be generated if the variable exceeds either of these bounds.



Name	Units	Parameter	Enforce Bounds	Lower Bound	Upper Bound
Steam:Amine Ratio			<input checked="" type="checkbox"/>	0.65	1.3

# PROMAX EXERCISES

COURSE AGENDA  
EXERCISES AND QUESTIONS  
SOLUTIONS

## PROMAX FOUNDATIONS EXERCISES

Let's try some exercises to help you become more familiar with ProMax. These exercises are designed to show the basic functionality of ProMax, and include drawing flowsheets, creating environments, specifying processes, and finding information from a completed project. This course also demonstrates how to rate a heat exchanger, how to set up specifiers and solvers, and how to utilize our scenario tool.

### COURSE AGENDA

#### DAY 1

- Exercise 1 Simple Gas Plant (O&G only)  
or Exercise 2 Simple Sour Water Stripper (R only)
- Exercise 3 Simple MDEA Sweetening Unit
- Exercise 4 Export/Append Flowsheet
- Exercise 5 Multiple Flowsheets
- Exercise 6 Glycol Dehydration Unit (O&G only)

#### DAY 2

- Three Bed Claus Unit
- Exercise 8 Hydrogenation Reactor
- Exercise 9 Pipeline Simulation
- Exercise 10 Crude Distillation with Side Strippers (R only)
- Exercise 11 Import/Export from Excel
- Exercise 12 Scenario Tool with Methanol Injection
- Exercise 13 Scenario Tool with Amine Absorber
- Exercise 14 Simple Specifiers

#### DAY 3

- Exercise 15 Simple Solvers
- Exercise 16 User Value Sets
- Exercise 17 Separator Sizing
- Exercise 18 Heat Exchanger Rating

↑  
CREATING YOUR PROCESS  
↓

↑  
PROCESS OPTIMIZATION  
↓

## EXERCISE 1 SIMPLE GAS PLANT

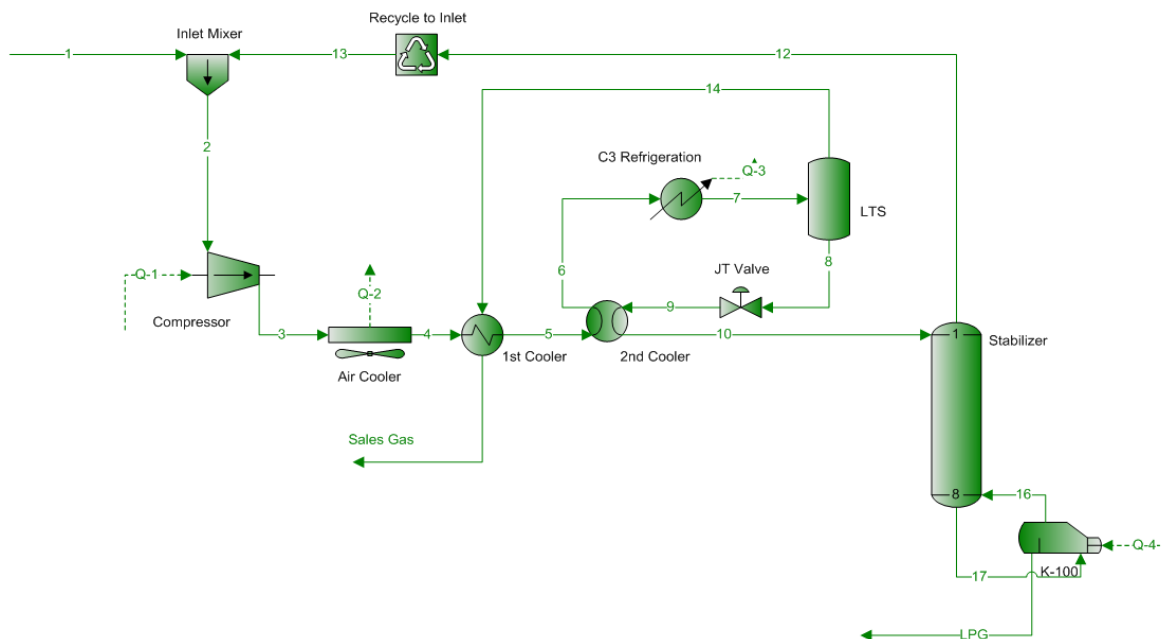
Let us start with a simple system in which a gas feed is separated into a liquid product and a sales gas. This is achieved by compressing, cooling, and flashing the gas before sending it to a distillation column. The distillation is operated with a reboiler that is used to control the composition of the bottom liquids.

### PROCESS INFORMATION

- The conditions and composition of the inlet stream are given in the table.
- The compressor outlet pressure is 560 psig. Use 75% polytropic efficiency.
- The outlet of the air cooler should be 110 °F.
- Sales gas passes through a gas/gas exchanger to cool the inlet stream. In this first cooler, the Minimum End Approach Temperature is 30 °F.
- The second cooler chills the stream feeding the propane cooler to 36 °F.
- The propane refrigeration cools the stream entering the low temperature separator to 20 °F.
- The pressure at the outlet of the JT valve is 200 psig.
- Use the stabilizer to obtain a 0.1 C<sub>2</sub>/C<sub>3</sub> standard liquid volume fraction ratio in the bottom liquid.
- Remember to supply a guess for stream 13. The temperature and pressure of the feed, along with 100 moles each of methane, ethane and propane can be used.
- After setting up the simulation, insert a Property Table to display the temperatures, pressures, flow rates, and compositions of the Inlet, Sales Gas, and LPG streams.

#### Inlet Conditions

Temperature	95 °F
Pressure	200 psia
Flow	5 MMSCFD
<b>Composition</b>	<b>Mole %</b>
Nitrogen	1.93
Carbon Dioxide	2.71
Methane	58.66
Ethane	16.17
Propane	12.86
i-Butane	1.58
n-Butane	0.70
i-Pentane	0.84
n-Pentane	3.73
n-Hexane	0.81

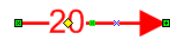
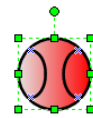




## HINTS

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- You may draw all process blocks first, and then use the “Connector Tool” in Visio to draw the streams.
- All heat exchangers should have a pressure drop specified, since this is a property of the exchanger. Setting an outlet pressure instead can result in unexpected results if conditions change later.
- Always set a value for the efficiency of pumps, compressors, and expanders. Setting both the outlet pressure and temperature is strongly discouraged because a small inaccuracy in the temperature can result in efficiencies less than 0% or greater than 100%.
- Recycle blocks always require the outlet PStream to be completely specified (Pressure, Temperature, Flow Rate and Composition).
- Visio shapes can be resized and rotated by utilizing points that become available when the object is selected. Process and Energy streams can be redirected from similar points.
  - The small green circle above the exchanger to the right is for rotating the drawing. The other green squares are to resize the shape. Some shapes allow for stretching, others only allow making it larger or smaller. A few shapes restrict rotation to maintain correct positioning of vapor and liquid exits.
  - The yellow diamond found on the stream shown to the right is for the label location. The name of blocks and streams can be moved by dragging this diamond.
  - To redirect streams, find the small bright-green squares located in the middle of the streams, then click and drag from these points.



## QUESTIONS

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1. What is the overall molecular weight of the feed?
2. Determine the compressor brake power, discharge temperature, and head.
3. What is the LMTD in the first cross exchanger and the sales gas temperature?
4. What is the duty required for the refrigeration unit?
5. What is the discharge temperature of the valve?
6. How many barrels of liquid and cubic feet of gas are produced each day?
7. Generate a phase diagram with only the dew point and bubble point lines for the sales gas stream.
8. Add the 90 and 10% quality lines to the phase diagram.
9. What is the critical point and what is the cricondentherm pressure for sales gas?
10. What are the RVP and TVP of the liquid product?
11. The pressure drop in the inlet stream is to be maintained below 5 psi/100 ft of horizontal length. Using schedule 40 pipe, what diameter is required? What is the actual pressure drop? What is the velocity?

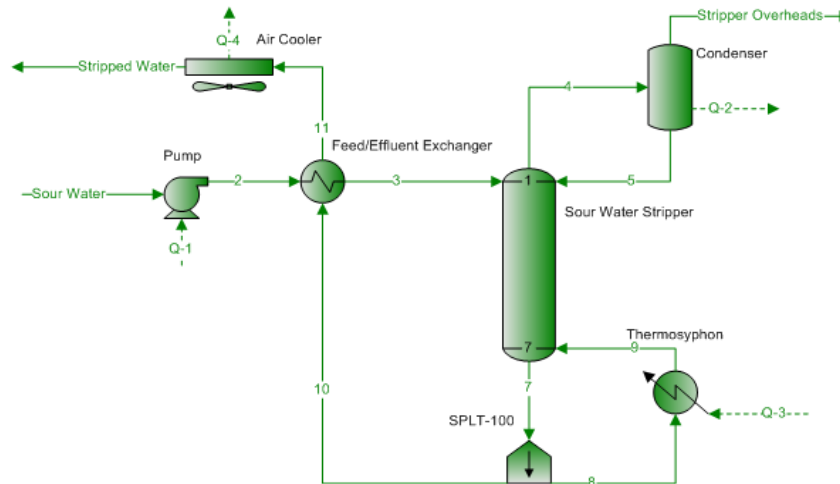
## EXERCISE 2 SIMPLE SOUR WATER STRIPPER

This unit is used to remove several contaminants from utility water before sending it to waste water treatment. Here, we will simulate a sour water stripper with a thermosyphon and an overhead condenser.

### PROCESS INFORMATION

- The pump outlet pressure is 40 psig. Use 65% pump efficiency.
- The Sour Water enters the Stripper at 190°F.
- The stripper has 7 ideal stages, and should be an Equilibrium column type.
- The top stage is 8 psig and the column has 1 psi of pressure drop.
- The Condenser outlet temperature is 185 °F.
- For stripping, a thermosyphon is used to heat and return 70% of the bottoms. This stream is 15% vaporized through the exchanger.
- The Air Cooler lowers the stripped sour water temperature to 110°F.
- The column may require a pump-around duty estimate. Give this initial guess for the thermosyphon loop as a “Pump-around Estimate” column specification.
- After setting up the simulation, insert a Property Table to display the temperatures, pressures, flow rates, and compositions of the Sour Water, Stripped Water, Stripper Overheads streams.

Inlet Conditions	
Temperature	95 °F
Pressure	0.3 psig
Flow	545 sgpm
Composition	Mass %
NH <sub>3</sub>	0.55
H <sub>2</sub> S	1.2
Phenol	0.1
HCN	0.001
H <sub>2</sub> O	98.149



### QUESTIONS

1. Determine the pump's head and required horsepower.
2. What are the duty, end-point approach temperature, and Effective UA in the Feed Effluent Exchanger?
3. What is the Stripper bottoms temperature?
4. What is the recovery of H<sub>2</sub>S and NH<sub>3</sub> in the Stripper Overhead?
5. What is the pH of the Sour Water from Tankage and the cooled Stripped Sour Water?
6. The pressure drop in the Stripper Overheads is to be maintained below 5 psi/100 ft of horizontal length. Using schedule 40 pipe, what diameter would be required? What is the actual  $\Delta P$  and velocity?
7. What is the critical point for the Stripper Overhead?

