Process Plant Design & Simulation Handbook

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ABOUT THE AUTHOR

Mr. Ajay S. Satpute is a reputed name in the Chemical Engineering field with 18+ years' experience in several industries like Oil & Gas, Chemicals, Energy, Utilities, Fertilizers, Iron & Steel, and Pulp & Paper etc. in India, Middle East, and the Far East. He has worked in the process industry in production, technical services and design department.

He has trained several process engineers in the field of process calculations and simulation.

He is an alumnus of the prestigious Indian Institute of Technology (I.I.T.), Madras with Master's Degree in Chemical Engineering.

He has shared several process calculation spreadsheets online. Over 50,000 + engineers worldwide have been benefited by his spreadsheets, articles and his guidance.

Dedicated to all my students, from whom I have learnt a lot.

ACKNOWLEDGEMENT

During the lockdown period of COVID-19 in the first week of April, my wife, Surekha, suggested, “Why don’t you write a book about plant design and simulation that process engineers can use as a working guide?”. Then, the wheels started spinning and I could not sleep that night. Thanks dear, for that push (or kick) that kept me busy for the next few months writing the book.

I’m very proud of my elder daughter, Rhea, for working on spell-check, formatting, drawing schematics & tables, numbering the figures & tables after the draft copy of this book was completed. I’m also thankful to my family members, my mom, sisters, and my younger daughter, Riena for their constant support and encouragement, not just for this book, but during the 18 years of my professional life and even before that.

Special thanks to my dear friends and process design and simulation experts, Mr. Rajesh Maguluri and Mrs. Khushboo Thakur for their time to meticulously checking the contents of the book and adding value to the same.

Many thanks to my guru, Prof. (Dr.) Dhruvprasad Mishra Sir for reviewing this book and providing valuable suggestions.

I’m grateful to those wonderful seniors, teachers who taught me everything they knew about process engineering. Without them, I would have never known how beautiful process engineering is.Many names come to my mind, Mr. Bhikaji P. Bhayye, Mr. SBVJ Rao, Prof. (Dr.) K. Krishnaiah, Mr. Atul Goswami, Mr. Sanjay B. Patil, Mr. Sudhir Kumar Mittal, Mr. S. Niraipandian, Mr. S. Chinnadurai, Mr. Raj K. Sahni, Mrs. Jayita Sen, Mr. Sivasubramanian N. and many more.

I remember my (late) dad on this day, who, as usual, would have been very proud of me.Thanks to the Almighty for everything.
Thx.

Ajay Satpute
December 2020

PREFACE

Process engineering, and especially, process design, in my opinion, is the most interesting and beautiful subject, there is. This book is an honest attempt to share the beauty of the subject with everyone. It will certainly help become an excellent process engineer. On purpose, it has been tried to keep the theoretical aspects at bay and focus mainly on practical implications of process design. Once the "how to do" part is clear, then readers will be ready for figuring out the "why" part themselves.

This is a must-have book for final year engineering students and for practicing engineers in engineering consultancies.

It must not be read like a storybook, because it is not one. Rather, it should be referred to while using spreadsheets or software and solve the problems with the help of this book.

I do not claim that this book will provide all the aspects of process design, but I can guarantee that if you follow this book thoroughly, then you will gain enough confidence to carry out any process plant design using simulation software.

It has been a great challenge for me to pen down my experience of designing, running and troubleshooting of the process plant on paper. I hope the younger generation gets benefitted by this.

Before entering process design, one must know what process engineering is. The same has been explained in

Chapter 1 - *Getting Started*

Chapter 2 - *Design condition evaluation* provides different terms and their meaning related to design pressure and temperature.

Chapter 3 - *Process deliverables* discusses major process deliverables like design basis, simulation or calculation report, operating & control philosophy, line list, datasheet, PFD, P&ID, and C&E matrix.

Nowadays there are several process simulation software which are used in process design.

Chapter 4 - *Process simulation software* provides a brief on different software.

Once the reader has a fair idea about process engineering, deliverables, and software, the actual sizing shall be initiated in **Chapter 5 - *Line sizing using Aspen HYSYS*** with line sizing in Aspen HYSYS.

Pump sizing is discussed in **Chapter 6 - *Pump sizing using Aspen HYSYS.*** Aspen HYSYS is used for the simulation

Chapter 7 - *Control valve sizing using Aspen HYSYS* provides a step-by-step procedure to carry out control valve sizing using Aspen HYSYS.

Orifice sizing using Aspen HYSYS is discussed in **Chapter 8 *Orifice sizing using aspen HYSYS.***

Chapter 9 - *Separator sizing using Aspen HYSYS* discusses separator sizing using Aspen HYSYS.

Chapter 10 - *Heat exchanger sizing using Aspen EDR* discusses heat exchanger sizing using Aspen EDR.

Distillation column sizing using Aspen HYSYS is discussed in **Chapter 11 - *Distillation column sizing using Aspen HYSYS.***

There is an important tool **- Optimizer**, in Aspen HYSYS. The same is discussed in **Chapter 12**.

PSV sizing using Aspen HYSYS is carried out in **Chapter 13 - *PSV sizing using Aspen HYSYS.***

A real project problem is solved using Aspen HYSYS in **Chapter 14 - *Process plant design using Aspen HYSYS.***

Chapter 15 - *Aspen HYSYS Dynamics - Simple problem* discusses a typical Dynamic simulation problem.

In the next chapter **Aspen HYSYS Dynamics – Project Problem**, the real project problem solved in **Chapter 14** is converted into a dynamic model and analyzed.

Typical interview questions are listed in the last chapter.

There are several exercises provided. It would help more to the reader if he/she prepares a presentation slides for each exercise and present in front of a group of process engineers.

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PROCESS PLANT DESIGN & SIMULATION HANDBOOK

Chapter 1

GETTING STARTED

Process engineering

Process engineering is the utilization of the laws of physics and chemistry to convert less useful raw materials to more useful products. This involves process plant design, operation, optimization, and troubleshooting. Process engineering is required in almost all industries like agriculture, automotive, biochemical, chemical, material development, mining, nuclear, oil & gas, petrochemical, pharmaceutical, etc.

What does a Process Engineer do?

- Design new equipment/plant as per internationally accepted engineering practices (Greenfield).
- Check the adequacy of the existing system for changed operating conditions (e.g. pressure, temperature, flow, etc.) as per internationally accepted engineering practices (Brownfield).
- Verify new processes.
- Work on optimization projects and troubleshoot plant issues.
- Use process simulation software like Aspen HYSYS or FluidFlow to model the process plant.
- Operate the process plant and equipment as per design.
- Size equipment and instrumentation to be implemented and issue relevant Process Datasheets.
- Elaborate Process Flow Diagram and Piping & Instrumentation Diagrams.
- Perform hydraulic and thermal calculations on piping systems, pipelines, flow lines in steady-state and transient scenarios.
- Define the utility requirements and design the associated systems.
- Define the quantity and quality of effluents to be disposed of to the environment.
- Participate in the preparation of the Operating Manual.
- Assess safety and environmental issues.
- Identify process hazards and participate in process safety reviews.

Skillset required for Process Engineers

- Interest in physics, chemistry and mathematics
- Analytical abilities
- Software skills
- Commercial skills
- Multi-tasking skills
- Good communication skills
- Problem-solving skills
- Tenacity

Various packages used in industry

There are mainly 3 packages/studies that are carried out in industry, namely;

- Concept / Feasibility Study
- FEED
- Detail Engineering

Concept / Feasibility Study

This is the beginning stage of any project. Before investing money in any new project, the client needs to ensure that the following concerns are addressed before the investment is justified and the wiser decision can be taken by the client.

- The process must be technically feasible, efficient, and safe.
- Select between batch or continuous plant.
- Budgetary cost of the project.
- Selling plan for the product.

Chapter 2

DESIGN CONDITION EVALUATION

The most severe combination of coincident pressures and temperatures normally determines design conditions. In general, piping up to and including DN 600 shall be designed for full vacuum at ambient temperature.

Temperature System

Operating Temperature

The operating temperature is the temperature at which the equipment is operated.

Where equipment operation may be switched from a high-pressure moderate temperature operation to a lower pressure but higher temperature one, then the option of designing for those separate operating modes may be considered (e.g. dual pressure/temperature ratings for the equipment).

Maximum Operating Temperature

The Maximum Operating Temperature (MOT) will be established for operational flexibility and required control system variations. It will be greater than or equal to the operating temperature. The MOT can be used as the basis for materials selection for long term corrosion and/or material degradation.

Upset Temperature

The upset temperature is the maximum temperature that can be reached under upset conditions assuming no barriers are in place. Typical upset scenarios include excessive process heat input (e.g. due to control failure) and loss of cooling medium to the system (e.g. due to power failure). The potential for upset temperatures exceeding the MOT due to exotherms, decompositions, or runaway reactions can be mitigated by one of the following:

- increased design temperature
- instrument safeguards

Fire exposure is an emergency condition that can result in wall temperatures higher than the equipment MOT. As all the process equipment exposed to fire will be subject to inspection, repair, or replacement, fire case temperatures will not be used for establishing design temperature. Upset conditions will be assumed to prevail only for the time required to correct the situation. These conditions will be considered both in materials selection and mechanical design, recognizing that these conditions prevail for a limited period and not indefinitely.

Design Temperature

The design temperature is used for the mechanical design (e.g. determination of minimum wall thickness) of equipment and piping. It is often referred to as the upper design temperature. It is the highest temperature to which equipment is designed at the design pressure. It will be equal to or greater than the MOT. The design temperature is typically at least 10 °C above the MOT.

Design temperature can be rounded up to the nearest 5 °C increment.

For unfired heat exchangers, the design temperature of the cold side can be set equal to the hot side to simplify safeguarding. For tubes in fired equipment, the design temperature can be either the temperature determined by the rules specified above or the calculated maximum tube skin temperature, whichever is higher.

For systems where steam out is intended, the steam out pressure/temperature combination should be specified as a separate design case. Typical steam-out conditions are a temperature of 150 °C under a full vacuum.

For systems where a design temperature has been specified at a value less than 120 °C, the Contractor may elect to designate the design temperature as 120 °C since often there is no increase in flange rating requirement.

Minimum metal temperature

The Minimum Metal Temperature (MMT) is the lowest metal temperature that equipment could reach and will be defined for all equipment, pipelines and piping systems. The MMT will be specified based upon the minimum of the following:

Chapter 3

PROCESS DELIVERABLES

Major process deliverables are discussed in this chapter.

Process Design Basis

The process design basis document is the collection of all the input parameters considered for process design. The process parameters include feed composition, flow rate, operating and design conditions, velocity criteria, pressure drop criteria, process scheme, different process scenarios etc. The client must approve a process design basis before the designer starts any calculations or simulation for process design.

Typically, this document is prepared by process engineer, checked by a senior engineer, and approved by process HOD.

Any change in process design basis will have a major impact on several documents viz. PFD, P&ID, Process calculations/simulation report, Equipment List, Heat Exchanger Thermal Design, Equipment Datasheets, Relief Valve Sizing & Datasheets, Electrical Load List etc.

Each document must undergo stringent quality checks. It starts with self-check. The person generating the document will first self-check his/her document. The same document will then be checked by senior discipline engineers. The document may also be checked by engineers from other disciplines. This checking step is called as Inter-discipline Check. The comments/corrections will be discussed amongst the project team and if those are agreed by the originator, then the same will be incorporated. If there is disagreement, then the project manager will make the final call.

A checklist is a list that guides the engineers to perform a check of the quality of the document and ensure that major criteria for the design are covered. A checklist will be specific to a specific type of project. Many companies have their checklist form specific to their projects.

A typical checklist for the process design basis document is given below;

- Correct document titles and revision
- Document number included
- Consultant standard title block and job number
- Consultant Disclaimer description block

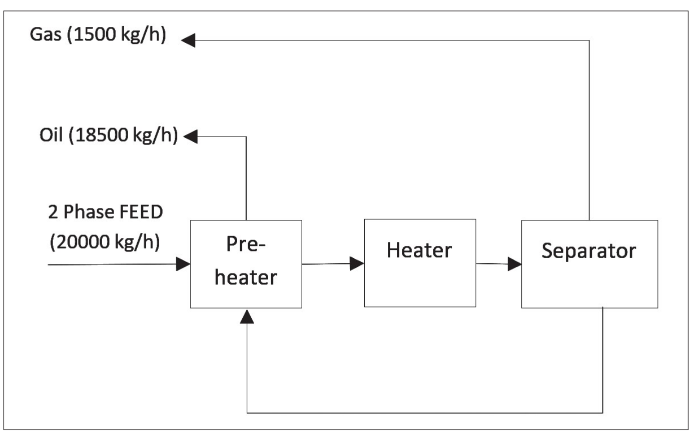
- All design information included.
- Operating and design conditions specified
- Requirements for references and are they specified
- Self-Discipline Check comments incorporated
- Inter Discipline Check commented incorporated
- Clients commented incorporated

Block Flow Diagram

A block flow diagram (BFD) is a process drawing used to simplify the basic structure of a system. It is the simplest form of the flow diagrams used in the industry. Blocks in a block flow diagram represent anything from a single piece of equipment to an entire plant.

A typical example is given below;

Figure 3.1: Block diagram



Process Flow Diagram

A process flow diagram (PFD) is a diagram commonly used in engineering to indicate the general flow of the plant process. The PFD displays the relationship between major equipment of a plant facility and does not show minor details such as piping details and designations.