## EXERCISE 3 SIMPLE MDEA SWEETENING UNIT

We are currently selling our gas to a plant that requires less than 2 mol% CO<sub>2</sub> and less than 4 ppm H<sub>2</sub>S. Use the following information to simulate this amine sweetening unit and determine if we are meeting our requirements or not. Use an Amine Sweetening environment, as there are reactions here that occur between ionic species. Start your simulation by opening “Exercise 3 – Simple MDEA Sweetening Unit.pmx” file in the unsolved exercises folder.

### PROCESS INFORMATION

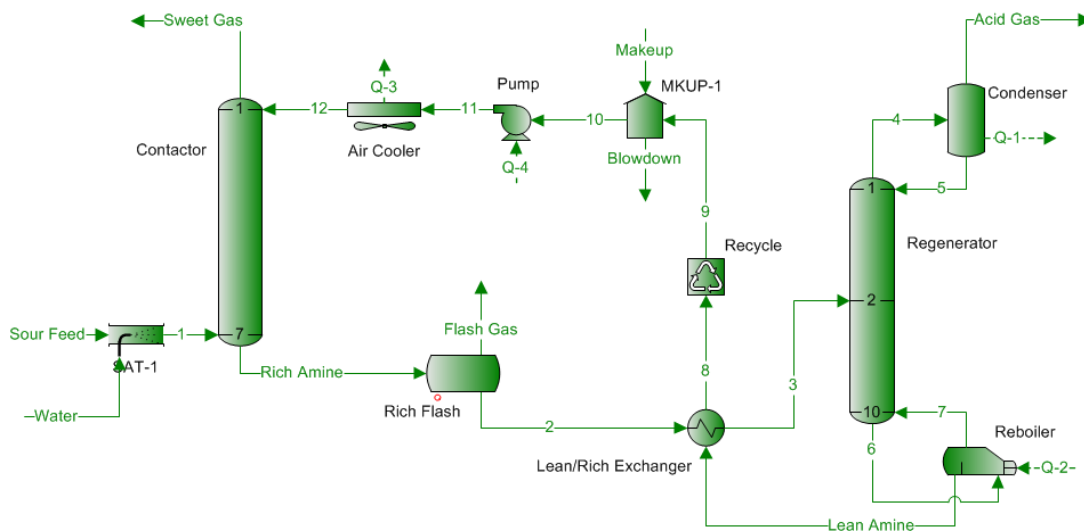
- Use the stream conditions to the right to define the inlet stream.
- The inlet gas stream is 100% saturated with water
- Use 40 wt% MDEA at a circulation rate of 190 sgpm.
- Absorber diameter is 4 ft and weir height is 3 in. System factor of 0.8 and tray spacing of 2 ft.
- The condenser operates at 120 °F and the reboiler duty is 17 MMBtu/hr.
- The regenerator top stage pressure is 12 psig with a 4 psi pressure drop through the tower.
- The rich amine enters the regenerator at 210 °F.
- The rich flash tank operates at 100 psia.
- Remember to supply a guess for the recycle block outlet stream.
- After setting up the simulation, place a Call-out to display the H<sub>2</sub>S and CO<sub>2</sub> mole fractions of the Rich Amine, Sweet Gas and Acid Gas streams.

#### Inlet Conditions

Temperature	100 °F
Pressure	1000 psia
Flow Rate	50 MMSCFD

#### Composition Mole%

H <sub>2</sub> S	1.5
CO <sub>2</sub>	3.5
Methane	83.4
Ethane	5.65
Propane	4.07
n-Butane	0.9
n-Pentane	0.5
n-Hexane	0.32
n-Heptane	0.15
Benzene	0.005
Toluene	0.002
Ethylbenzene	0.001
o-Xylene	0.002



### QUESTIONS

1. What are the sweet gas CO<sub>2</sub> and H<sub>2</sub>S compositions?
2. What are the H<sub>2</sub>S, CO<sub>2</sub>, and total lean loadings (mol/mol)? Rich loadings?
3. What is the liquid residence time and percent flood on an absorber tray?
4. What is the lean and rich approach in the absorber for H<sub>2</sub>S?

## EXERCISE 4 EXPORT/APPEND FLOWSHEET

Additional flowsheets provide a convenient way to organize your flow diagram, and to handle multiple processes that require different environments.

One way to create additional flowsheets in your project is to append them from a previously created project. This is done through the export/append flowsheet options found under the File menu. In this exercise, you will append your amine unit to an existing template project of a dehydration unit.

### PROCESS INFORMATION

1. From the file menu, select “Export ProMax Project...” Save your project in an easily accessible location, and close the file.
2. Open the file named “Ex6 - TEG Unit.pmx”.
3. From the file menu, choose “Append ProMax Project...” Browse and select the “.pmxexp” file you saved in step 1.

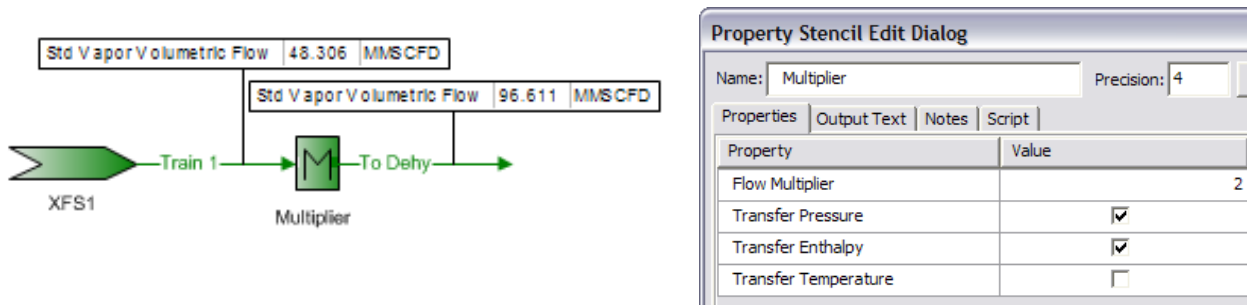
## EXERCISE 5 MULTIPLE FLOWSHEETS

Often you would prefer to create a *new* blank flowsheet in your project. In this exercise, you will create and configure a new flowsheet in an existing project, and you will learn how to copy conditions between two streams.

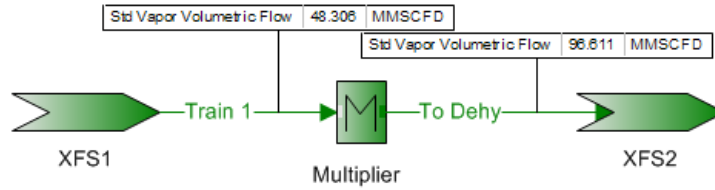
### PROCESS INFORMATION

Using your MDEA + TEG project you now have open, create a new flowsheet by right-clicking in the flowsheet tab area and name it “Mixing”. Create a new environment to be used by selecting “Amine Sweetening - PR” and choosing “duplicate”. This creates a copy of the existing environment that we can modify, instead of us redefining all of the same components. Rename the environment “Mixing”, and let’s assign this new environment the SRK thermodynamics package. Select “OK” to save the environment. Once we have designed the new environment, we must select this environment to be used.

In the new flowsheet, construct the simple mixing process illustrated below. Use the Cross Flowsheet Connector block to connect the Sweet Gas stream from the MDEA flowsheet to the new flowsheet. We will use the “Inline Flow Multiplier” Property Stencil to propagate the pressure and enthalpy, and to set the outlet flow rate as double the inlet flow rate. The composition will always be identical using this block. The Property Stencil set is found in the “File”->“Shapes” menu, if not already available in your project.



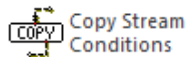
Connect the “To Dehy” stream in the mixing flowsheet with the inlet stream to the glycol contactor via a Cross Flowsheet Connector. Duplicate the Mixing Environment, but this time exclude MDEA from the component list and remember to include TEG.



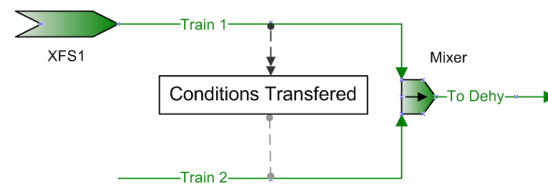
## QUESTIONS

1. What is the difference in temperature between the “Sweet Gas” stream in the MDEA flowsheet and “Train 1” stream? What caused this discrepancy? How can this be corrected? (Incorporate this change to your project.)
2. What variables were transferred between streams “Train 1” and “Train 2”?
3. In the Cross Flowsheet Connector, you can set the Mole Fraction Transfer Threshold to prevent the transfer of trace components across flowsheets. This can be useful in some cases where the component might cause instabilities across the different units. In the exercise, use the Threshold value to limit for material transfer to 2 ppm. What components will not be transferred to the Dehy Flowsheet? What if this threshold value was increased to 10ppm?

## Tips



This process has an alternative that will display both inlet streams. The “Copy Stream Conditions” property stencil is connected to both a reference stream and a blank target stream with connector lines, as illustrated. Composition, mass flow rate, molar enthalpy and pressure are transferred.



## EXERCISE 6 GLYCOL DEHYDRATION UNIT

Simulate a TEG dehydration unit that dries the inlet gas to a water content of less than 7 lb H<sub>2</sub>O/MMSCF.

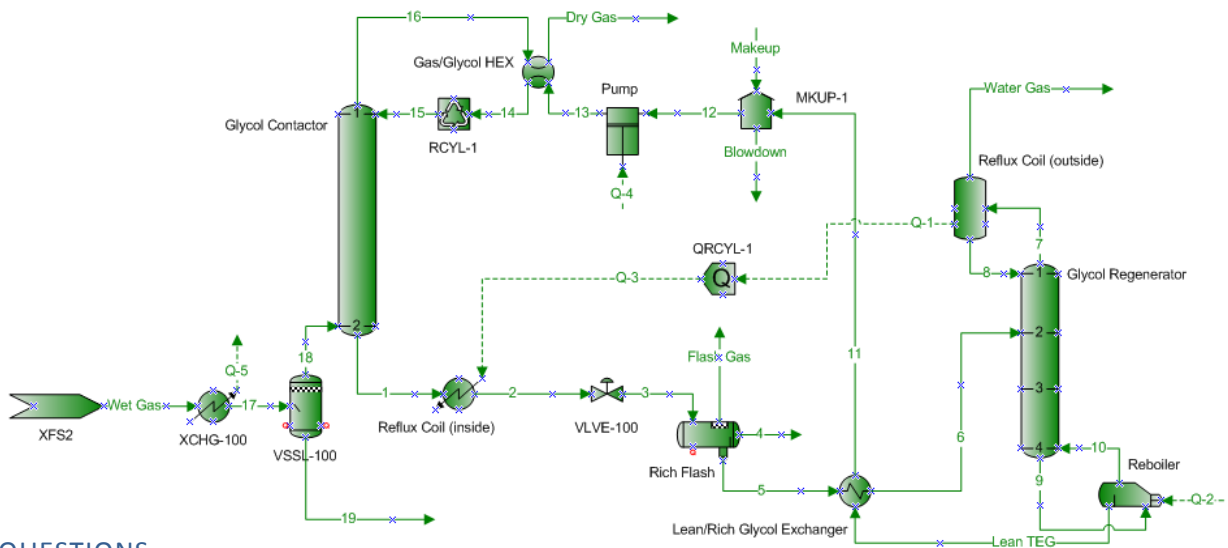
### PROCESS INFORMATION

- Use the stream conditions to the right only if you did not work the previous exercises. Otherwise, use the inlet stream we have created.
- The Wet Gas stream is first cooled to 100 °F.
- The absorber has 2 ideal stages and the regenerator has 4 ideal stages.
- Use 5.6 sgpm for the glycol circulation rate.
- Specify a complete guess for the recycle.
- The rich flash operates at 60 psig.
- The rich feed to the regenerator is 300 °F.
- The regenerator reboiler should not exceed 390°F.
- The regenerator operates at atmospheric pressure with a small amount of reflux generated from the reflux coil.
- Use a guess of 20 000 BTU/hr for the Q-Recycle.
- The lean glycol enters the absorber at 110 °F.
- After setting up your simulation, insert Callouts to display the water content of the Dry Gas and Lean TEG streams.

#### Inlet Conditions

Temperature	125 °F
Pressure	990 psia
Flow Rate	10600 lbmol/hr

Composition	Mole%
H <sub>2</sub> S	3.1ppm
CO <sub>2</sub>	1.5
Methane	86.33
Ethane	5.84
Propane	4.15
n-Butane	0.95
n-Pentane	0.48
n-Hexane	0.6
n-Heptane	0.2
Benzene	0.15
Toluene	0.01
Ethylbenzene	0.02
o-Xylene	0.02
Water	0.22



### QUESTIONS

1. What is the water content of the dry gas?
2. At what temperature will hydrates form in the dry gas?
3. What is the mass flow of water in the feed gas?
4. Create a ProMax report of your choice using the current project.

## EXERCISE 7 THREE BED CLAUSS UNIT

This exercise simulates a three-bed Claus sulfur recovery unit. All reactors in this exercise are Gibbs Minimization reactors, utilizing specialized Gibbs Sets to select the reactive species and add the necessary constraints.

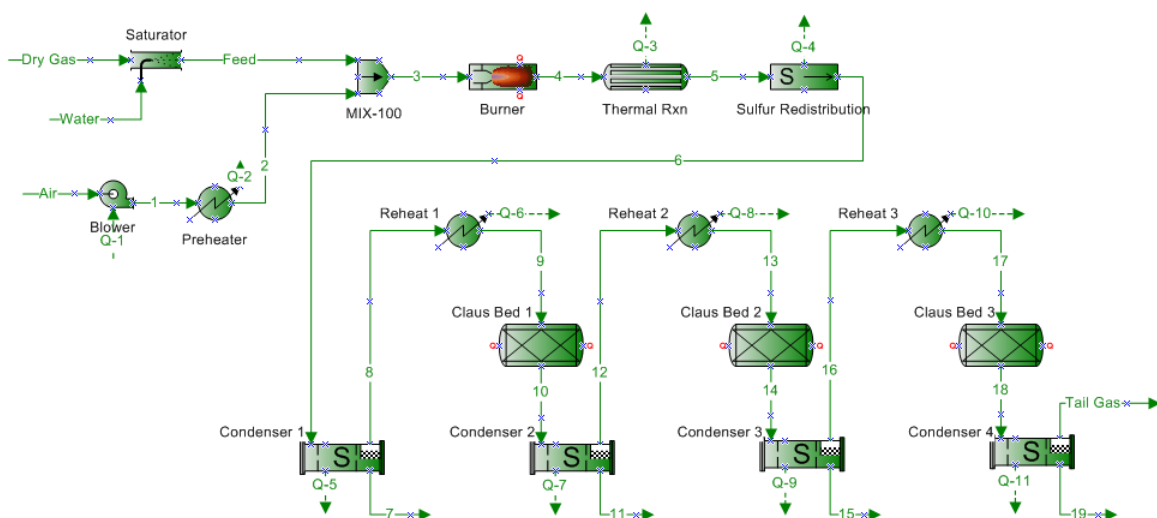
### PROCESS INFORMATION

- **Additional Components Needed:**  $H_2$ ,  $SO_2$ ,  $CO$ ,  $COS$ ,  $CS_2$ , S1 – S8
- The blower increases the air pressure to 16 psig; the preheater then heats it to 500 °F with a  $\Delta P = 0.5$  psi.
- The Burner uses the “Acid Gas Burner” Gibbs Set. Constraints for  $COS$  and  $CS_2$  formation are automatically added for this reactor type. Assume 0% bypass fraction.
- The Thermal Reaction zone is the first pass of the waste heat boiler, and produces an outlet temperature of 1200 °F. This uses the “Sulfur Thermal Reaction Zone” Gibbs Set, goes to equilibrium, and has a  $\Delta P = 0.5$  psi. In this set, certain components are “quenched” to keep from reacting beyond specified temperatures, better reflecting actual performance.  $COS$  and  $CS_2$  are excluded from reacting.
- The Sulfur Redistribution block is the second pass of the waste heat boiler and produces an outlet temperature of 700°F. The pressure drop is 0.5 psi.

Stream	Acid Gas	Air
Temperature (°F)	115	77
Pressure (psig)	15	1
Flow rate (lbmol/hr)	165	200
Composition	Mol %	
Hydrogen Sulfide	55	0
Carbon Dioxide	43	0
Methane	1	0
Ethane	0.6	0
Propane	0.4	0
Oxygen	0	21
Nitrogen	0	78
Water	0	1

It may be easiest to specify the Claus Beds, reheats and condensers *sequentially*, using the following information:

- All sulfur condensers use the Gibbs Set “Sulfur Condenser”, with a 0.5 psi pressure drop. Condensers 1 and 2 have an outlet temperature of 320 °F, while condensers 3 and 4 have outlet temperatures of 300 °F.
- All reheats have a pressure drop of 0.5 psi. Reheater 1 increases the temperature to 500 °F, Reheater 2 increases the temperature to 480 °F and Reheater 3 increases the temperature to 430 °F.
- The Claus beds have a 5% bypass fraction, with a 0.2 psi pressure drop. Claus Bed 1 uses the “GPSA Hydrolyzing Claus Bed” Gibbs set in order to partially destroy the  $COS$  and  $CS_2$ . Beds 2 and 3 use the Gibbs Set “Claus Bed” as they do not have the catalyst and temperature required for the  $COS$  and  $CS_2$  destruction.



## QUESTIONS

1. What is the burner outlet temperature?
2. What is the molar flow for  $H_2S$  and  $SO_2$  in the tail gas?
3. Add an analysis to calculate the sulfur dewpoint exiting the first Claus bed.
4. How much  $COS$  and  $CS_2$  are formed in the burner?
5. How many long tons per day (tonb/d) are produced from each condenser?
6. Plot the sulfur dew point and bed temperature vs. increment for Claus Bed 2.
7. For Condenser 1, plot liquid sulfur production vs. temperature.

## EXERCISE 8 HYDROGENATION REACTOR

The tail gas stream from the last Claus sulfur condenser is to be treated in a hydrogenation reactor to convert all remaining sulfur species to  $H_2S$ . This exercise may be added to the same flowsheet as 0. If you would prefer, you may instead use the composition provided below for the Claus Tail Gas stream.

### PROCESS INFORMATION

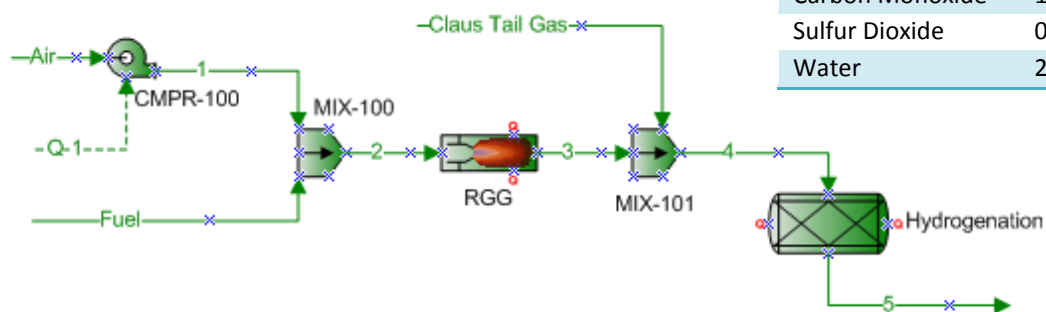
- The fuel is methane at 30 psig and 77 °F. The initial flow rate is 1.5 lb-mol/hr.
- The blower supplies air at ambient conditions with an initial flow rate of 15 lb-mol/hr.
- The burner is a Gibbs Minimization reactor with zero pressure drop allowing all components to react.
- The Hydrogenation Reactor is a Gibbs Minimization reactor and the Gibbs Set is Sulfur Hydrogenation.

#### Conditions:

Temperature	300 °F
Pressure	10 psig
Flow Rate	9900 lb/hr

#### Composition: Mole %

Hydrogen Sulfide	3.4
Carbon Dioxide	19.8
Nitrogen	45.5
Hydrogen	1.4
Carbon Monoxide	1.9
Sulfur Dioxide	0.6
Water	27.4



## QUESTIONS

1. What is the burner outlet temperature?
2. What is the remaining  $H_2S$  content in the hydrogenation reactor outlet?
3. Is all the  $SO_2$  converted in the reactor?



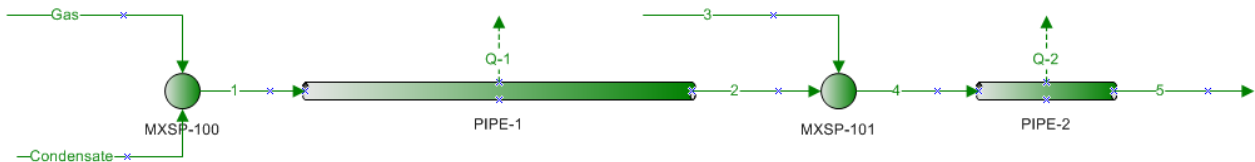
## EXERCISE 9 PIPELINE SIMULATION

Natural gas and condensate are mixed and sent through a 17.3 mile long pipeline to the processing facility. Along the way, another gas stream from a different production facility is added to the mixture. Build a simulation to represent this process based on the information below.

### PROCESS INFORMATION

- The first 15 miles of 8 inch pipe is to be divided into 3 segments, 24,000 ft, 25,000 ft, and 30,000 ft long.
- The second gas stream is mixed after 15 miles
- After the second gas stream joins the pipeline, it becomes a 12 inch line and continues for another 2.3 miles to the processing facility.
- The pipe is horizontal except the second pipe segment has a 500 ft increase in elevation and the last pipe segment has a 10 ft increase.
- Add a 45° elbow after the first segment.
- The ambient temperature for the first segment is 50 °F, 40 °F for the second, 30 °F for the third, and 40 °F for the fourth.
- The heat transfer coefficient should be calculated by ProMax based on Carbon Steel A134 welded pipe buried 24 inches in dry clay ground.
- The pipe schedule for all piping is 80S.