Process flow diagrams of a single unit process will include the following:

- Major process piping
- Major bypass & recirculation lines
- Major equipment symbols, names, and identification numbers
- Process flow directions
- Major control loops
- Interconnections with other systems
- Stream Identification
- Heat & Mass Balance

PFDs generally do not include the following:

- Piping class or piping line numbers
- Pipe size
- Instrumentation
- Minor bypass lines
- Isolation and shut-off valves
- Maintenance vents and drains
- Relief and Safety Devices
- Pipe fittings and flanges

Exercises

a. Mr. Yashpal is a fresher in a reputed consultancy in Navi Mumbai. As his first assignment, his boss has asked him to prepare a process design basis for a cooling water supply system project. Can you advise Mr. Yashpal on how to prepare such a document?

b. Ms. Sayali needs to prepare a block diagram and PFD of the BTX separation system. How would she include in both the drawings?

c. Mr. Aditya is having trouble with the BTX system P&ID. Can you help him draw such a system?

d. Mr. Nimesh is assigned to prepare a line list for Mr. Aditya's project. Can you help him with this activity?

e. Mr. Saurabh is also a part of your team who is supposed to complete OCSP of BTX plant. He has been reassigned to some other urgent project. You are his replacement. Please submit his deliverable.

f. Mr. Pradip is preparing a cooling water pump datasheet. Can search on the internet and help him with the template.

g. Mr. Prasad is the HAZID chairman. What exactly are his job responsibilities?

h. Mr. Naresh is planning to conduct a HAZOP session for the BTX plant designed by Mr. Aditya. How exactly he will execute this activity?

Chapter 4

PROCESS SIMULATION SOFTWARE

Process simulation software is used for the design, development, analysis, and optimization of technical processes such as chemical plants, chemical processes, environmental systems, power stations, complex manufacturing operations, biological processes, and similar technical functions. There are several commercial simulation software available. A few of those are discussed below.

Aspen HYSYS

General process simulation and modeling software very commonly used in the upstream oil and gas industry is HYSYS. HYSYS is extensively used for developing PFD and mass and heat balance.

Aspen Flare System Analyzer

It is extensively used for modeling of flare or cold vent networks commonly required in upstream oil and gas. It allows determining the type of relief device and sizing of connected piping including individual tailpipes, flare sub-header, and flare the main header.

Aspen Exchanger Design and Rating

Aspen Exchanger Design And Rating (EDR) enables you to easily design and simulate the heat exchangers. Deliver the optimum heat exchanger size and rating when both cost and performance must be balanced with rigorous up-to-date integrated modeling capabilities.

FluidFlow (from Flite Software NI Ltd.)

FluidFlow is the most comprehensive and easy to use pipe flow software. It has an intelligent and easy-to-use graphical interface. FluidFlow has following modules:

- FluidFlow Liquid
- FluidFlow Gas
- FluidFlow Two-Phase
- FluidFlow Non-Newtonian & Slurry

Chapter 5

LINE SIZING USING ASPEN HYSYS

Line sizing is the most widely used process calculation activity and the most important as well. Line sizing means to find out the adequate line or pipe size for the given flow rate. There are mainly 2 line sizing criteria; velocity criteria and pressure drop criteria.

The sizing criteria for liquid piping systems will depend on the application. The function and application of the piping system will determine the sizing criterion to be selected. Where pressure drop is not a determining parameter, the size should be determined by the velocity constraints.

The velocities shall be kept low enough to prevent problems with erosion, water hammer, pressure surges, noise, and vibration, and reaction forces. In some cases, a minimum velocity is required. When determining the velocity of the medium in the lines, account should be taken for the possible generation of static electricity.

Velocity Criteria

- Pump suction line (Typical velocity ~ 1 m/s)
- Pump discharge line (Typical velocity ~ 3 m/s)
- Gas line (< 18 m/s)
- Gravity line (~ 1 m/s)
- Two-phase line ($V < V_e$)

Pressure Drop Criteria

- Sub-cooled liquids (0.25 bar / 100 m)
- Boiling Liquids (0.05 bar / 100 m)

Misc. Criteria

- PSV inlet line ($\Delta P < 3\%$ of set point pressure)
- PSV outlet or tailpipe (Mach no. < 0.7)
- Flare header (Mach no. < 0.5)
- Flare lines ($\rho V^2 < 200{,}000$ kg/ms²)

- Depressurization line (Mach no. < 0.7)
- Vent line for atmospheric tank (MABP < 0.07 bar) (MABP = Max Allowable Back Pressure)

When sizing piping, the following constraints shall be addressed:

- Required Capacity / Available Driving Pressure
- Noise / Vibration
- Pressure Surges
- Material Degradation – Erosion, Corrosion, Cavitation
- Solids Accumulation

Pipe Roughness

For all calculations of pressure drop, the following pipe roughness values should be used:

- Carbon steel (CS) corroded: 0.46 mm (0.018 inch) (Note-1)
- Carbon steel (CS) non-corroded (for relief system piping): 0.15 mm (0.006 inch)
- Carbon steel (CS) non-corroded (other systems): 0.046 mm (0.0018 inch)
- Stainless steel (SS): 0.046 mm (0.0018 inch)
- Titanium and Cu-Ni: 0.046 mm (0.0018 inch)
- Glass fiber reinforced polyester (GRP): Vendor to provide
- Polyethylene, PVC: Vendor to provide

Note 1 – The value of 0.46 mm (0.018 inch) shall be used when hydraulic calculations are performed for existing pipe installations including relief piping.

Water service

Hazen-Williams equation is used for pressure drop calculation.

The Hazen–Williams equation is an empirical relationship that relates the flow of water in a pipe with the physical properties of the pipe and the pressure drop caused by friction. It is used in the design of water pipe systems such as fire sprinkler systems, water supply networks, and irrigation systems. It is named after Allen Hazen and Gardner Stewart Williams.

The Hazen–Williams equation has the advantage that the coefficient "C" is not a function of the Reynolds number, but it has the disadvantage that it is only valid for water. Also, it does not account for the temperature or viscosity of the water.

$$h_f = 10.67\ L\ \frac{Q^{1.85}}{C^{1.85}\ d^{4.87}}$$

Where;

- h_f = head loss in meters (water) over the length of pipe
- L = length of pipe in meters
- Q = volumetric flow rate, m^3/s (cubic meters per second)
- C = pipe roughness coefficient
- d = inside pipe diameter, m (meters)

Liquid and Gas service

The pressure loss in pipe flow is calculated using Darcy-Weisbach equation (equation 1).

Equation 1: $$\Delta P = \frac{f_D\ L\ \rho\ V^2}{2d}$$

This equation is valid for both laminar and turbulent flow regimes of any fluid with fully developed and incompressible flow. It can be used for gas services as long as there is only a negligible change in gas density across the pipe length. The formula for calculating the Darcy friction factor is different for laminar (equation 2) and turbulent flow (equation 3 - Haaland equation). Laminar flow meaning Reynolds number less than 2000.

Exercises

a. Mr. Ravindra is designing a cooling water system. Can you find adequate line size for pump suction and discharge line, if the flow rate is 75 m^3/h? What input parameters will be required to solve this problem? Can you make a reasonable assumption in this case?

b. Ms. Kanchan needs to decide the natural gas line size. Operating pressure, temperature, and flow rate are 5 barg, 40 ^oC, and 2500 kg/h respectively. Can you find out the line size?

c. Mr. Sundararajan is finding it difficult to select an adequate line size for 2 phase flow (methane and decane) at 3 barg pressure and 5% vapor content. Please help him.

d. Mr. Abdul is interested in finding out energy loss in INR in your city, if 5 barg saturated steam line (6», 500 m, 12 TPH) is kept uninsulated. What do you think his approach would be?

e. Mr. Nilesh is presenting his paper on flow-induced vibration. What this paper should contain?

f. Mr. Akshay wants to learn about surge analysis. Make a presentation file to help him learn.

Chapter 6

PUMP SIZING USING ASPEN HYSYS

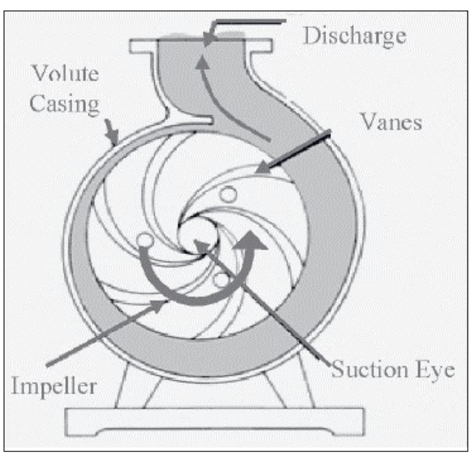
A pump is a mechanical device used to move fluids from one destination to another. Fluids can mean either liquids, gases, or a combination of liquids and solids (slurries).

Types of Pumps

Centrifugal Pump

A centrifugal pump is a roto-dynamic pump that uses a rotating impeller to increase the pressure and flow rate of a fluid. Centrifugal pumps are the most common type of pump used to move liquids through a piping system. The fluid enters the pump impeller along or near to the rotating axis and is accelerated by the impeller, flowing radially outward or axially into a diffuser or volute chamber, from where it exits into the downstream piping system. Centrifugal pumps are typically used for large discharge through smaller heads.

Figure 6.1: Centrifugal pump



Positive Displacement Pump

A positive displacement (PD) pump causes a fluid to move by trapping a fixed amount of it and then forcing (displacing) that trapped volume into the discharge pipe.

Some positive displacement pumps work using an expanding cavity on the suction side and a decreasing cavity on the discharge side. Liquid flows into the pump as the cavity on the suction side expands and the liquid flows out of the discharge as the cavity collapses. The volume is constant given each cycle of operation.

PD Pump Behavior and Safety

Positive displacement pumps, unlike centrifugal or roto-dynamic pumps, will in theory produce the same flow at a given speed (RPM) no matter what the discharge pressure. Thus, positive displacement pumps are "constant flow machines". However, due to a slight increase in internal leakage as the pressure increases, a truly constant flow rate cannot be achieved.

A positive displacement pump must not be operated against a closed valve on the discharge side of the pump, because it has no shut-off head like centrifugal pumps. A positive displacement pump operating against a closed discharge valve will continue to produce flow and the pressure in the discharge line will increase, until the line bursts or the pump is severely damaged, or both.

A relief or safety valve on the discharge side of the positive displacement pump is therefore necessary. The relief valve can be internal or external. The pump manufacturer normally has the option to supply internal relief or safety valves. The internal valve should in general only be used as a safety precaution, an external relief valve installed in the discharge line with a return line back to the suction line or supply tank is recommended.

Chapter 7

CONTROL VALVE SIZING USING ASPEN HYSYS

Three inter-dependent parameters work in tandem whenever there is a flow across a system; viz. Flow rate (Q), Pressure drop (ΔP), and Flow area (A).

It can be visualized in the below table.

Table 7.1: Interdependency of A, ΔP and Q

Flow Area	**Pressure Drop**	**Flow Rate**
Constant	Increases	Increases
Constant	Decreases	Decreases
Increases	Constant	Increases
Decreases	Constant	Decreases
Increases	Decreases	Constant
Decreases	Increases	Constant

It can be read as, e. g. for the same cross-sectional area available for flow, the flow rate will increase with the increase in pressure drop across it. This is the basic principle of fluid dynamics. A control valve also works on the same principle of A, ΔP, and Q inter-dependency.

Choked flow is a limiting condition where the mass flow doesn't increase with a further decrease in the downstream pressure environment for a fixed upstream pressure and temperature. The choked flow of gases is useful in many engineering applications because the mass flow rate is independent of the downstream pressure, and depends only on the temperature and pressure and hence the density of the gas on the upstream side of the restriction. Under choked conditions, valves and calibrated orifice plates can be used to produce a desired mass flow rate. A common example can be given as the fuel gas supplied to pilot burners at the flare stack top is tapped from a pressurized fuel gas header. This tapping usually has a restriction orifice, that leads to a pressure drop exceeding 50% of the inlet pressure. It ensures choked flow, meaning unless there is any fluctuation in fuel gas header pressure, flow to pilot burners would remain the same. Orifice shall prove to be a cheaper option in such cases as compared to the flow control valve. The 50% figure mentioned above is easy to remember. Each gas has a different value of Ideal Gas Critical Flow Pressure Ratio, like Methane is 0.54, Steam is 0.54 and Air is 0.53.

If the fluid is a liquid, a different type of limiting condition (choked flow) occurs when the restriction in the valve causes a decrease of the liquid pressure beyond the restriction to below that of the liquid's vapor pressure at operating temperature. At that point, the liquid will partially flash into bubbles of vapor and the subsequent collapse of the bubbles causes cavitation. Cavitation is quite noisy and can be sufficiently violent to physically damage valves, pipes and associated equipment. In effect, the vapor bubble formation in the restriction prevents the flow from increasing any further. If a control valve has such a cavitation problem, then the vendor may choose another valve with anti-cavitation trim (that has high F_L value or liquid pressure recovery factor). The control valve with a high value of F_L is costlier.

What is a control valve?

- A control valve is a valve used to control fluid flow by varying the size of the flow passage as directed by a signal from a controller.
- This enables the direct control of flow rate and the consequential control of process quantities such as pressure, temperature, and liquid level.

What is a Cv?

Cv is a flow coefficient that provides the capacity of a valve.

Where;

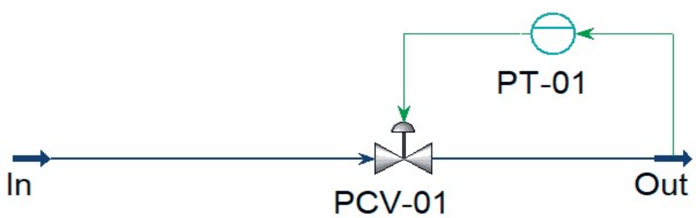
- Q : Flow rate (USgpm)
- SG : Specific gravity of the fluid (for water =1)
- ΔP : Pressure drop across the valve (psi)

In more practical terms, Cv is the volume (in US gallons) of water at 60° F that will flow per minute through a valve with a pressure drop of 1 psi across the valve.

If a valve has a Cv of 20 that means we can pass 20 gallons of water per minute with a one-pound pressure drop.

Let's consider an example given in figure 1.
Saturated steam at 800 kPa enters the pressure control valve (PCV-01). PCV-01 maintains a downstream pressure of 600 kPa. The calculated capacity (Cv) of such a control valve shall be 78.57. When the valve is 100% open then for 200 kPa pressure drop, it shall allow 5000 kg/h steam to pass through. [If we use the same valve and decrease the pressure drop across from 200 kPa to 100 kPa, what happens to the flow rate using guidelines given in table 7.1 Less pressure drop means less flow, right?]