Stream	Condensate	Gas	3
T (°F)	75	100	50
P (psia)	610	610	510
Flow rate	1100 sbbl/d	900 lbmol/h	8 MMSCFD
Composition	Mole %		
CO <sub>2</sub>	0	0.2	0.1
N <sub>2</sub>	0	0.5	0.8
C1	3.5	84.3	85
C2	3.5	5	6.5
C3	15	5	3.7
iC4	15	1.5	1
nC4	14	1.5	1
iC5	11	0.7	0.6
nC5	11	0.3	0.4
nC6	23	0.5	0.4
nC7	4	0.5	0.5



### QUESTIONS

- What is the temperature and pressure of the gas exiting the pipeline to the processing facility?
- What is the calculated overall heat transfer coefficient for the first pipe segment?
- If the upstream dehydration facility is shut down and the inlet gas becomes saturated with water, where do hydrates start to form?
- For each pipe segment, plot increment vs. pressure drop.

## EXERCISE 10 CRUDE DISTILLATION WITH SIDE STRIPPERS

Model the following atmospheric crude distillation column. Create a 60/40 Oil A/Oil B blend from the two individual oil characterizations given below.

### PROCESS INFORMATION

- The feed is heated to 482°F in the inlet heater. The Feed Flash outlet conditions are 468°F and 40 psia. Liquids are pumped to 185 psia then heated to 700°F in the Feed heater.
- The tower has 33 ideal stages with a three phase partial condenser. Note: Since the condenser is attached to the column, this will affect the tower “flash type”.
- The top of the tower operates at 25 psia and the bottom at 33 psia.
- Each side stripper has 5 ideal stages and should reference the Atmospheric tower as its main column.
- All specifications will be made in the atmospheric column.
- Use the specifications provided below to define the system first:
  - Reflux ratio – 1.3
  - Flow Ratio for Side Cooler 1 – 0.9
  - Flow Ratio for Side Cooler 2 – 0.5
  - Flow Ratio to Side Stripper 1 – 0.06
  - Flow Ratio to Side Stripper 2 – 0.4
  - Flow Ratio to Side Stripper 3 – 0.9
  - Flow Ratio to Side Stripper 4 – 0.35
  - Return 68% of the liquid distillate to the column as reflux.
- Remove 90 MMBtu/hr of heat from Side Cooler 1.
- Remove 55 MMBtu/hr of heat from Side Cooler 2.
- Use 60 psia superheated steam at 700°F in the following quantities:
  - Main column: 23,000 lb/hr
  - Side Stripper 1: 220 lb/hr
  - Side Stripper 2: 1,800 lb/hr
  - Side Stripper 3: 2,600 lb/hr
  - Side Stripper 4: 2,200 lb/hr

#### Conditions

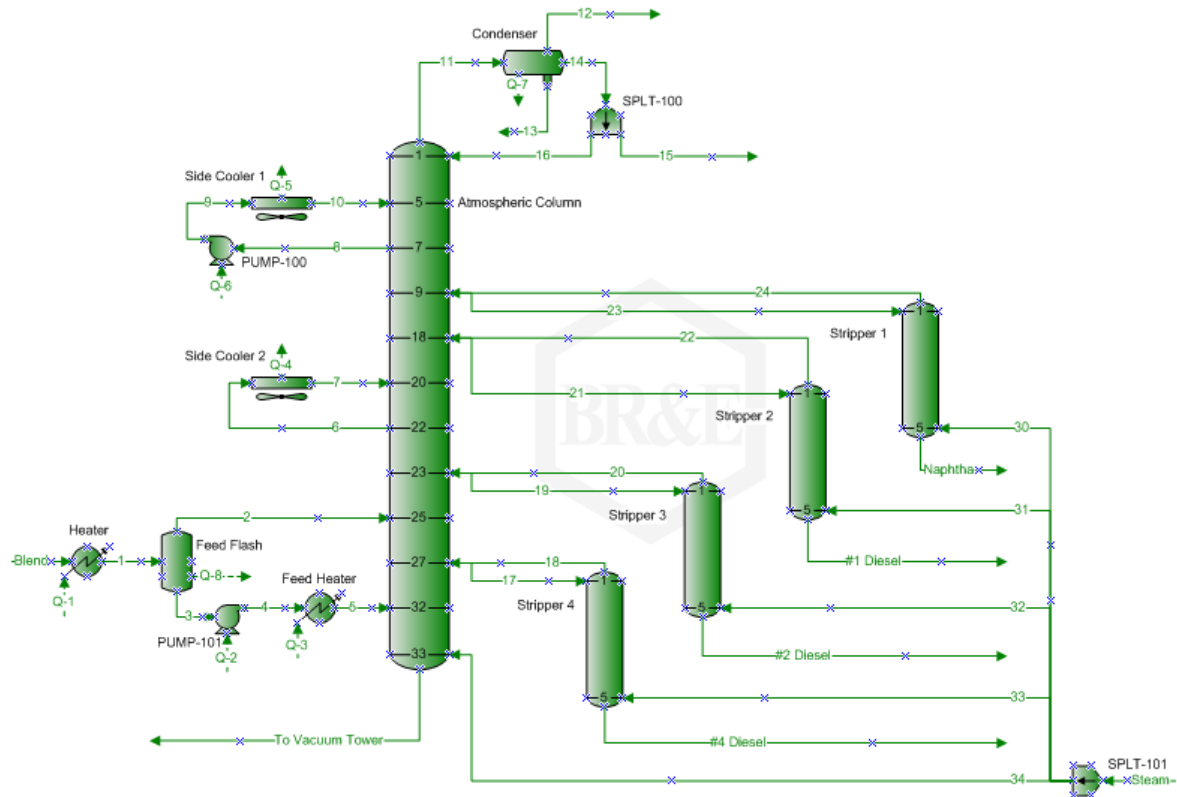
Temperature	230 °F
Pressure	85 psia
Flow	200,000 bbl/d

#### TBP Data

	Oil A	Oil B
<b>Vol. %</b>	T (°F)	T (°F)
<b>2</b>	60	60
<b>10</b>	209	241
<b>20</b>	280	358
<b>30</b>	359	479
<b>40</b>	437	586
<b>50</b>	507	692
<b>60</b>	582	800
<b>70</b>	669	916
<b>80</b>	772	1067
<b>85</b>	830	1159
<b>93</b>	1000	1329
<b>100</b>	1500	1500

#### Light Ends

<b>Ethane</b>	0.3	0.2
<b>Propane</b>	0.7	1.2
<b>i-Butane</b>	1.3	2.2
<b>n-Butane</b>	2.5	3.1
<b>i-Pentane</b>	3.5	3.6
<b>n-Pentane</b>	4	3.9



## QUESTIONS

### PART 1:

1. What is the overall specific gravity of the blended crude oil?
2. Which correlation was used to calculate molecular weight?
3. What is the Flash Point of the #1 Diesel Product?
4. What is the maximum column diameter needed for 80% Flooding with 2 ft Tray Spacing and 3 inch Weir Height on each stage?
5. What fraction of the heat removal is accomplished through the pumparounds versus pumparounds plus overhead condenser?

### PART 2:

Raise the pumparound duties to 100 MMBtu/hr each and calculate a new column diameter.

Add inactive column specifications for:

- |                                       |                      |                      |
|---------------------------------------|----------------------|----------------------|
| a. Naphtha Flash Point                | d. #1 Diesel D86 90% | g. #4 Diesel D86 10% |
| b. Naphtha D86 90% Distillation Point | e. #2 Diesel D86 10% | h. #4 Diesel D86 90% |
| c. #1 Diesel Flash Point              | f. #2 Diesel D86 90% |                      |

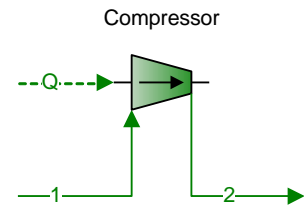
Make the #2 Diesel Product Flow Ratio an Active Estimate. Activate the specification for #2 Diesel D86 90% and set the target to 510 °F.

## EXERCISE 11 IMPORT/EXPORT FROM EXCEL

In this exercise, you will use ProMax interactions with Excel to perform some external calculations using a spreadsheet. To activate the Import/Export functionality in ProMax, you first need to add an Excel sheet to the project through the ProMax menu. Any value in ProMax's Project Viewer is available for exporting to Excel, but import is available only for *blank* cells in the Project viewer.

### PART 1: OPERATION COST

Set up the first stage of a compression system as shown in the diagram. The compressor is being fed with 100 lbmol/hr pure methane at 120 °F and 20 psia. Embed an Excel sheet to the project and setup ProMax to import the compressor's *polytropic efficiency* and the *discharge pressure* from Excel, and export the *compressor's power* (in kW) from ProMax to Excel. Set the efficiency and the output pressure to 80% and 100 psia, respectively, through Excel.



Calculate the compressor operating cost assuming a price of \$0.06/kWh, 4200 operation hours per year, 85% running time, and 90% loading. Use the following expression:

$$Cost = \frac{(power) \cdot (operation\ hours) \cdot (\$ \text{ per kWh}) \cdot (fraction\ running\ time) \cdot (fraction\ loading)}{(efficiency)} \quad (1)$$

### QUESTIONS

1. What is the annual operation cost for running the compressor at 80% efficiency? What will be the cost if the output pressure is increased to 110 psia?
2. If the compressor efficiency drops to 70%, what will be the annual operation cost to run the compressor at 100 psia discharge pressure?

### PART 2: BRAKE POWER

The compressor's brake power (in horsepower) can be estimated using the following equation:

$$P_{bhp} = \frac{\gamma \cdot Q \cdot h}{33000} \cdot \left( \frac{1}{\eta_p} \right) \quad (2)$$

Where  $\gamma$  = mass density (lb/ft<sup>3</sup>),  $Q$  = inlet actual volumetric flow (ft<sup>3</sup>/min),  $h$  = polytropic head (ft) and  $\eta_p$  = polytropic efficiency (fractional). Use ProMax to export the required variables for equation (2) and calculate  $P_{bhp}$  for the compressor in Excel.

### QUESTIONS

3. What is the brake power calculated by ProMax? What is the value calculated with the equation above?

## EXERCISE 12 SCENARIO TOOL WITH METHANOL INJECTION

Use the Scenario Tool available with ProMax to study using methanol injection for the prevention of hydrates. This simple scenario will compare the hydrate prediction temperatures for the given stream at various methanol injection levels.

Information on loading and using the Scenario Tool can be found on page 30, "Using the Scenario Tool in ProMax".

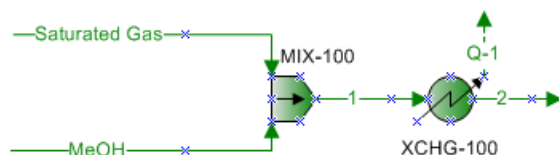
### PROCESS INFORMATION

#### Conditions:

Temperature 100°F  
Pressure 950 psig  
Flow Rate 30 MMSCFD

#### Process Information:

- The methanol is added at 80°F and 950 psig.
- The cooler XCHG-100 cools stream 2 to 15°F.
- Vary the MeOH from 15 to 195 lb/h.