Figure 7.1: Control valve



Out		
Temperature	163.8	C
Pressure	600.0	kPa
Vapour Fraction	1.0000	

In		
Temperature	170.4	C
Pressure	800.0	kPa
Vapour Fraction	1.0000	

PCV-01		
Pressure Drop	200.0	kPa
Cv	78.57	USGPM(60F,1psi)
Mass Flow	5000	kg/h
Percentage open	100.00	%

Chapter 8

ORIFICE SIZING USING ASPEN HYSYS

An Orifice meter is a type of flow meter used to measure the rate of flow of fluid using differential pressure measurement principle. An orifice plate is nothing but a thin hole with a hole that is placed in a pipe in which fluid flows. As fluid flows through the orifice, it causes pressure drop due to reduced flow area. More flow rate means more pressure drop. Hence for a constant flow area of the orifice, as pressure drop is measured, then flow rate can be calculated.

Figure 8.1: Orifice

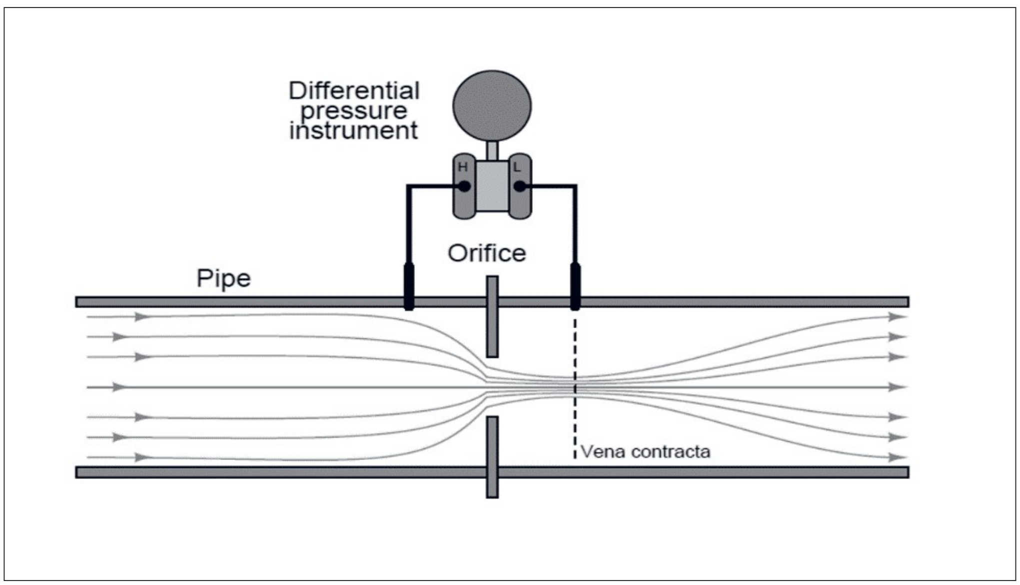


Figure 8.3: Component list

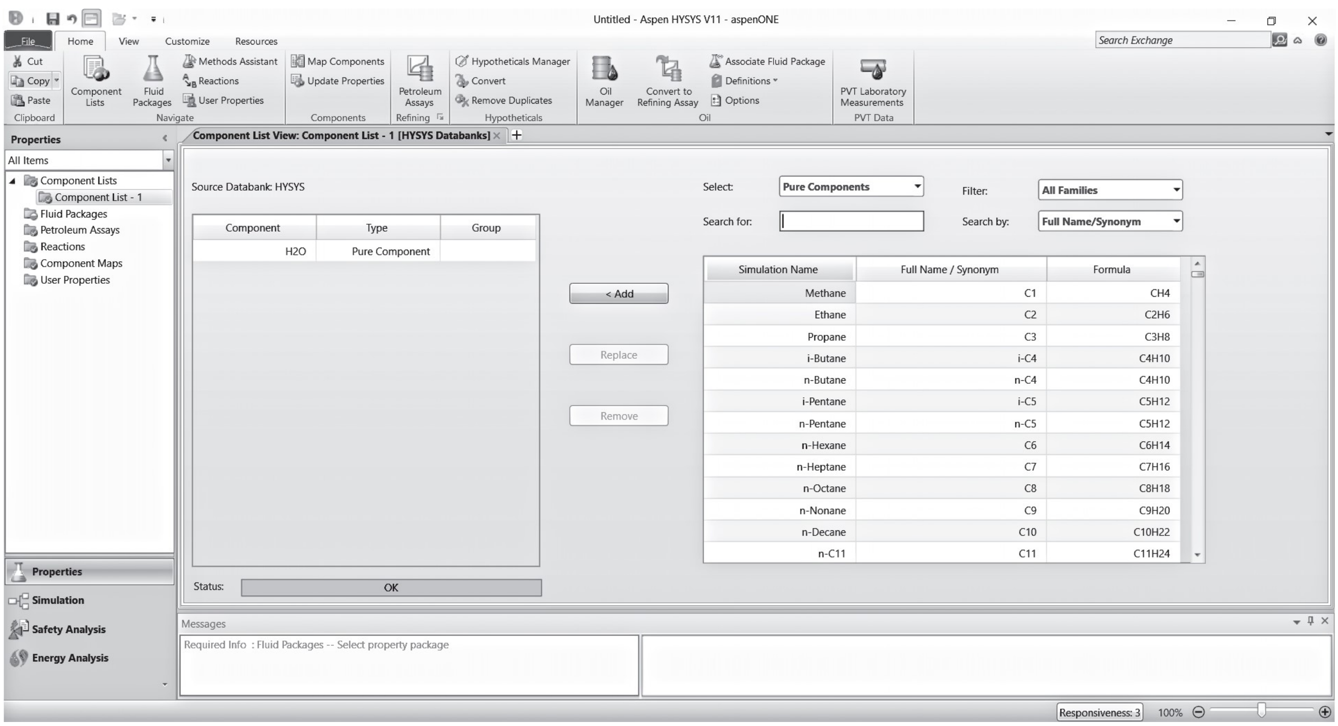
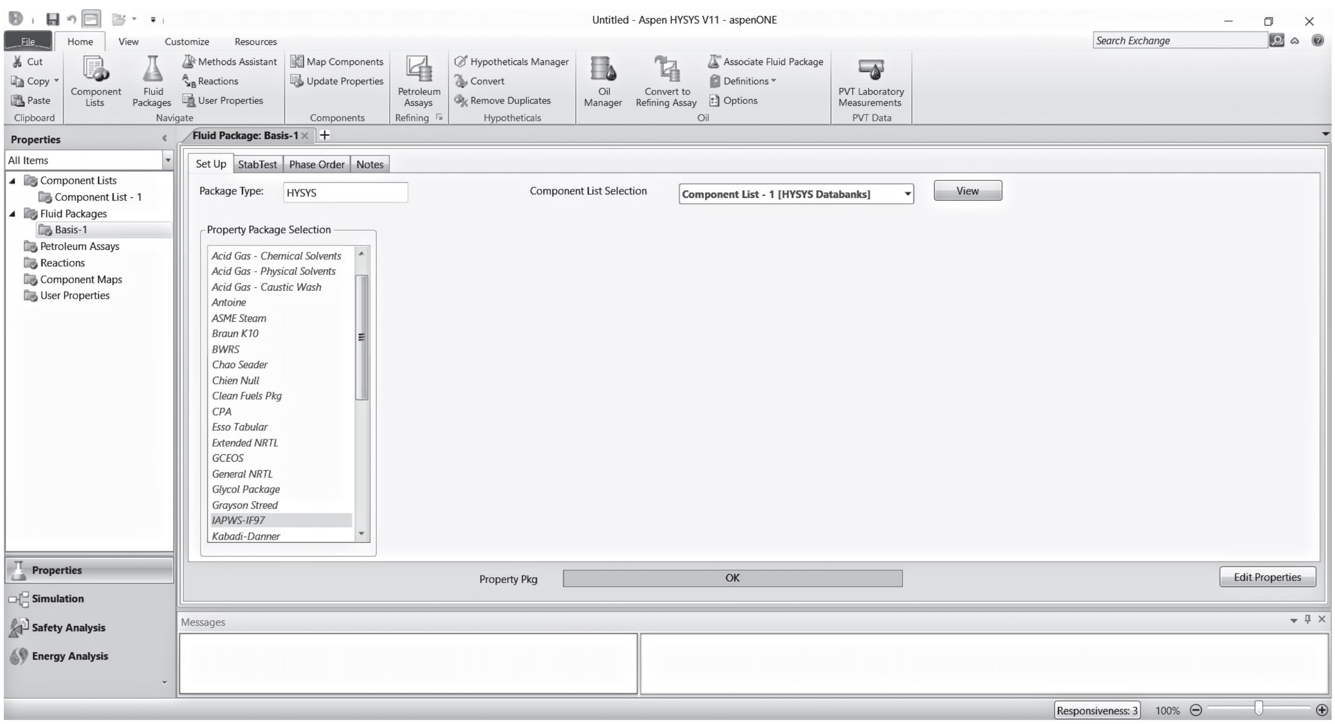


Figure 8.4: Fluid package



Chapter 9

SEPARATOR SIZING USING ASPEN HYSYS

Separator is a pressure vessel used for separating well fluids from oil & gas wells into gaseous and liquid components. A separator for petroleum production is a large vessel designed to separate production fluids into the components of oil, gas, and water.

Types of Separators

Flash Vessel

A vessel used to separate the gas evolved from liquid flashed from a higher pressure to a lower pressure.

Gas-Liquid-Solid Separator (Filter Separator)

A filter separator usually has two compartments. The first compartment contains filter-coalescing elements. The liquid particles coalesce into large droplets and when the droplets reach sufficient size, the gas flow causes them to flow out of the filter elements into the center core. The particles are then carried into the second compartment of the vessel (containing a vane-type or knitted wire mesh mist extractor) where the larger droplets are removed.

Knock out drum (Gas-Liquid Separator)

A vessel designed to handle streams with high gas to liquid ratios (GLR). The liquid is generally entrained as mist in the gas or is free-flowing along the pipe wall. These vessels usually have a small liquid collection section.

Two-Phase Separator (Gas-Liquid Separator)

A vessel that separates the well fluid into gas and liquid. A two-phase separator can be horizontal, vertical, or spherical. The liquid leaves the vessel at the bottom through a level control or dump valve. The gas leaves the vessel at the top passing through a mist extractor to remove the entrained liquid droplets in the gas.

Table 9.7: Standard separator sizes as per API

D [in] x H or L [ft]
12¾ in x 5 ft
12¾ in x 7½ ft
12¾ in x 10 ft
16 in x 5 ft
16 in x 7½ ft
16 in x 10 ft
20 in x 5 ft
20 in x 7½ ft
20 in x 10 ft
24 in x 5 ft
24 in x 7½ ft
24 in x 10 ft
30 in x 5 ft
30 in x 7½ ft
30 in x 10 ft
36 in x 5 ft
36 in x 7½ ft
36 in x 10 ft
36 in x 15 ft
42 in x 7½ ft
42 in x 10 ft
42 in x 15 ft
48 in x 7½ ft
48 in x 10 ft
48 in x 15 ft
54 in x 7½ ft
54 in x 10 ft
54 in x 15 ft
60 in x 7½ ft
60 in x 10 ft
60 in x 15 ft

Simulation

Let's solve a separator sizing problem using Aspen HYSYS.

Inlet to the separator is a mixture of Methane and n-Butane. Separator operating temperature and pressure are 80 °F and 814.7 psia respectively. The flow rate is 3221 lbmol/h. Methane 81.32 % (mole) and 18.68 % (mole) n-Butane. The fluid package is Peng Robinson.

Figure 9.6: Component list

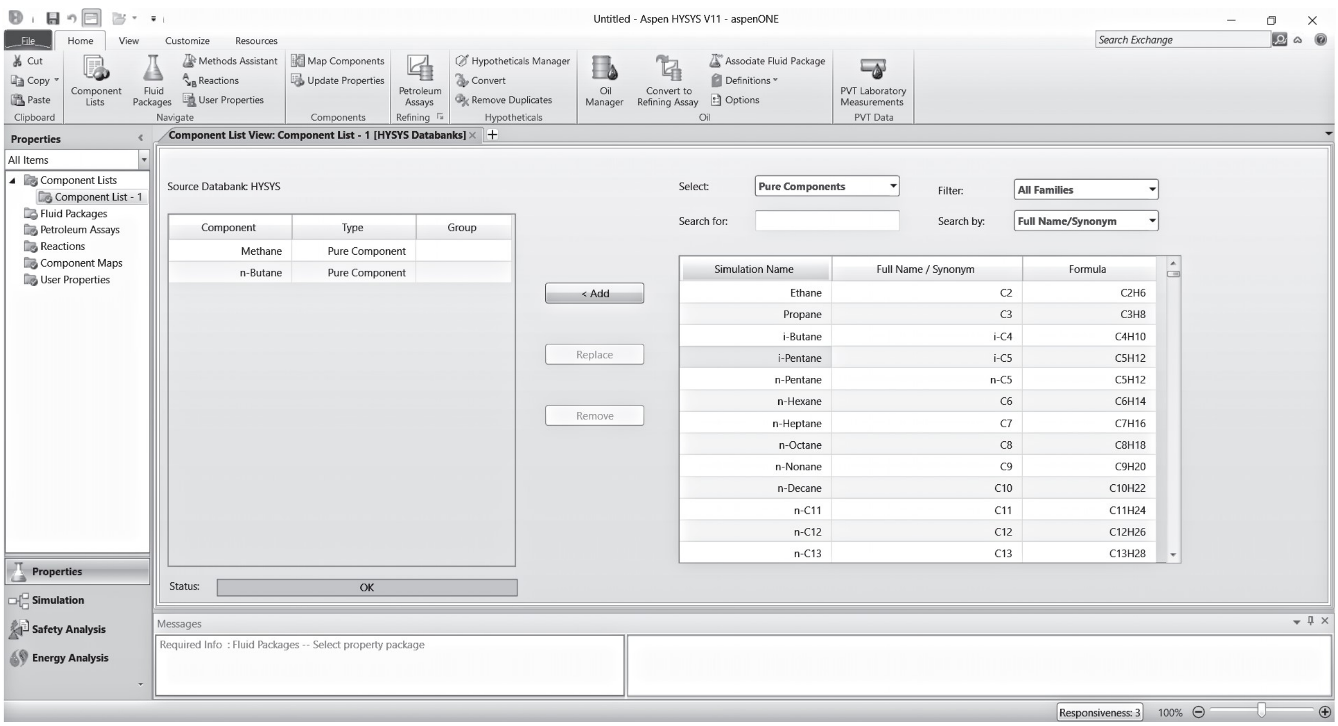
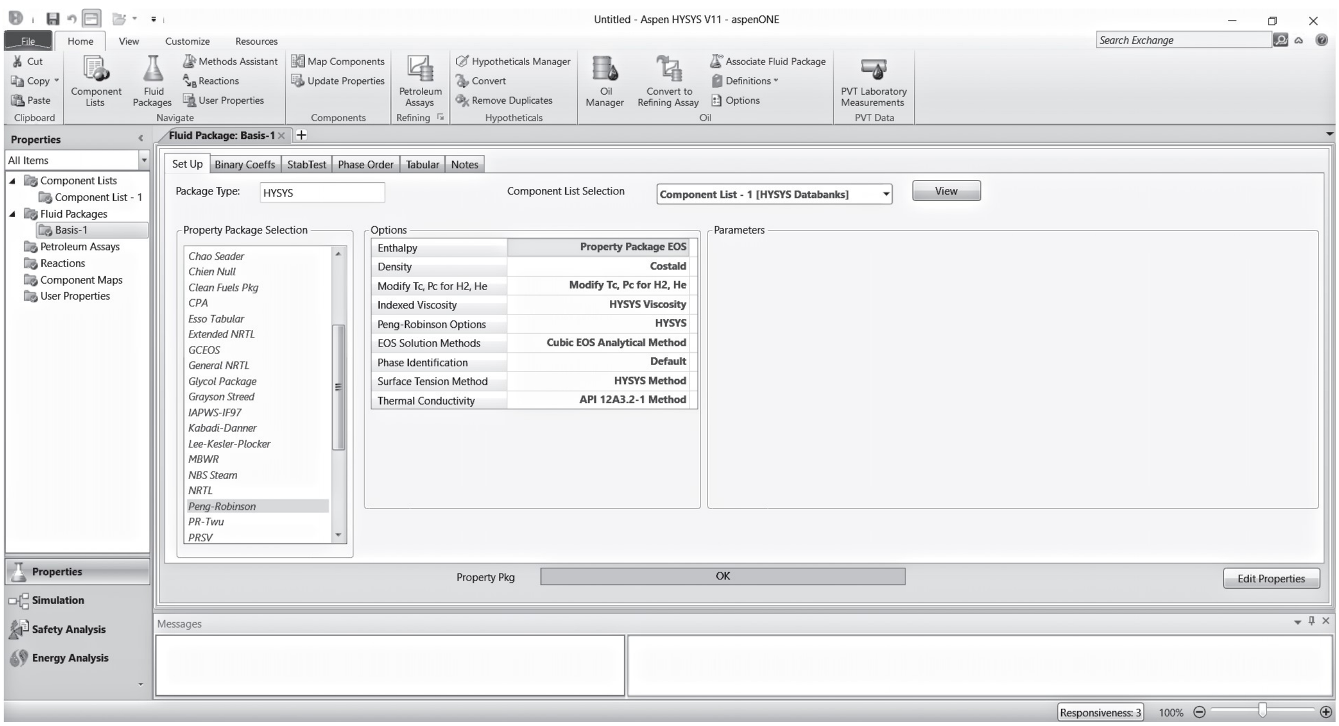
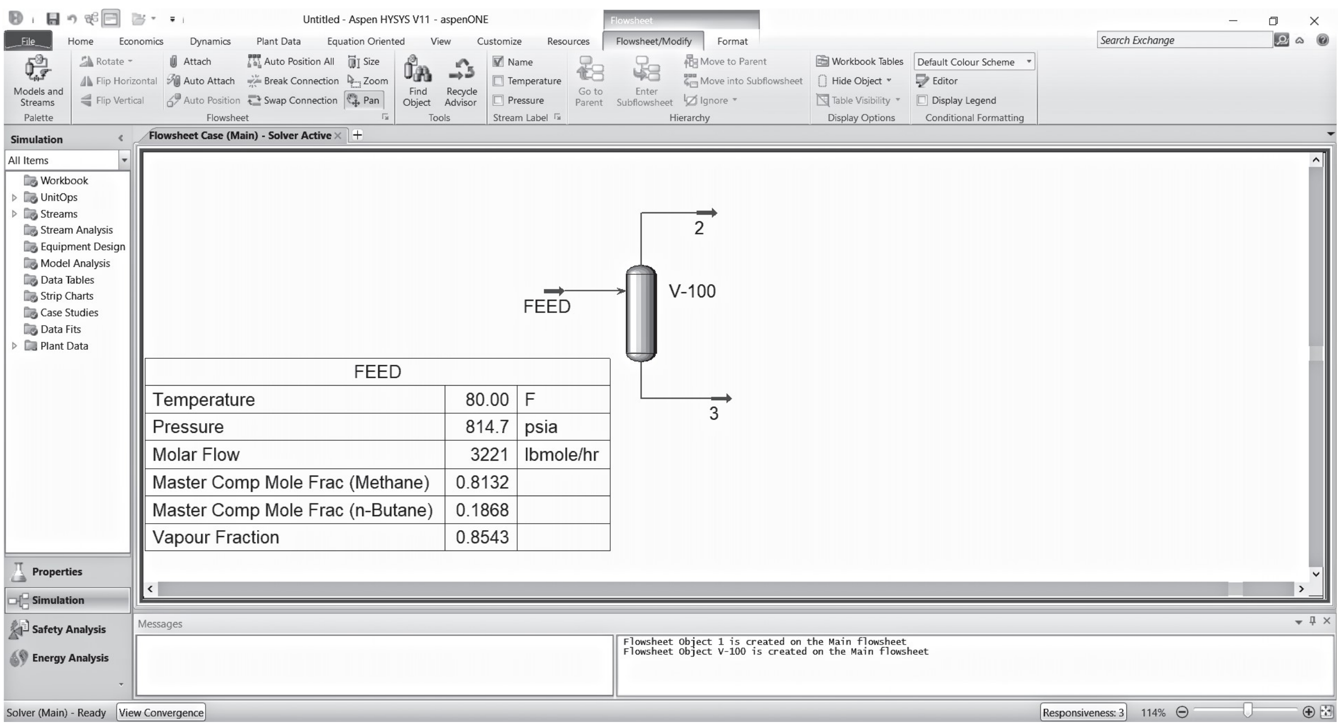


Figure 9.7: Fluid package



Select the Separator from the model palette and connect the material streams.

Figure 9.8: Separator



Chapter 10

HEAT EXCHANGER SIZING USING ASPEN EDR

Aspen Exchanger Design and Rating (EDR) enables you to find the optimal design for your heat exchanger needs based on cost. The seamless integration between the thermal and mechanical design tools of Aspen EDR and process simulation tools from AspenTech enables analysis of several different alternatives before presenting you with the most optimal design. Use this tutorial to get started using Aspen Shell & Tube Exchanger to create, evaluate, and save designs.

Simulation

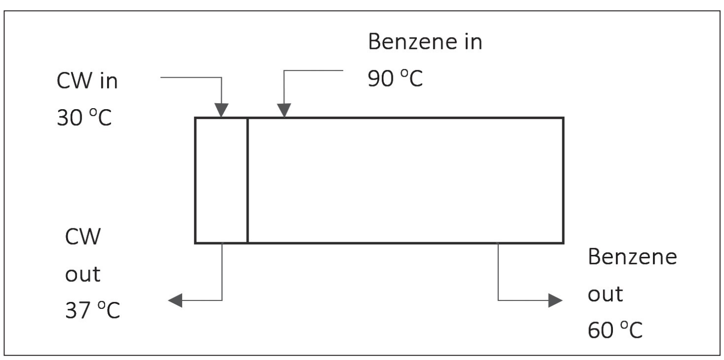
Let's solve an example.

Design a shell and tube exchanger for the following duty 20000 kg/h of benzene. It enters the heat exchanger at 90 ^oC and to be cooled to 60 ^oC. The cooling medium is cooling water entering the exchanger at 30 ^oC and exits at 37 ^oC. Benzene inlet pressure is 5 bar and that of water is 6.5 bar.

A pressure drop of 0.8 bar is permissible on both the sides. Allowance should be made for fouling by including a fouling factor of 0.0003 m^2.K/W on the Benzene side and 0.0001 m^2.K/W on waterside.

We limit the exchanger length as 5 m.

Figure 10.1: Heat exchanger problem



SOLUTION

Open Aspen EDR new file. Check the "Shell & Tube" box and "Create" the new file.

Figure 10.2: New case

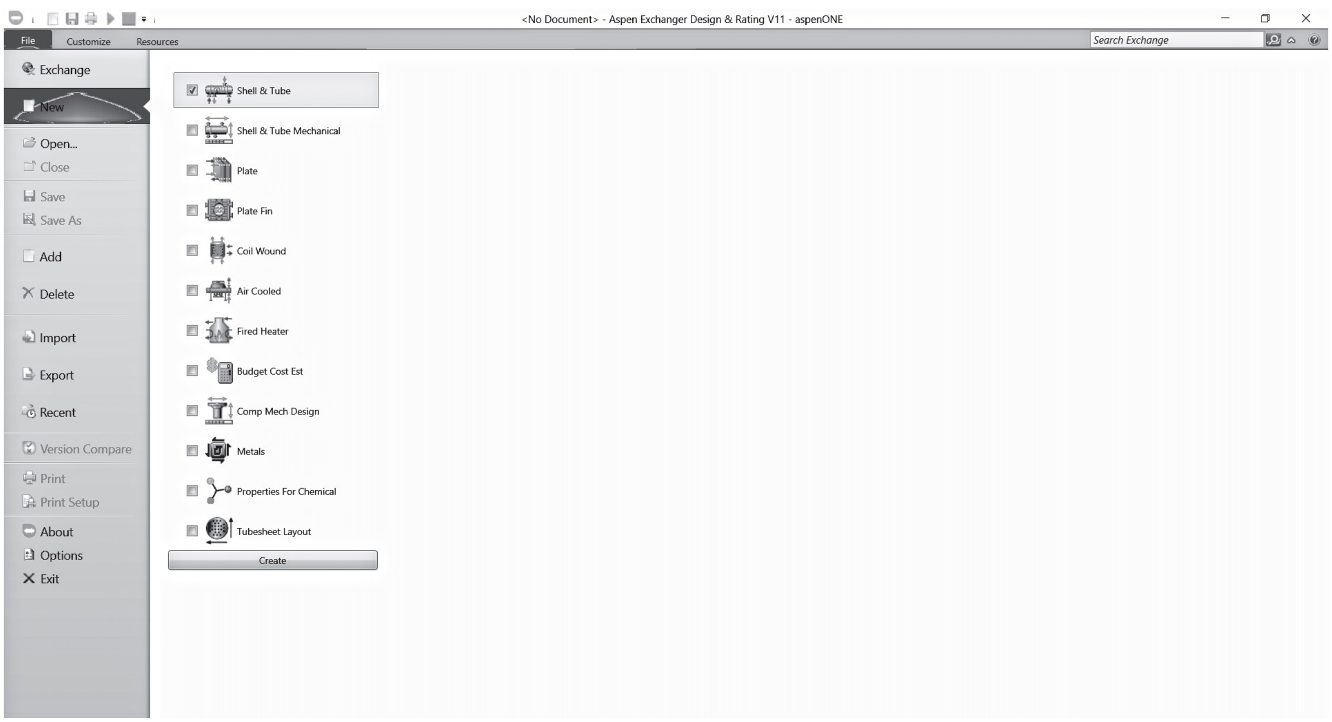
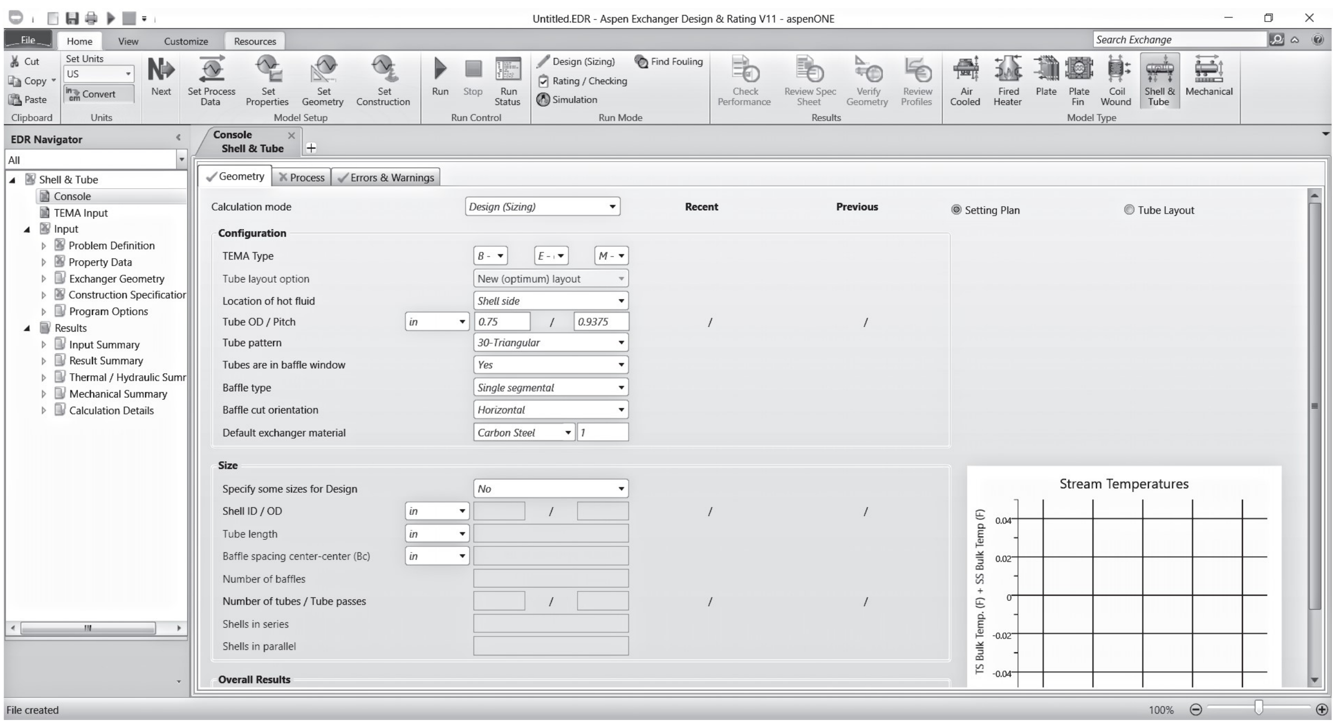


Figure 10.3: New case



Chapter 11

DISTILLATION COLUMN SIZING USING ASPEN HYSYS

Separation of light products is present in any hydrocarbons operations. In this chapter, a column will be modeled to separate light and heavy components from each other using a distillation column with 12 trays.