Composition	Mole%
CO <sub>2</sub>	2
Methane	85.9
Ethane	5
Propane	5
n-Butane	1
n-Pentane	0.5
n-Hexane	0.3
n-Heptane	0.2
Water	0.1

### QUESTION

1. If the downstream pipeline requirement states that the gas must have a solid formation temperature of less than 0°F, what is the optimal feed rate of methanol?

## EXERCISE 13 SCENARIO TOOL WITH AMINE ABSORBER

Finding the ideal flow rate of an amine acid gas absorber unit includes studying several variables at different flow rates. The sweet gas composition is certainly important, so you know you can meet the specifications required downstream, but it is not the only variable to consider. Some other variables to consider:

- Fraction Flood – If this is an existing tower, the flooding on the trays is important to track.
- Rich Loading – especially with H<sub>2</sub>S, if this is too high, there may be severe corrosion problems.
- Lean and Rich Approach to equilibrium in the tower – if either of these is  $\geq 100\%$ , any perturbation of the inlet feed could cause acid gas slip, and subsequently the sweet gas to no longer be within specifications.
- Regeneration costs and sizing of towers and reboilers – for this study we are ignoring the regeneration.

### PROCESS INFORMATION

Using our Scenario Tool, track the *Sweet Gas H<sub>2</sub>S Content*, *H<sub>2</sub>S Lean Approach*, *H<sub>2</sub>S Rich Approach*, *Fraction Flooding on stage 1*, and the *Rich Loading* for a 40 wt% MDEA solution with flow rates from 150 sgpm to 280 sgpm in steps of 10 sgpm. Leave the regenerator disconnected from the system for the scenario runs.

### QUESTIONS

1. At approximately what flow rate of amine does the rich loading reach 0.45 mol/mol?
2. At approximately what flow rate of amine does the rich approach become less than 85%?
3. At approximately what flow rate of amine does the absorber reach the H<sub>2</sub>S specification of 4 ppm?

## EXERCISE 14 SIMPLE SPECIFIERS

Continuing with our absorber from Exercise 13 “Scenario Tool with Amine Absorber”, we will now create a more robust project. The Excel sheet can be ignored for these exercises; please see Exercise 13 Scenario Tool with Amine Absorber on page 53 if you are interested in how the scenarios shown were created. The changes we are about to make will have the project automatically adjust some variables to account for changes in the feed temperature and MDEA circulation rate.

We will start by creating Simple Specifiers to set one variable based on an already known variable. For more detailed instructions on specifiers, please see “Using a Simple Specifier in ProMax” on page 32.

First, connect the regenerator to the amine loop. Then, change the flow rate to be 280 sgpm of amine, if it is not already set to this.

### PART 1: LEAN AMINE TEMPERATURE

Add a Specifier to keep the lean amine contactor feed exactly 10 °F above the temperature of the sour gas feed.

#### QUESTIONS

---

1. If the feed gas temperature decreases to 90°F, what are the new sweet gas CO<sub>2</sub> and H<sub>2</sub>S compositions?

### PART 2: REBOILER DUTY

Continue using the same project as above. Now add a Specifier to automatically calculate the reboiler duty based on 1 pound of steam per gallon of solvent circulation. Use 50 psig saturated steam.

#### QUESTIONS

---

2. What are the sweet gas CO<sub>2</sub> and H<sub>2</sub>S compositions?
3. What is the mass flow of steam required?
4. What is the reboiler duty?

## EXERCISE 15 SIMPLE SOLVERS

When the variable you want to set is based on another that is not yet determined, you will need to use a Solver within ProMax. The Solver will take an initial guess from the user and reiterate until a final solution is reached. This exercise demonstrates the use of Simple Solvers on previous exercises. For more information on solvers, please see “Using a Simple Solver in ProMax” on page 33.

### PART 1: AMINE RICH LOADING SOLVER

Open the unsolved Exercise 15 Simple Solvers file from the training course CD. Add a solver to automatically calculate the amine circulation rate needed to obtain a rich amine loading equal to 0.35 mole/mole. Remember to assign the best priority to your solver for the most efficient execution.

#### QUESTIONS

---

1. What is the amine circulation rate to achieve a 0.35 rich loading?
2. What are the sweet gas CO<sub>2</sub> and H<sub>2</sub>S compositions?

### PART 2: AMINE LEAN LOADING SOLVER

Delete the specifier on the steam rate and create an additional simple solver to determine the required mass flow of steam to achieve a lean loading of 0.0015 mole/mole total acid gas loading. Please review the priorities required for each solver for efficient execution of the project.

#### QUESTIONS

---

3. What are the sweet gas CO<sub>2</sub> and H<sub>2</sub>S compositions when using both solvers?
4. What is the mass flow of steam required to achieve the new lean loading?
5. What is the reboiler duty?

### PART 3: SULFUR RECOVERY TAIL GAS RATIO SOLVER

Add a solver to automatically adjust the air flow rate to obtain an H<sub>2</sub>S/SO<sub>2</sub> tail gas ratio of 2. Make note of the original air flow rate and overall sulfur recovery prior to creating this solver.

#### QUESTIONS

---

6. What is the required air flow rate? What percent increase of air flow was required?
7. What is the new overall sulfur recovery?

### PART 4: HYDROGENATION REACTOR

You must now add two solvers to calculate the required air and fuel rate to maintain an outlet temperature from the Hydrogenation reactor at 700 °F and a Hydrogen composition of 1 mole%. Although not strictly required, group these two solvers using the “grouping” function available in the Solver dialog (below where the priority is found).

#### QUESTIONS

---

8. How much air and fuel is required to meet the outlet temperature and composition?

## EXERCISE 16 USER VALUE SETS

If a desired value is not calculated by ProMax, you can specify a new user-defined value to be calculated. The following exercise is to show some examples of how this can be useful. For additional information on creating these user-defined variables and user value sets, please see User Defined Variables on page 37.

### PART 1: AMBIENT TEMPERATURE

Open Exercise 16 UDV Part 1. Add a user-defined variable to declare an ambient temperature for the current case. Set the temperature to be 65°F. Modify the project so that both air-cooled exchangers will always use this variable as their inlet temperature.

#### QUESTIONS

---

1. Display this ambient temperature on the flowsheet by your method of choice.

### PART 2: PUMP HORSEPOWER REQUIREMENTS

Create a user-defined variable to make the total pump horsepower requirement for this unit available throughout the project (there are 4 pumps). Once created, add the value as a short moniker in the project. Then add a property table to display this value on the flowsheet, based on the short moniker name.

#### QUESTIONS

---

2. Try setting an upper bound of 275 HP for this variable. What happens?

### PART 3: COST ESTIMATION

Some operations can estimate an operating cost based on the BTUs required. Create a user-defined variable to allow you to input this cost; use \$6.00/MMBtu to begin with. Add an additional user-defined variable in the same set to display the cost of running exchanger 106 based on this information.

#### QUESTIONS

---

3. What is the current operating cost of this exchanger, based only on the required energy?



## EXERCISE 17 SEPARATOR SIZING

Size a 3-phase horizontal bucket & weir separator with the following parameters.

### PROCESS INFORMATION

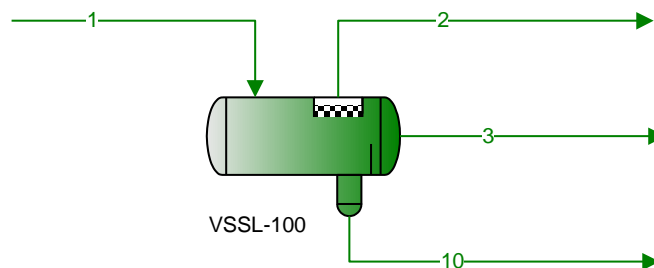
- Create a hypothetical component to represent oil with a molecular weight of 180 lb/lbmol and API gravity of 42.
- The feed conditions and composition are shown in the attached table.
- Use a K-value of 0.8 ft/s for V-L separation.
- Use a liquid droplet diameter of 150 micron for L-L separation.
- Both the light liquid and heavy liquid holdup times are 0.5 minutes and surge times are 0.25 minutes.
- The light liquid low level shutdown depth is 6 inches.
- Light and heavy liquid residence times are 3 minutes.
- Demister pad thickness and overhead clearance is 6 inches.
- Use carbon steel A516-70 for the shell and head material of construction.
- Design temperature is 200 °F and MAWP is 450 psia.
- Corrosion allowance is 0.0625 inches.
- Use ellipsoidal heads.

#### Inlet Conditions

Temperature	155 °F
Pressure	415 psia
Flow Rate	58,225 lbmol/hr

#### Composition Mole%

Methane	4.9
Ethane	1.9
Propane	1.5
n-Butane	1.0
n-Pentane	0.5
Water	84.5
Oil	5.7



### QUESTIONS

1. What is the calculated L/D ratio?
2. In the range  $1.5 < L/D < 6$ , what is the smallest (by mass) separator that will meet design requirements? What is the mass when the vessel is filled with water?
3. What are the shell and head thicknesses?
4. What is the settling compartment length?

## EXERCISE 18 HEAT EXCHANGER RATING

### PART 1: AIR COOLER EXCHANGER RATING

Using the heat exchanger specification sheet on page 59, rate the fin fan heat exchanger used to cool the lean amine before entering the amine contactor.

#### PROCESS INFORMATION

---

- This will require creating a second side to the exchanger by connecting a second single-sided exchanger to the first via a common energy stream.
- “Air” is not a component in ProMax, and must be created from its constituent components – at a minimum nitrogen and oxygen, and additionally water, argon, carbon dioxide and other lesser components, if desired.
- The rating option is available once you have connected the exchangers with a common energy stream (or if you have replaced the single-sided air cooler icon with a double-sided exchanger). This option is found in the Project Viewer of the heat exchanger under the Process Data Tab at the bottom. Check the box for “Enable Rating”, and select the correct exchanger type from the drop-down list. Once you have checked this box, a new tab appears in the Project Viewer for “Rating”.

#### QUESTIONS

---

1. What is the calculated pressure drop for the process stream?
2. How can you export the heat exchanger rating to an .hexr file?

### PART 2: SHELL & TUBE EXCHANGER RATING

A shell and tube heat exchanger specification sheet is provided on page 60. Use this information to rate the Lean/Rich Exchanger in this amine unit.

#### QUESTIONS

---

1. What is the area available in the exchanger for heat transfer?
2. Display the percent over-design on the flowsheet via the method of your choice.
3. Are the tubes the supply or demand side?