We need to separate a mixture of five paraffins into light and heavy fraction by using a distillation column with 12 trays, a full reflux condenser, and a Kettle reboiler. The feed stream (2000 lbmol/hr) consists of 20% (mole %) ethane, 20% propane, 20% n-butane, 20% n-pentane, and 20% n-hexane at 255 °F and 270 psia, which enters the column on the sixth tray, counting from the top. The condenser and reboiler pressures are 255 and 260 psia, respectively.

The preliminary design specifications require a reflux ratio of 2 and a vapor overhead product of 700 lbmol/hr. Subsequently, the design is modified to ensure propane overhead flow of 350 lbmol/hr and n-butane bottom flow of 380 lbmol/hr.

Use SRK Fluid Pkg.

Calculate the following;

- The Condenser, the Reboiler Temperatures & the Reflux Ratio after modification
- Condenser Temp
- Reboiler Temp
- Reflux Ratio

Define the components and Fluid package (SRK).

Figure 11.1: Components

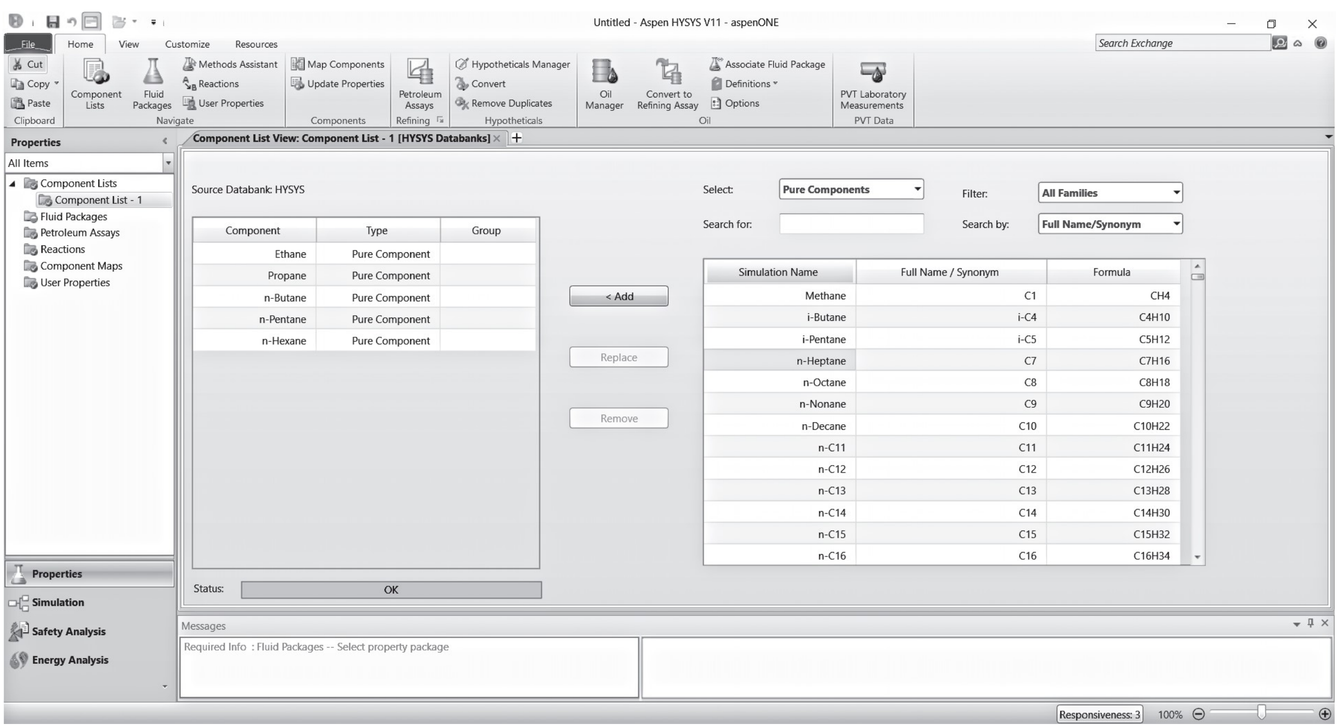
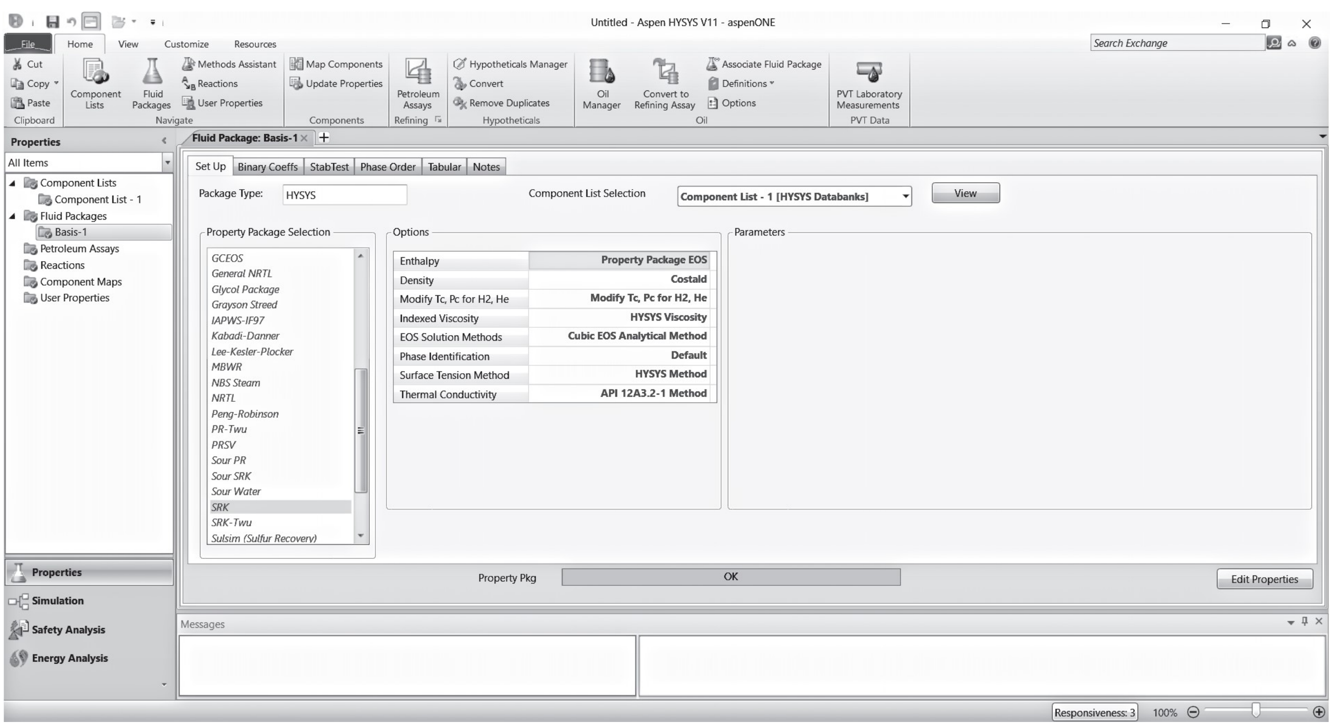
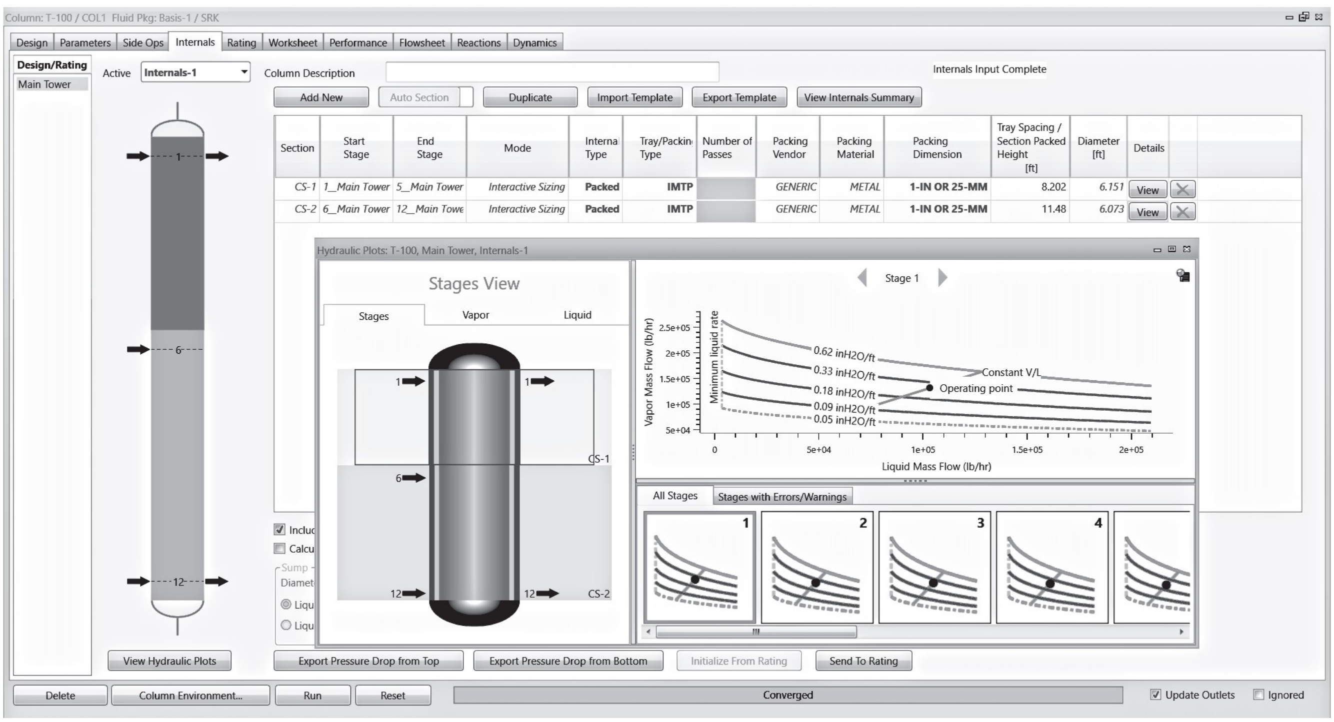


Figure 11.2: Fluid package



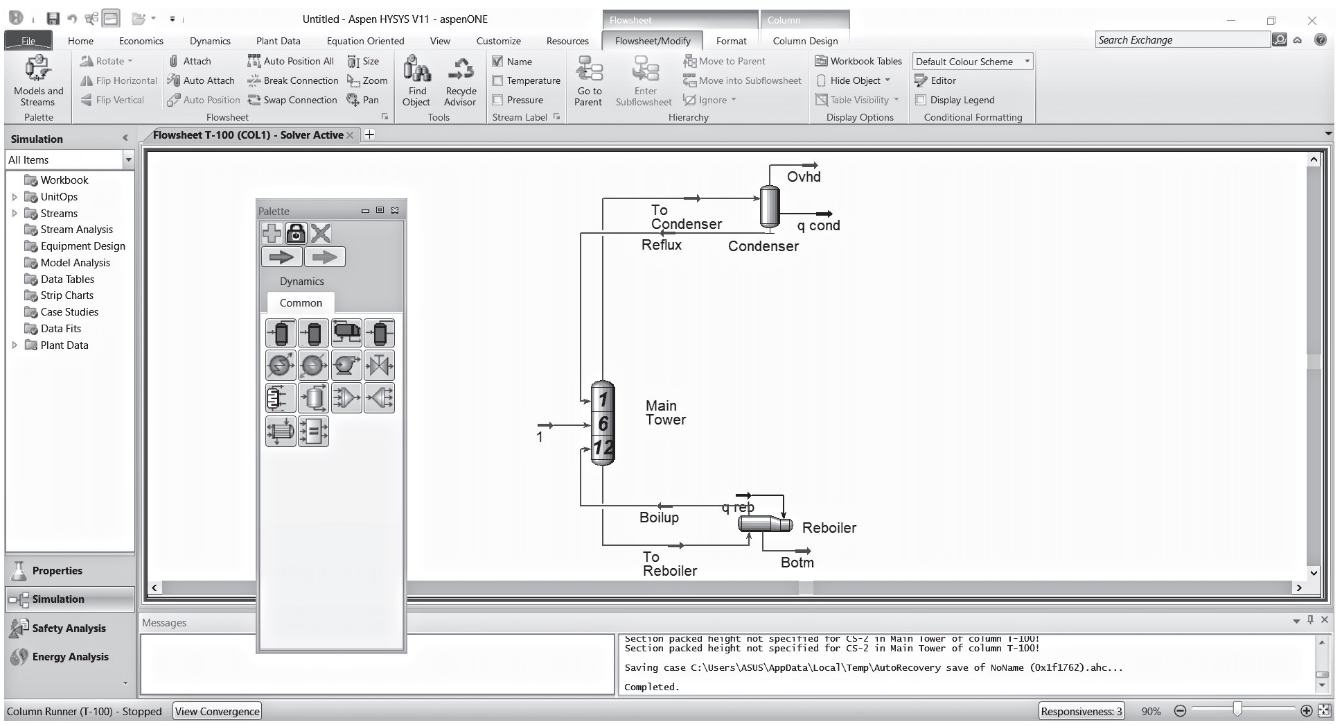
Different hydraulic plots can also be generated in Aspen HYSYS.

Figure 11.27: Distillation column



Clicking "Column Environment" will take you to column flowsheet with internal streams.

Figure 11.28: Distillation column



Exercises

a. Mr. Nitin needs to simulate a distillation column which has the same process parameters as given in the solved example. He has, however, a tray column with 36 actual trays with 50% efficiency, available in his plant. What do you think would be reflux ratio, condenser and reboiler duty in this case? Without carrying out any simulation, is it possible for you to answer that question qualitatively?

b. Mr. Ranjit is Mr. Nitin's colleague and has been tasked to convert the available tray column into a packed column. What are the different options he has with packings? Can the same column be used?

c. Mr. Amit wants to run the solved example with same column and process parameters, but with 50% more feed flow rate. Do you expect to get 50% more product yield? If not, what other measures should be taken by him?

d. Mr. Himanshu is required to carry out a comparative study of solved example w.r.to the effect of reflux ratio on reboiler duty and condenser duty. Can you help him with that assignment?

e. Mr. Rohan wants to convert beer into whiskey. Can you make a problem statement and solve it so that Mr. Rohan can use it for reference?

f. Ms. Madhugandha needs to simulation the ammonia absorption column. Can you make a problem statement and solve it so that Ms. Madhugandha can use it for reference?

g. Mr. Adeeb wants to learn about the gas sweetening plant. Can you make a problem statement and solve it so that Mr. Adeeb can use it for reference? You may use MDEA as a solvent.

h. Mr. Payas needs to design a column to manufacture absolute alcohol. Can you make a problem statement and solve it so that Mr. Payas can use it for reference? This solution must not have any solvent.

i. Mr. Viraj needs to design a column to manufacture absolute alcohol. Can you make a problem statement and solve it so that Mr. Viraj can use it for reference? This solution should have some solvent.

j. Mr. Anil wants to learn about the BTX purification plant. Can you make a problem statement and solve it so that Mr. Anil can use it for reference?

Chapter 12

OPTIMIZER TOOL IN ASPEN HYSYS

In this example, a simple distillation column to separate Tetrahydrofuran (THF) from Toluene is simulated. The object of the exercise is to select the product specifications such that profit is maximized. A special tool in HYSYS, the Optimizer, will be used to find the optimum operating conditions.

HYSYS includes additional modeling and decision support tools that can be used to enhance the usability of your models. In this module, you will use the HYSYS optimization tool available in HYSYS to investigate the debottlenecking and optimization of a crude column.

Once you have completed, you will be able to;

- Use the Optimizer tool in HYSYS to optimize flow sheets
- Use the Spreadsheet to perform calculations

5000 kg/hr mixture of Tetrahydrofuran & toluene (30 mass% THF) at 20 ^{o}C and 160 kPa is to be separated by distillation to get each of them with a purity of 99.2 mass% of THF & 95 mass% of Toluene (THF is the more volatile component).
Use Wilson fluid package.
The column specifications are:

- The condenser & reboiler pressure are 113 kPa & 117 kPa.
- The condenser works on total condensation conditions.
- Number of stages = 16.
- Feed enters from the 8th tray.

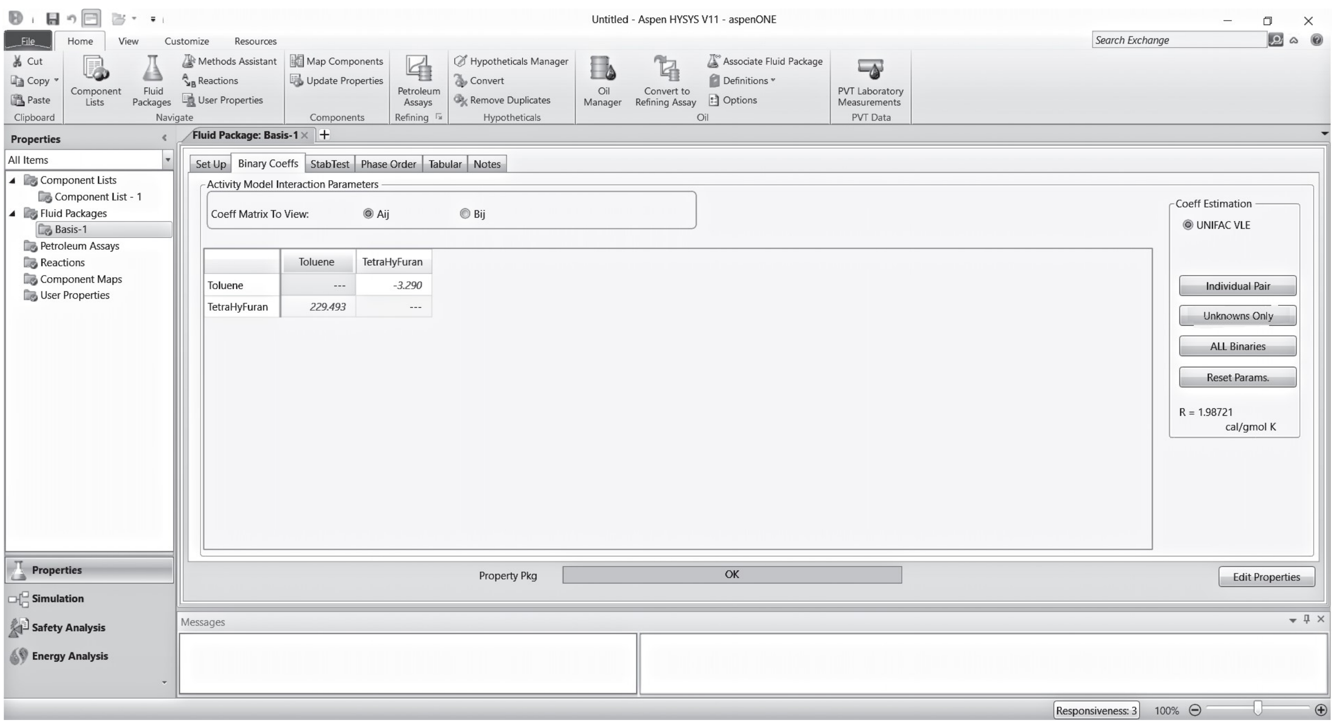
Calculate:
The reflux ratio and the distillate rate under the specified conditions.
Data:

- Feed price = 0.04 $/kg
- Pure toluene selling price = 0.12 $/kg
- Pure THF selling price = 0.35 $/ kg
- Cooling Cost = 0.43 $/ kWh
- Heating Cost = 0.75 $/kWh

Note:
Profit = (Total Toluene selling price + Total THF selling price) - (Feed cost + Heating cost + Cooling Cost)
Use a range of 0.99 to 0.999 for the THF limit & 0.9 to 0.99 for the toluene.

Figure 12.3: BIP

Now you can start drawing the flow sheet for the process by clicking the Simulation button. Add a material stream to define



Insert a column.

Figure 12.25: Spreadsheet

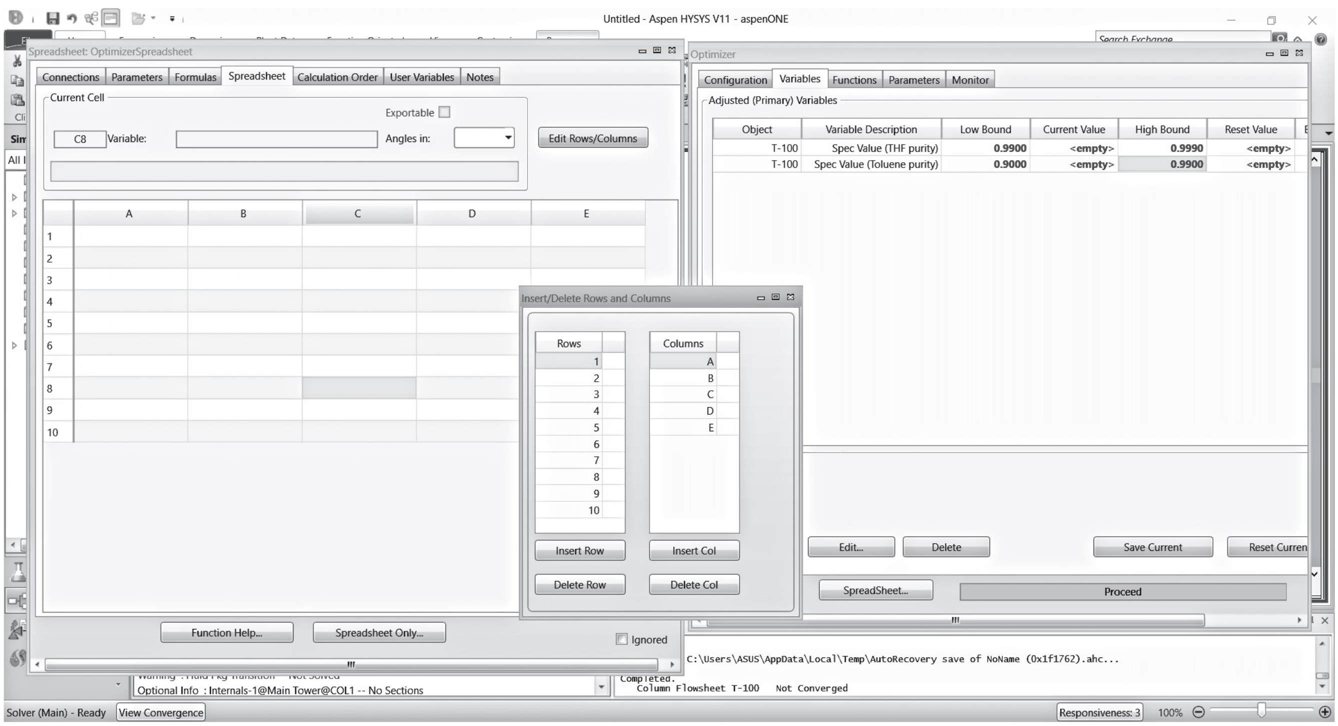
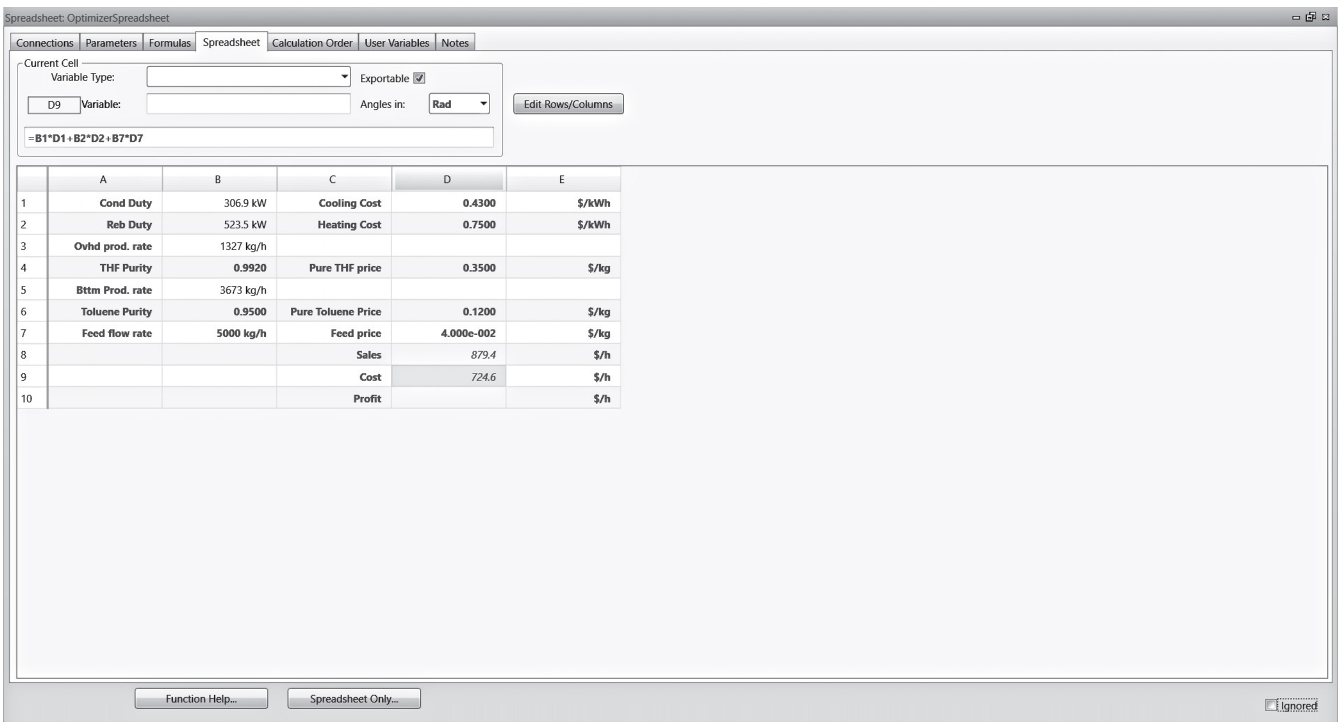


Figure 12.36: Spreadsheet



	A	B	C	D	E
1	Cond Duty	306.9 kW	Cooling Cost	0.4300	$/kWh
2	Reb Duty	523.5 kW	Heating Cost	0.7500	$/kWh
3	Ovhd prod. rate	1327 kg/h			
4	THF Purity	0.9920	Pure THF price	0.3500	$/kg
5	Bttm Prod. rate	3673 kg/h			
6	Toluene Purity	0.9500	Pure Toluene Price	0.1200	$/kg
7	Feed flow rate	5000 kg/h	Feed price	4.000e-002	$/kg
8			Sales	879.4	$/h
9			Cost	724.6	$/h
10			Profit		$/h

Chapter 13

PSV SIZING USING ASPEN HYSYS

Before attempting to size the PSV, we must know what is a PSV. Consider a vessel with a design pressure of 7.5 barg. Due to some reasons, if the vessel pressure increases beyond 7.5 barg, then it may lead to vessel leakage or it can burst also. To safeguard the vessel, a PSV is attached to the vessel top section. PSV is set at 7.5 barg. So, when the pressure reaches 7.5 barg, PSV opens and vessel pressure gets relieved. As pressure starts to go below 7.5 barg, PSV is closed.