<b>Specification Sheet Air Cooled Heat Exchanger</b>										
Client					Service			Item No.		
Location					Manufacturer			Inq. No.		
Unit Air Cooler					Job No.			P.O. No.		
1	Bay Size	12 ft x 4.125 ft	Type	Forced	No. Bays	1				
2	Surface Area per Unit:	Finned Tube 11251.5 ft <sup>2</sup>	Bare Tube 540.354 ft <sup>2</sup>							
3	Duty	4.49487E+06 Btu/h			MTD Eff. (Cross)	52.9476 °F				
4	Transfer Rate	Btu/(h*ft <sup>2</sup> *°F)	Finned	10.3965	Bare	216.481	Service	7.54501	Clean	10.3965
<b>PERFORMANCE DATA - TUBE SIDE</b>										
6	Fluid Name (inlet stream name):		Physical Properties of Fluid			Inlet		Outlet		
7	11					Liquid	Vapor	Liquid	Vapor	
8	Total Flow	86460.7 lb/h	Mass Flow	lb/h	86460.7			86460.7		
9	Vapor Condensed	lb/h	Temperature	°F	167.744			110		
10	Noncondensables	lb/h	Density	lb/ft <sup>3</sup>	62.9017			64.1416		
11	Inlet Pressure	1000 psig	Viscosity	cP	1.16622			2.47777		
12	Spec. Pressure Drop	5 psi	Mol. Wt.	lb/lbmol	27.2831			27.2831		
13	Calc. Pressure Drop	5.26301 psi	Spec. Heat	Btu/(lb*°F)	0.927219			0.87258		
14	Average h	421.951 Btu/(h*ft <sup>2</sup> *°F)	Th. Cond.	Btu/(h*ft <sup>2</sup> *°F)	0.233627			0.23196		
15	Fouling Resistance	0 (h*ft <sup>2</sup> *°F)/Btu	Bubble Point	°F				Pour Point	°F	
16	Avg. Latent Heat	Btu/lb	Lethal Service	Yes / No						
<b>PERFORMANCE DATA - AIR SIDE</b>										
18	Mass Flow	613358 lb/h	Act. Static Press	3 psig	Altitude					
19	Average h	43.3859 Btu/(h*ft <sup>2</sup> *°F)	Mass Velocity	4.51939 lb/(ft <sup>2</sup> *s)	Temperature In/Out (°F)		70 / 100			
20	Flow per Fan	204453 lb/h	Face Velocity	64.228 ft/s	Min. Design Ambient					
<b>DESIGN - MATERIALS - CONSTRUCTION</b>										
22	Design Pressure:		Test Pressure:		Design Temperature:					
<b>TUBE BUNDLE</b>			<b>HEADER</b>			<b>TUBE</b>				
24	Size: 12 ft x 4.125 ft x 1.29904 ft		Material:			Material: Carbon Steel A214 Wld. Tube K01807 G24, T2, W6 BPVC				
25	No./Bay:	1	Type:			Type: Straight OD: 1 in				
26	No. Tube Rows:	8	No. Passes:	6	Corr. Allow.(In/Out) in 0/0					
27	<b>Arrangement</b>	<b>Parallel</b>	<b>Series</b>	Slope wrt Horizontal: 0 °		Min. Thick. in/BWG: 0.12/11				
28	Bundles	1	Plug Mat.:			No./Bundle	172	Length	12 ft	
29	Bays	1	Gasket Mat.:			Pitch	2.25 in	30 Triangle		
30	Bundle Frame:		Corrosion Allow:			<b>FIN</b>				
31	<b>MISCELLANEOUS</b>		In Nozzle No./Diam.:			Material: Aluminum 1100 B209 Plate, sheet A91100 O T4 BPVC				
32	Struct. Mount.	Grade / Piperack	Out Nozzle No./Diam.:			OD: 2.25 in				
33	Surface Prep:		Special Nozzles:			Stock Thk. 0.049 in				
34	Louvers:	Automatic / Manual	Rating and Facing:			No./in 10 1/in				
35	Vibration Switches:	Yes / No	TI:			Fin Design Temp.:				
36	Bug Screen:	Yes / No	PI:			Code:		Stamp: Yes / No		
37	Hail Screen:	Yes / No	Chem. Cleaning:			SPECS.				
<b>MECHANICAL EQUIPMENT</b>										
<b>FAN</b>			<b>DRIVER</b>				<b>SPEED REDUCER</b>			
40	Mfr.:	Model	Type:		Type:					
41	No./Bay:	3	rpm:	Mfr:		Mfr:				
42	Diameter:	4 ft	No. Blades:	Model:		Model:				
43	Pitch	Man. Adj. / Auto	No./Bay:		No./Bay:					
44	Angle:		hp/Driver:		AGMA Rating:					
45	Blade Material:		rpm:		Ratio:					
46	Hub Material:		Enclosure:			Support: Structure / Pedestal				
47	hp/Fan, Design:	345.501	Volt/Phase/Cycle:			/ /				
48	hp/Fan, Min. Amb.:									
49	Control Action on Air Failure:		Fan Pitch	Min / Max / Lockup	Louvers Open / Close / Lockup					
50	Degree Control of Outlet Process Temp. (Max. Cooling):									
51	Recirculation:	None / Internal / Ext. Over Side / Ext. Over End	Steam Coil:			Yes / No				
52	Plot Area:	Proposal Drawing No.								
53	Bundle Weight:	Shipping Wt:								
54	Remarks:									
55										
56										
57										
58										
59										

## Specification Sheet Shell and Tube Heat Exchanger

Client	Service	Item No.
Location	Manufacturer	Inq. No.
Unit <b>Lean/Rich Exchanger</b>	Job No.	P.O. No.

1 Size 30 in x 30 in x 25 ft	Type: NEN(Horiz)	Connected In: 1 Parallel 1 Series
2 Surf/Unit (Eff.): 3656.03 ft^2	Shells/Unit: 1	Surf/Shell (Eff.): 3656.03 ft^2

PERFORMANCE OF ONE UNIT					
		SHELL SIDE		TUBE SIDE	
		Inlet	Outlet	Inlet	Outlet
6 Fluid Name (inlet stream name)		2		Lean Amine	
7 Mass Flow, Total	lb/h	93729.2		86101.9	
8 Mass Flow, Vapor	lb/h		2307.94		
9 Mass Density, Vapor	lb/ft^3		0.526206		
10 Dynamic Viscosity, Vapor	cP		0.0178628		
11 Molecular Weight, Vapor	lb/lbmol		38.9562		
12 Mass Cp, Vapor	Btu/(lb*°F)		0.245671		
13 Thermal Conductivity, Vapor	Btu/(h*ft*°F)		0.0133241		
14 Mass Flow, Liquid	lb/h	93729.2	91421.3	86101.9	86101.9
15 Mass Density, Liquid	lb/ft^3	66.5269	63.9795	60.1866	62.8622
16 Dynamic Viscosity, Liquid	cP	1.87892	0.774631	0.517245	1.17856
17 Molecular Weight, Liquid	lb/lbmol	27.9925	27.795	27.3413	27.3413
18 Mass Cp, Liquid	Btu/(lb*°F)	0.819994	0.944002	1.01313	0.928642
19 Thermal Conductivity, Liquid	Btu/(h*ft*°F)	0.207605	0.213263	0.229537	0.23309
20 Temperature	°F	131.372	210	257.328	165.685
21 Noncondensables	lb/h				
22 Liquid Vaporized	lb/h		2307.94		
23 Vapor Condensed	lb/h				
24 Latent Heat	Btu/lb	190.841	545.459		
25 Inlet Pressure	psig		85.3041		16
26 Velocity	ft/s		0.503036		0.716337
27 Average h	Btu/(h*ft^2*°F)		258.488		144.982
28 Pressure Drop, Allow/Calc	psi		5 / 0.366343		5 / 4.28102
29 Fouling Resistance (min)	(h*ft^2*°F)/Btu		0.002		0.001
30 Heat Exchanged:	7.66283E+06 Btu/h	MTD:	36.5035 °F	CMTD:	36.5035 °F
31 Transfer Rate	Btu/(h*ft^2*°F)	Serv:	57.4177	Clean:	79.2504
				Calc:	63.275

CONSTRUCTION OF ONE SHELL			SKETCH (BUNDLE/NOZZLE)			
		SHELL SIDE	TUBE SIDE			
34 Pressure (Design/Test)		/	/			
35 Design Temp. (Min/Max)		/	/			
36 No. Passes per Shell		1	3			
37 Corrosion Allowance (Iner/Outer)	in	/	0/0			
38 Connections	Inlet/Rating	10/	14/			
39 Size (in)	Outlet/Rating	10/	14/			
40 & Rating	Intermediate/Rating	/	/			

41 Tube No.: 760	OD: 0.75 in	Thk/BWG: 0.065 in/16	Length: 25 ft	Pitch: 0.9375 in	30 Triangle
42 Tube Type: Plain		Tube Material: Carbon Steel A214 Wld.		Fin Material:	
		Tube K01807 G24, G35, T2, W6 BPVC			
43 No. Fins ():		Fin Thickness:		Fin Height:	
44 Shell:		Shell ID: 30 in		Shell OD:	
45 Channel:		Channel ID: 29.3951 in		Channel OD:	
46 Channel Cover:		Tubesheet-Stationary:		No	
47 Tubesheet-Floating: Yes		Floating Head Cover:		Impingement Protection:	TEMA Required
48 Baffles-Cross: 17		Diam. Cut: 34 %	Spacing Inlet: 12 in	Central: 18 in	Outlet: 12 in
49 Baffles-Long:			Seal Type:		
50 Supports-Tube:	U-Bend:			Type:	
51 Bypass Seal Arrngmt:			Tubesheet Joint:		
52 Expansion Joint:			Type:		
53 rho v^2 Inlet Nozzle: 34.2526 lb/(ft*s^2)		Bundle Entrance:		Bundle Exit:	
54 Gaskets-Shell Side:		Tube Side:		Float Head:	
55 Code Requirements:		Tema Class:		U-Stamp:	
56 Weight/Shell:		Water Filled:		Bundle:	

57 Remarks:
58
59
60

## ADDITIONAL EXERCISES

The following is a list of various additional exercises that you may work for further experience with ProMax. The projects are all available in pre-drawn .pmx files from the course materials.

### EXERCISE 19 MIXED AMINES

**Goal:** Sweet Gas with < 0.5 mol% CO<sub>2</sub> and 100 ppm (mol) H<sub>2</sub>S.

**Process Information:**

- Use 100 sgpm of 30 wt% MDEA / 15 wt% DEA
- Absorber: 21 real trays,  $\Delta P = 4$  psi,  $D=3.5$  ft, weir height = 3 in, tray spacing = 2 ft
- Stripper: 20 real trays, operating  $P=24.4$  psia,  $\Delta P = 5$  psi, condenser = 120°F, reboiler = 5.5 MMBtu/hr
- Flash tank operates at 80 psia

**Questions:**

1. What is the rich amine loading?
2. What is the makeup rate of water, MDEA, and DEA?
3. What is the liquid residence time on a tray in the absorber?