Any equipment with design pressure equal to or more than 15 psig can be termed as a vessel. And the one with less than 15 psig is called a tank. A tank may have relief devices called as breather valve or PVRV and sizing are done as per API 2000.

The vessel may have a relief device called PSV or RD. There are the following 3 major standards that deal with PSV and RD.

- API 520 Part 1 : PSV and RD sizing equations are provided in this standard.
- API 521 : Depressurization, Flaring, liquid expansion is discussed in this standard.
- API 526 : The selection of PSV size that is available in the market is given in this standard.

Terminology

- **Operating pressure**

  It is nothing but the normal operating pressure of the vessel.
  In our example, let's assume operating pressure to be 5 barg. The maximum operating pressure (MOP) is usually taken at a 1.7 bar above normal operation. So MOP will be 6.7 barg. Vessels are often overdesigned relative to the maximum operating pressure, i.e. 10% over MOP. Hence design pressure value will be 7.37 barg or round figure 7.5 barg.

- **MAWP**

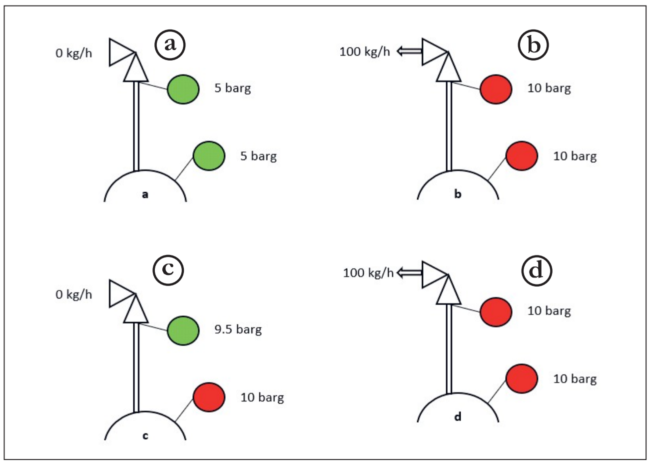
  The maximum gauge pressure permissible at the top of a completed vessel in its normal operating position at the designated coincident temperature specified for that pressure. The pressure is the least of the values for the internal

Table 13.1: Accumulated pressure and set pressure guideline

Contingency	Single Device Installations		Multiple Device Installations	
	Maximum Set Pressure, %	**Maximum Accumulated Pressure, %**	**Maximum Set Pressure, %**	**Maximum Accumulated Pressure, %**
Non-Fire Case				
First Relief Device	100	110	100	116
Additional Device(s)	-	-	105	116
Fire Case				
First Relief Device	100	121	100	121
Additional Device(s)	-	-	105	121
Supplemental Device	-	-	110	121
NOTE: All values are percentages of the maximum allowable working pressure.				

The above table from API 520 Part 1 can be used to determine allowable set pressure and maximum accumulated pressure. If there is a single PSV, then for non-fire (blocked outlet) case, the vessel shall be allowed to have a maximum pressure of 110% of design pressure. If design pressure is 7.5 barg, then maximum pressure allowable shall be 110% of 7.5 barg (8.25 barg).

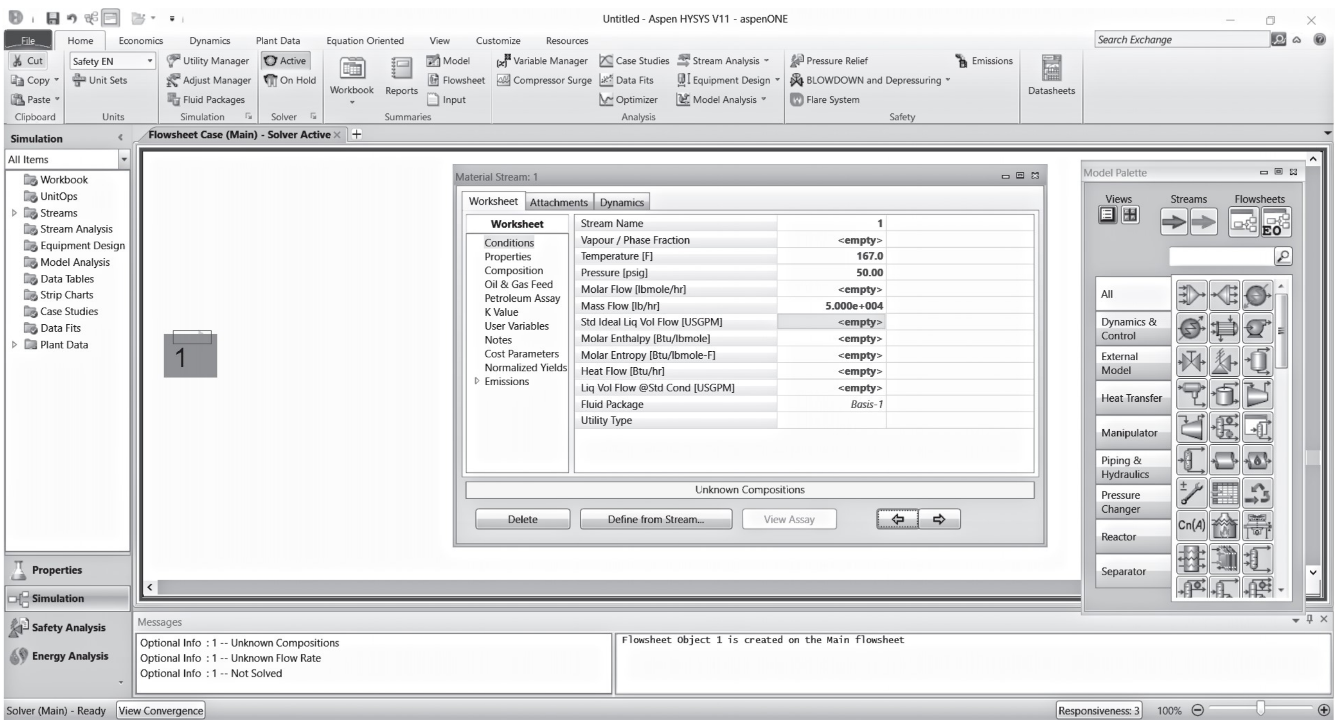
Figure 13.6: Chattering



Figure(**a**) represents the normal operation, wherein the vessel operates at operating pressure. Hence the pressure at the pressure relief valve and the vessel is the same. Let's say that the operating pressure is 5 barg. As vessel pressure increases due to process upset, relief valve pressure will also increase. Relief valve will open at 10 barg, which the set pressure (figure **b**). So the pressure at the vessel and the relief valve is 10 barg. Let's assume that 100 kg/h vapor flows from the vessel to the relief valve. At the vessel, vapor pressure is 10 barg and due to pressure drop (say, 0.5 bar) in the relief valve inlet pipe, vapor will be left with 9.5 barg pressure. Since 9.5 barg is less than the relief valve set pressure, the relief valve will close and pressure at the relief valve will rise again (figure **c**). When pressure reaches sept pressure, then the relief valve opens again (figure **d**).

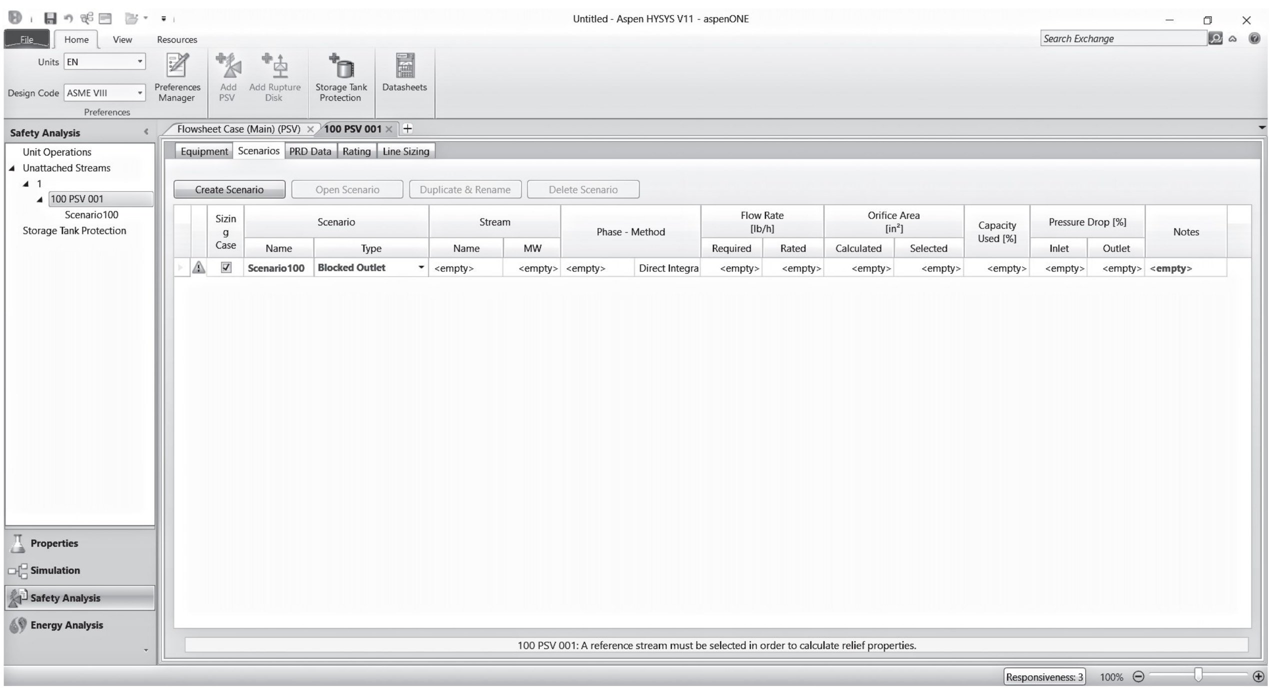
Enter Simulation environment and model a material stream. Provide pressure as 50 psig (normal operating pressure), temperature (167 °F), 50,000 lb/h flow rate and composition 0.5-mole fraction each for n-Butane and Propane.

Figure 13.13: Material stream



Select the "Scenario" tab. One can have several scenarios created. But in this example, there is only one scenario, hence it will be ticked as "Sizing Case". Scenario type selected is "Blocked outlet", as the relief scenario is triggered by operational upset as per problem statement. Double click on "Scenario Name" to "Open Scenario" window.

Figure 13.17: Scenario



Chapter 14

PROCESS PLANT DESIGN USING ASPEN HYSYS

Process plant design is the combination of theoretical aspects and practical or experience-based aspects.
A process engineer must be able to consider appropriate numbers using the available standards and experience on similar projects.

Maximum design pressure
Below table will come handy to arrive at design pressure value of pressurized system;

Table 14.1: Design pressure guideline

Maximum operating pressure, barg	Design pressure, barg
0 to 35	Maximum operating pressure + 3.5 bar
35 to 70	Maximum operating pressure + 10%
70 to 200	Maximum operating pressure + 8.5%, but between (7 to 10 bar)
200 +	Maximum operating pressure + 5%

Operational drain, vent and flushing requirements

All equipment and piping shall be provided with high point vents and low point drains within isolation valves isolating equipment or process sections. All such vents and drains shall be fitted with a valve and blind flange. For piping and headers, low point drain and high point vent shall, in general, be provided.

Steam-out and utility connections shall be provided and located to ensure efficient flushing and cleaning required for inspection and maintenance.

Where provisions are made for chemical cleaning of heat exchangers with the tube bundle in place, blind flange connections shall be provided for chemical hose attachments. The connections shall be minimum DN 80 (3 in), but not exceeding line size, and shall be located between the exchanger nozzles and the block valves.

Plant design problem

So far, we have simulated control valve, PSV, line, orifice, separator, and pump. We are now going to use this skill to design a real plant.

Simulation

Problem statement is given below;

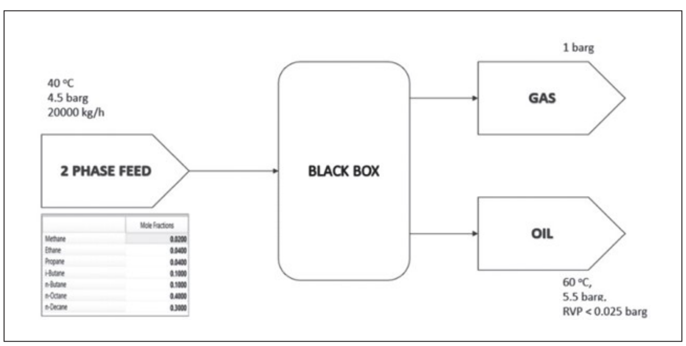
We need to design a separation system to separate gas from oil in a 2 phase fluid, that is available at 40 ^oC, 4.5 barg pressure, and 20000 kg/h. Mole fraction of feed is provided in the below table.

Table 14.1: Feed composition

Component	**Mole fraction**
Methane	0.02
Ethane	0.04
Propane	0.04
i-Butane	0.10
n-Butane	0.10
n-Octane	0.40
n-Decane	0.30

The gaseous product shall be connected to the existing LP flare header at 1 barg pressure.
Oil shall be sent to the existing header at 60 °C and 5.5 barg pressure. RVP of the oil shall be less than 0.025 barg.