Inlet Conditions	
Temperature	100 °F
Pressure	500 psia
Flow Rate	25 MMSCFD

Composition	Mole%
H2S	0.1
CO2	3.3
Methane	72.4
Ethane	13.3
Propane	7.5
n-Butane	2.7
n-Hexane	0.7
100% water saturated	

### EXERCISE 20 ACTIVATED MDEA FOR ACID GAS REMOVAL

**Goal:** Compare sweetening results using activated MDEA with the results using basic MDEA.

**Process Information:**

- Process set-up is identical to Exercise 3 Simple MDEA Sweetening Unit; the unsolved version of this exercise is identical to the solved version of Exercise 3
- Add piperazine as a component in the environment, then modify the Make-up/Blowdown block to maintain 3% piperazine in addition to the 40% MDEA

**Question:**

1. How does the H<sub>2</sub>S and CO<sub>2</sub> absorption compare? What caused the results to shift this way?

### EXERCISE 21 PHYSICAL SOLVENT ACID GAS REMOVAL

**Goal:** Sweet Gas with 3% CO<sub>2</sub>.

**Process Information:**

- The flash tanks should operate at 250 psia, 25 psia and 5 psia
- The first flash vapor is compressed and mixed with the inlet
- Circulate 325 sgpm of DEPG (make-up pure DEPG)
- Chill the lean solvent to 45°F before entering the contactor

Inlet Conditions	
Temperature	95 °F
Pressure	950 psia
Flow Rate	9 MMSCFD

Composition	Mole%
Methane	65
CO <sub>2</sub>	35
100% water saturated	

**Question:**

1. Try various chiller temperatures to see how this affects the treated gas and acid gas compositions.

## EXERCISE 22 DEHYDRATION WITH STRIPPING GAS

**Goal:** See the improvement using stripping gas will give to the Exercise 6 Glycol Dehydration Unit model.

**Process Information:**

- Modify this process to feed 18 SCFM of dry gas as stripping gas into the reboiler (approximately 3 SCF / gallon glycol circulation). Reduce the pressure to 20 psig, and then preheat the stream to 400°F.

**Questions:**

1. What is the new water content of the dry gas?
2. What is the impact of BTEX emissions from the flash tank and regenerator?

## EXERCISE 23 ETHYLENE GLYCOL INJECTION

**Goal:** Prevent solids when processing a 0.7 gravity gas using EG.

**Process Information:**

- Circulate 500 lb/hr EG solution
- Operate the LTS at -5°F
- Heat the LTS liquids temperature to 30°F so emulsions forming at low temperature will separate in the oil/glycol separator
- Operate the oil/glycol separator at 265 psia
- Regenerate the EG solution to 80 wt% using an atmospheric regenerator. A reflux ratio of 0.15 is sufficient
- Sales gas temperature from the gas/gas exchanger is 100°F

Inlet Conditions	
Temperature	110 °F
Pressure	1000 psia
Flow Rate	25 MMSCFD
Composition	
Methane	86.05
Ethane	6.06
Propane	3.39
i-Butane	0.84
n-Butane	1.36
n-Pentane	2.30
100% water saturated	

**Questions:**

1. What is the solids formation temperature of the low temperature separator feed?
2. What is the water dew point (or freeze out temperature) of the sales gas?

## EXERCISE 24 CO<sub>2</sub> REMOVAL WITH NaOH

**Goal:** Simulate CO<sub>2</sub> removal using a caustic solution.

**Process Information:**

- Use 5 sgpm of 7 wt% NaOH solution
- Select the Caustic property package

**Questions:**

1. Using the ionic info analysis information, determine how much Na<sub>2</sub>CO<sub>3</sub> will be formed.
2. What is the CO<sub>2</sub> content of the fuel gas in ppm?
3. What are the respective CO<sub>2</sub> contents when the NaOH circulation is decreased to 4 sgpm, then 3 sgpm?
4. What is the liquid viscosity of the rich caustic solution?

Inlet Conditions	
Temperature	100 °F
Pressure	165 psia
Flow Rate	15 MMSCFD
Composition	
CO <sub>2</sub>	0.1
Nitrogen	10
Hydrogen	11
Methane	40
Ethylene	17
Ethane	16
Propylene	0.8
Propane	3.9
n-Butane	1.2

## EXERCISE 25 MERCAPTAN REMOVAL FROM LPG USING NAOH

**Goal:** Simulate mercaptan removal using a caustic solution.

**Process Information:**

- Use 1 sgpm of 10 wt% NaOH solution; assume there is residual methyl mercaptan in the caustic of 0.01 wt%
- The caustic solution should be cooled to 80 °F
- Specify a two stage LLE column

**Inlet Conditions**

Temperature	80 °F
Pressure	300 psia
Flow Rate	33 sgpm

Composition	Mole%
Propane	99.973
Methyl Mercaptan	0.027

**Questions:**

1. What percent recovery of CH<sub>3</sub>S is achieved in the absorber?
2. What is the liquid viscosity of the lean caustic solution feeding the column?

## EXERCISE 26 MEA FLUE GAS CO<sub>2</sub> CAPTURE

**Goal:** Reduce CO<sub>2</sub> to <1% mol in an inlet flue gas stream.

**Process Information:**

- The gas is first treated in a 3-stage equilibrium caustic SO<sub>2</sub> scrubber (10 sgpm of 10% wt NaOH).
- A 4-stage TSWEET Kinetics tower is sufficient for the absorber, using 2' spacing and 2" weir heights.
- Circulate 1300 sgpm of 28.2% MEA; cool to 125°F
- Strip with 0.8 lb/gal of 60 psia saturated steam, and a 120 °F condenser. The regenerator operates at 10 psig.

**Inlet Conditions**

Temperature	125 °F
Pressure	16 psia
Flow Rate	50 MMSCFD

Composition	Mole%
H <sub>2</sub> O	11.8
CO <sub>2</sub>	12.8
O <sub>2</sub>	5.6
N <sub>2</sub>	69.8
SO <sub>2</sub>	0.01

**Questions:**

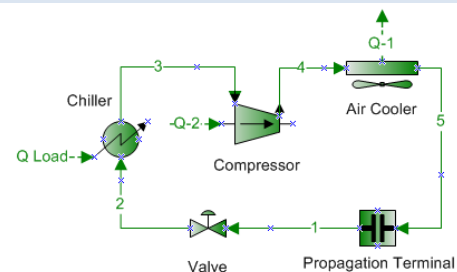
1. Why is the scrubber required? If it is not modeled, what happens to the simulation?
2. Why does the cooler not need to keep the amine 10°F above the feed gas temperature?
3. What is the diameter of the column? What is the rich loading?

## EXERCISE 27 REFRIGERATION LOOP

**Goal:** Use the Propagation Terminal in ProMax to determine the required refrigerant flow.

**Process Information:**

- Use 100% propane as the refrigerant
- Compress to 250 psia, then cool to 120F
- Expand to 35 psia across the valve
- The Q-Load stream can connect to any chiller in your process. Use 10 MMBtu/hr for this example.



**Questions:**

1. What is the required flow rate of propane?
2. What is the compressor HP?

## EXERCISE 28 FRACTIONATION TRAIN

**Goal:** Fractionate the liquids from a demethanizer into ethane, propane, butanes, and a C<sub>5+</sub> condensate.

**Process Information:**

- Deethanizer
  - An initial guess is required for column convergence; use 99% ethane recovery in the top
  - The column operates at 300 psia with a  $\Delta P=7$ psi
  - Ethane product exits at a 65°F condenser temperature
  - Specify a 0.04 C<sub>2</sub>/C<sub>3</sub> ratio in the bottoms product
- Depropanizer
  - The exchanger cools the feed to 180°F
  - The column operates at 205 psia with a  $\Delta P= 3$ psi
  - Use a reflux ratio of 2
  - 99.9% of the C<sub>3</sub> is to be recovered in the vapor distillate
  - Use an initial guess of 98% i-C<sub>4</sub> recovery in the bottoms
- Debutanizer
  - The condenser is sub-cooled and operates at 160F
  - Column pressure is 150 psia with a  $\Delta P= 5$  psi
  - Recover 99.9 mol% n-C<sub>4</sub> in the overhead product
  - Use a boil-up ratio of 4
  - Use an initial guess of 99.9 mol% recovery of i-C<sub>5</sub> in the bottoms
- Butane Splitter
  - The column operates at 135 psia with a  $\Delta P= 20$ psi
  - Use a total condenser with the i-Butane product sub-cooled to 70F
  - Use a boil-up ratio of 11.5
  - The bottoms product purity specification is 97.5 mol% n-C<sub>4</sub>

**Inlet Conditions**

Temperature	80 °F
Pressure	500 psia
Flow Rate	2400 lb-mol/hr

**Composition Mole%**

Methane	0.63
Ethane	49.00
Propane	27.00
i-Butane	4.15
n-Butane	7.60
i-Pentane	2.20
n-Pentane	2.14
n-Hexane	3.80
n-Heptane	0.60
Benzene	0.12
Toluene	0.17
Ethylbenzene	0.009
p-Xylene	0.13
Nitrogen	0.051
CO <sub>2</sub>	2.40

**Questions:**

1. What is the ethane recovery in the deethanizer?
2. What is the propane recovery in the depropanizer?
3. What is the RVP of the C<sub>5+</sub> split?
4. What is the temperature difference between stages 2 and 60 of the butane splitter?



## EXERCISE 29 SIMPLE CRUDE FRACTIONATION

**Goal:** Fractionate an oil to produce a kerosene fuel with an ASTM D86 10% cut point of  $\sim 360^\circ\text{F}$  and 90% cut point of  $\sim 490^\circ\text{F}$ .

**Process Information:**

- Have ProMax generate light ends for n-C<sub>6</sub> and n-C<sub>7</sub>
- The crude feed stage is 15, and the side stripper withdraw/feed is on stage 10
- The main column operates with a total condenser and a reflux ratio of 8.5. A specification of 0% vapor or a sub-cooled condenser temperature is required in the condenser loop
- The main column has 16 ideal stages, a steam rate of 120 lb/hr (450°F, 35 psia), an operating P= 21 psia and a  $\Delta P=3$ psi
- The side stripper has 4 stages, a steam rate of 15 lb/hr (450°F, 35 psia), and a  $\Delta P=1$  psi
- The draw to the side stripper is 33 mol% of the total feed to the main column

**Questions:**

1. What is the overall specific gravity of the crude oil?
2. Which correlation was used to calculate molecular weight?
3. Does the product meet the cut point specifications?
4. What is the flash point of the product?
5. What is the kinematic viscosity of the product?
6. What is the API gravity at 60°F of the product?
7. What is the temperature on stage 6 of the main distillation column?

**Inlet Conditions**

Temperature	530 °F
Pressure	25 psia
Flow Rate	10,000 bbl/d

**ASTM D86 Data**

Volume %	Temp (°F)
0	99
5	243
10	331
20	422
30	474
40	487
50	510
60	549
70	604
80	719
90	785
100	819

## EXERCISE 30 ADDITIONAL SOLVER EXERCISES

### PIPELINE SOLVER

Start with a solved Exercise 9 Pipeline Simulation model. If inlet gas dehydration is reestablished, how much condensate can be introduced into the pipeline such that the line does not fall below 450 psia at the entrance to the facility? Limit the step size of the solver to 1000 bbl/d.

### EG INJECTION SOLVER

Start with a solved Exercise 23 Ethylene Glycol Injection. Use a solver to calculate the required EG circulation rate to maintain the solids formation temperature at  $-15^\circ\text{F}$  (10 degrees below the chiller temperature) in stream 5. What mass flow of EG is required?

### HEAT EXCHANGER SIZING SOLVER

Start with a solved Exercise 18 - Part 2: Shell & Tube Exchanger Rating. Add a solver to adjust the length of the tubes until the percent overdesign for the exchanger is equal to zero.

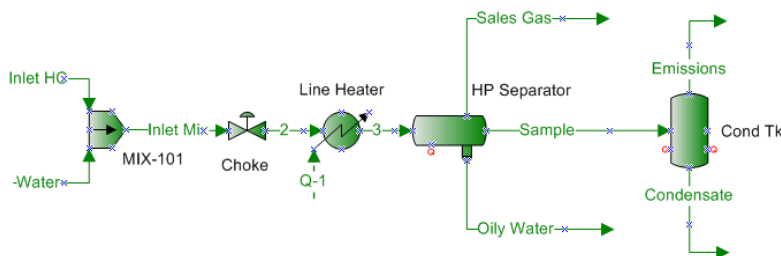
## EXERCISE 31 ENVIRONMENTAL BTEX CALCULATIONS

### CONDENSATE TANK FLASH

**Goal:** Build the following flowsheet which represents a field production and separation facility.

**Process Information:**

- In “Project Options”, set Atmospheric Pressure to 11.3 psia
- Use the Peng-Robinson property package in the environment. Add the components listed in the inlet composition and H<sub>2</sub>O
- Water rate is 0.5 sgpm
- The inlet mix goes through a choke valve and line heater and then enters the high pressure separator at 875 psig and 95F. Set the line heater pressure drop to 0 psi.
- The sample line contains material that will be sampled for extended GC analysis
- The liquids leave the condensate tank at 0 psig. Do not set pressure drop in the condensate tank



**Inlet HC:**

**Conditions**

Temperature	115 °F
Pressure	2000 psig
Flow Rate	1.04 MMSCFD

**Inlet HC:**

Composition	Mole%
Methane	90.2
Ethane	6.3
Propane	1.2
i-Butane	0.06
n-Butane	0.08
n-Pentane	0.13
n-Hexane	0.15
n-Heptane	0.5
n-Octane	0.2
n-Nonane	0.17
n-Decane	0.73
Benzene	0.03
Toluene	0.13
Ethylbenzene	0.012
m-Xylene	0.137

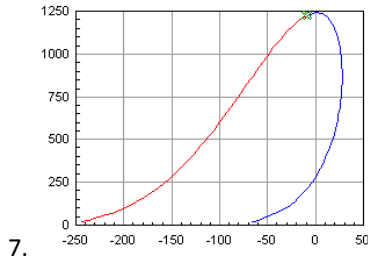
**Questions:**

1. What is the molecular weight of the inlet HC feed?
2. How much heat in BTU/hr must be supplied to the line heater?
3. What mole fraction of the HP Flash feed left as a vapor?
4. How many barrels/day of liquid condensate are produced?
5. What is the API gravity of the condensate?
6. How many tons/yr of BTEX leave with the condensate tank emissions? Use the “Sum Components” ProMax Property Stencil.
7. Prepare a Phase Envelope Analysis of the Sales Gas. What are the critical temperature and pressure?
8. Select the “Hydrate Curve” option in the phase envelope from the previous question. At what temperature will hydrates form if this stream remains at 875 psig?
9. What are the Reid Vapor Pressure (RVP) and True Vapor Pressure (TVP) of the condensate?
10. Using a combustion analysis, determine the rate of oxygen required (lbmol/hr) to completely combust the emissions stream.

## SOLUTIONS

### EXERCISE 1

- 26.9998 lb/lbmol
- 517.91 hp; 222.5 F; 29415 ft
- 49.9 °F, 80 °F
- 0.45 MMBtu/h
- 10.1 °F
- 522.1 bbl/d; 4.31 MMSCFD



- 8.
- 
- 1238.4 psia, -9.7 °F; 891.4 psia
  - 106.2 psi; 106.7 psig
  - 3 in Nominal Pipe Size; 4.89 psi/(100 ft); 82.1 ft/s

### EXERCISE 2

- 92.5 ft; 19.5 hp
- 26.1 MMBtu/h; 47.1 °F; 546539 Btu/(h\*°F)
- 237.1 °F
- H<sub>2</sub>S = 100%; NH<sub>3</sub> = 99.4%
- Tankage pH = 7.45; Stripped pH = 8.81
- 4 in Nominal Pipe Size; 2.95 psi/100 ft; 257.2 ft/s
- 1450 psig, 242.1 °F

### EXERCISE 3

- (mol) 3.3 ppm H<sub>2</sub>S, 1.55% CO<sub>2</sub>
- 0.0007; 0.00151; and 0.00239
- 1.54 seconds, 72.7% flood
- 9.2%; 80.2%

### EXERCISE 4

(no questions)

### EXERCISE 5

- 5.7 °F. Changing from PR to SRK. Be consistent with the vapor phase package.
- Pressure, Molar Flow, Molar Enthalpy, and Composition
- MDEA only; MDEA, H<sub>2</sub>S and EB

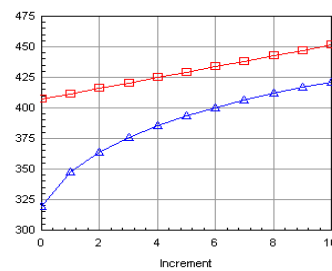
### EXERCISE 6

- 6.89 lbm/MMSCF
- 40.5 °F
- 233.5 lb/h
- 24.72 ton/yr

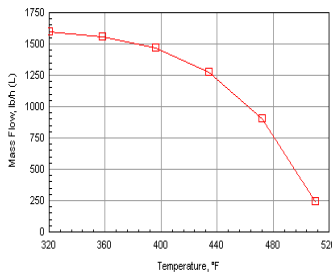
### EXERCISE 7

- 1885 °F
- H<sub>2</sub>S: 11.5lbmol/h; SO<sub>2</sub>: 0.0086 lbmol/h
- 478.5 °F
- COS: 1.09 lbmol/h; CS<sub>2</sub>: 4.80 lbmol/h
- Condenser 1 thru 4: 17.35 tonb/d; 7.11 tonb/d; 1.25 tonb/d; 0.089 tonb/d

6.



7.

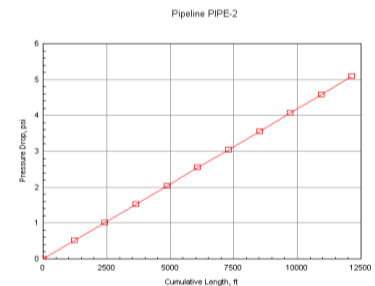
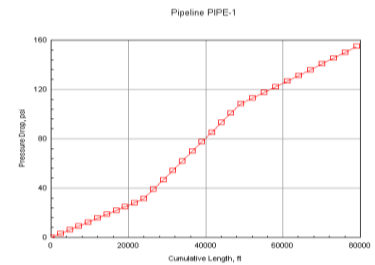


### EXERCISE 8

- 3607.8 °F
- 4.35%, 15.6 lbmol/h (w/TG from Claus); 1.73%, 6.36 lbmol/h (w/TG from table)
- Yes (conversion = 100%)

### EXERCISE 9

- 50.7 °F, 492.3 psig
- 0.11489 Btu/(h\*ft<sup>2</sup>\*°F)
- 70,000 ft in (Segment 4)
- 



### EXERCISE 10

- Bulk Specific Gravity = 0.8125
- BR&E ProMax Oil Molecular Weight Twu Class
- ASTM D93 Flash Pt = 116.4 °F
- 32.3 ft
- 39.7%

### EXERCISE 11

- \$20,180/yr; \$21,630/yr
- \$27,090/yr
- 112.323 hp; the same.

**EXERCISE 12**

1. Approximately 120 lb/hr

**EXERCISE 13**

1. At ~ 260 sgpm
2. At ~ 180 sgpm
3. At ~ 190 sgpm

**EXERCISE 14**

1. H<sub>2</sub>S = 5.0 ppm; CO<sub>2</sub> = 1.81%
2. H<sub>2</sub>S = 7.2 ppm; CO<sub>2</sub> = 1.81%
3. 16,800 lb/h
4. 15.41 MMBtu/h

**EXERCISE 15**

1. 300.7 sgpm
2. H<sub>2</sub>S = 6.8 ppm; CO<sub>2</sub> = 1.84%
3. H<sub>2</sub>S = 0.37 ppm; CO<sub>2</sub> = 1.84%
4. 40,925 lb/h
5. 37.5 MMBtu/h
6. Original airflow: 200 lbmol/h  
New: 225.5 lbmol/h; 12.8% increase
7. Original recovery: 82.7%  
New: 93.0%
8. Air: 25.5 lbmol/h; Fuel: 1.25 lbmol/h

**EXERCISE 16**

1. n/a
2. Since the total HP required is 283 hp, the program returns a warning and will not execute.
3. \$259.73 / hr, or MM\$2.275/yr

**EXERCISE 17**

1. L/D = 4.17
2. 71,059.1 lb; 231,974 lb
3. Shell: 1.467 in; Head: 1.449 in
4. 27.7 ft

**EXERCISE 18**

1. 5.26 psi
2. The "Export..." button is on the Rating tab, below the "Solve" button.
3. 3656.03 ft<sup>2</sup>
4. n/a
5. Supply (hot side)

**EXERCISE 19**

1. Rich Loading = 0.44
2. Water = 401 lb/hr; MDEA = 0.63 lb/hr; DEA = 0.023 lb/hr
3. 1.96 s

**EXERCISE 20**

1. MDEA = 3.3ppm H<sub>2</sub>S / 1.5% CO<sub>2</sub>; aMDEA = 119 ppm H<sub>2</sub>S / 0.65% CO<sub>2</sub>. The selectivity of the solution has been lowered, and the tower is beginning to be rich end pinched.

**EXERCISE 21**

1. 45F = 2.9%; 30F = 0.7%; 40F = 1.1%; 50F = 4.9%; 60F = 8.6%

**EXERCISE 22**

1. 6.1 lb/MMSCF
2. 25 t/yr vs. 24.7 t/yr

**EXERCISE 23**

1. -5.9°F
2. -17.4°F

**EXERCISE 24**

1. 174.5 lb/hr
2. 4.8e-5 ppm CO<sub>2</sub>
3. 4 gal= 4e-4ppm; 3 gal= 83ppm
4. 1.34 cP (5 gal circulation)

**EXERCISE 25**

1. 99.6% recovery
2. 2.09 cp

**EXERCISE 26**

1. SO<sub>2</sub> will destroy amine. If it feeds the tower, it will require 2 mole extra amine to makeup per mole of SO<sub>2</sub>. The model will not converge the recycle.
2. There are no hydrocarbons to condense
3. ~12.5ft; RL=0.466

**EXERCISE 27**

1. 108062 lb/h
2. 2418 hp

**EXERCISE 28**

1. 98.6%
2. 99.9%
3. 10.3 psi
4. 34°F (178.7°F-144.7°F)

**EXERCISE 29**

1. 0.831
2. BR&E ProMax Oil Molecular Weight Twu Class
3. Yes
4. 130.1°F
5. 1.518 cSt
6. 42.9
7. 300.4°F

**EXERCISE 30**

1. 4596 bbl/d
2. 733 lb/h
3. 22.6 ft

**EXERCISE 31**

1. 19.48 lb/lbmol
2. 3492.4 Btu/h
3. 86.6%
4. 23.67 bbl/d
5. 61.76
6. 1.962 ton/y
7. P<sub>c</sub>=867.23psia; T<sub>c</sub>=-86.17°F
8. 57.93°F
9. RVP=3.7 psi; TVP=4.0 psig
10. 3.25 lbmol/h