Figure 14.2: Schematic of problem



The black box signifies all the unit operations/calculations/sizing that is needed to achieve the project objectives. **What does the black box contain?**

- Separator sizing
- Heater sizing
- Pump sizing
- Line sizing
- LCV sizing
- PCV sizing
- FCV sizing
- Flow orifice sizing
- PSV sizing

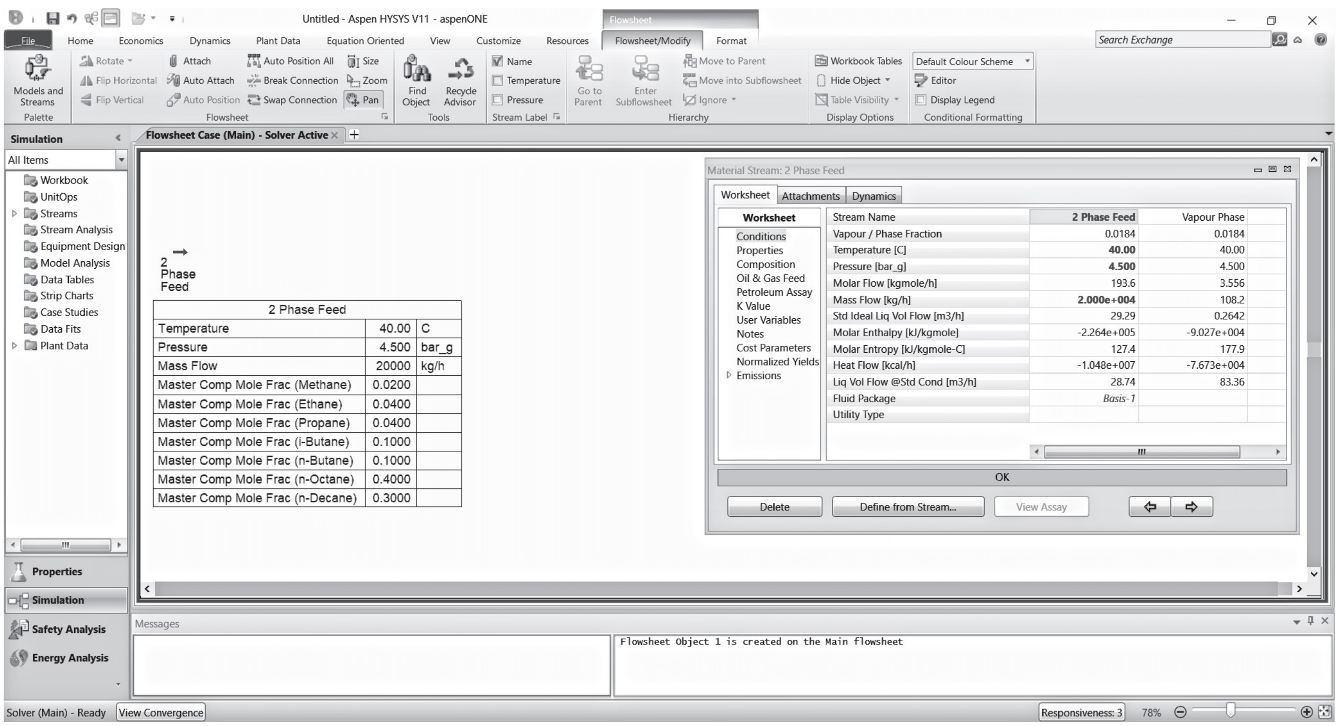
Solution :

Let's simulate.

First, get the components added and the fluid package selected shall be Peng Robinson.

The feed stream is converged.

Figure 14.3: Material stream



Chapter 15

ASPEN HYSYS DYNAMICS (SIMPLE PROBLEM)

In this chapter, we are going to discuss the dynamic modeling of two-phase separator, which includes modeling of the material stream, separator, valves, and PID block. Also, one will be able to manipulate the variables and check the dynamic response.

Once you have completed this module, you will be able to:

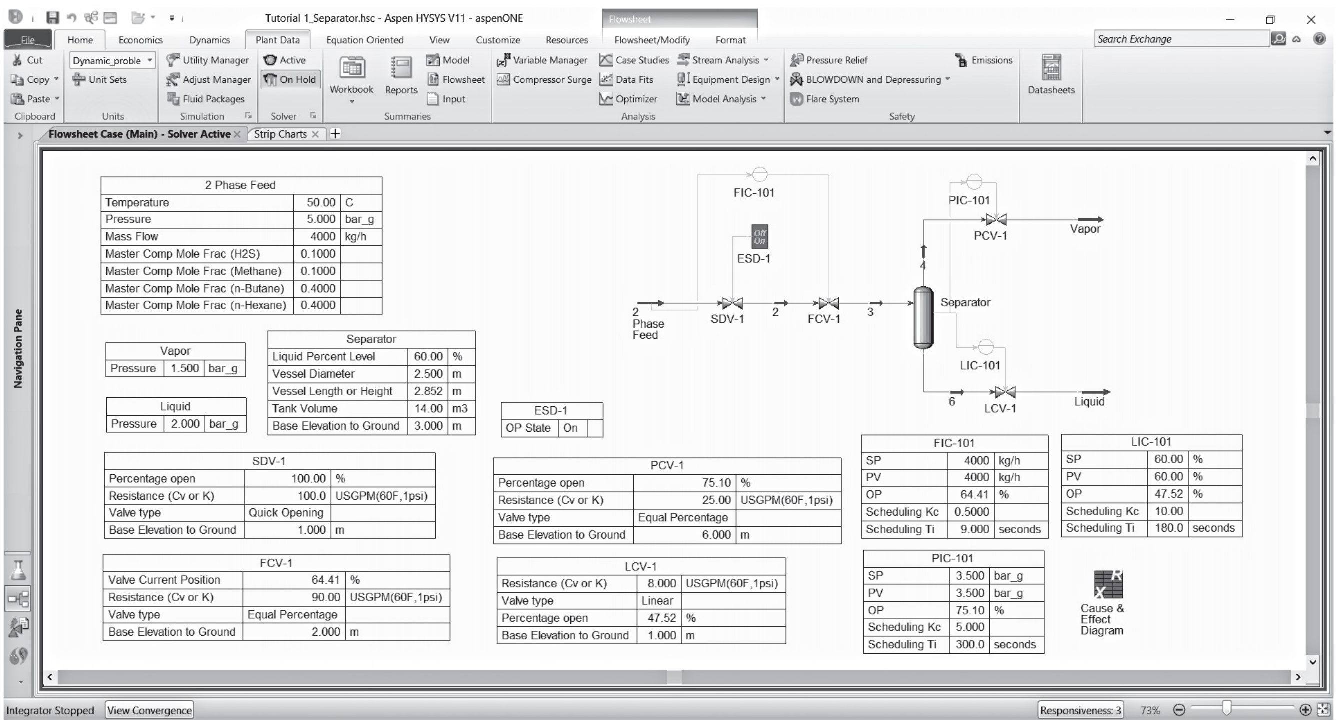
- Simulate valve in dynamic mode.
- Simulate vessel in dynamic mode.
- Simulate controller in dynamic mode.
- Study the dynamic behavior of the model.
- Prepare Cause and Effect Matrix

Please refer HYSYS model snapshot below;

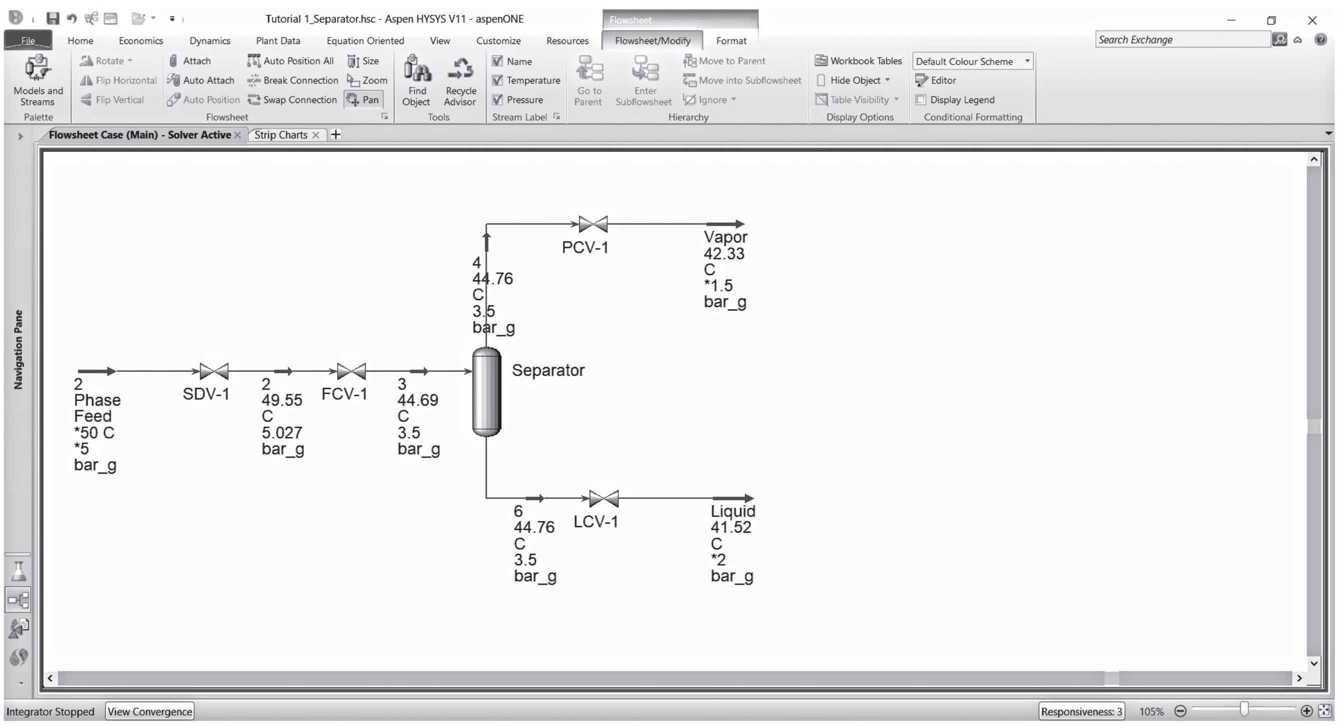
A two-phase feed stream is sent to the separator.

- SDV-1 acts as an emergency shutdown valve. A negligible pressure drop of 5 kPa is to be considered for the same.
- FCV- controls the mass flow rate of the feed stream. The pressure drop of 150 kPa is to be considered for the same.
- Separator separates vapor and liquid streams.
- PCV- controls the separator pressure.
- LCV- controls the separator level.
- Vapor stream tie-in point pressure is 1.5 barg and that of liquid stream is 2 barg.
- Use Peng Robinson as a fluid package.

Figure 15.1: Steady-state model

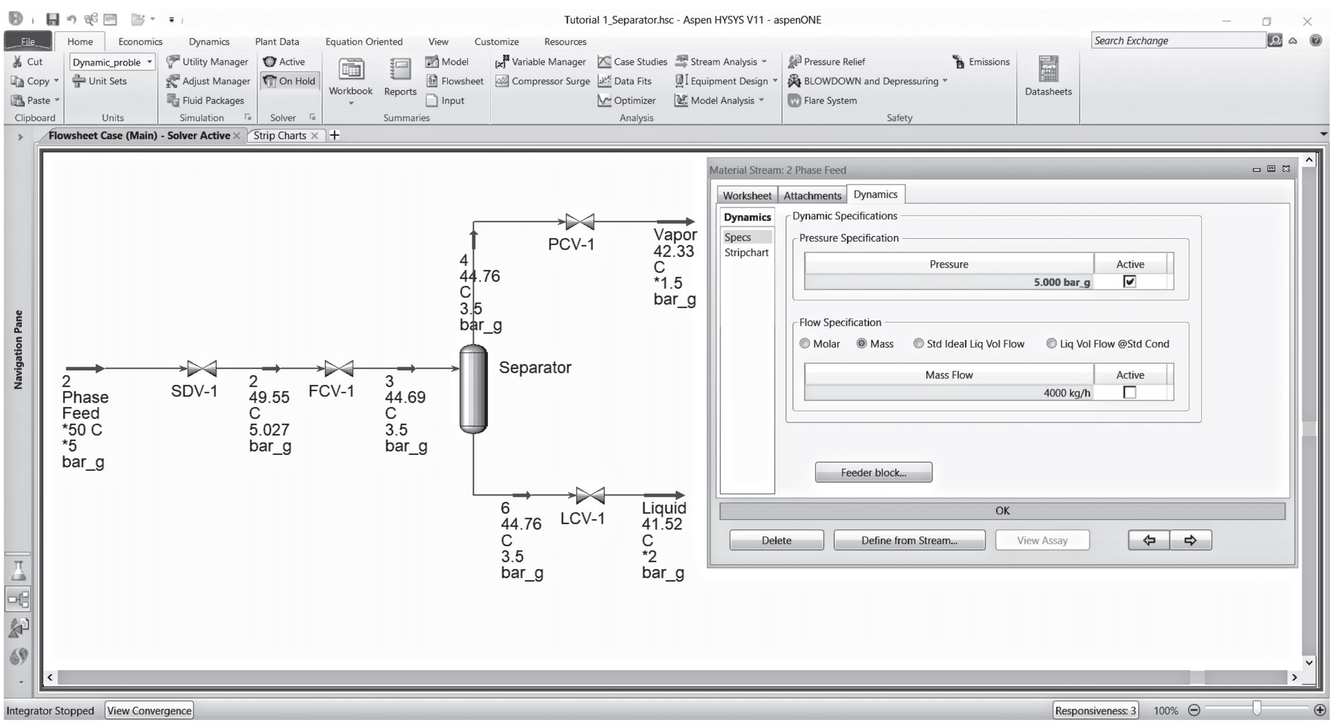


Add components and fluid package.
Prepare the model as shown below.
Figure 15.2: Steady-state model



Select dynamic specifications as shown below; Flow rate is calculated w.r.to pressure differential.

Figure 15.3: Dynamic specifications

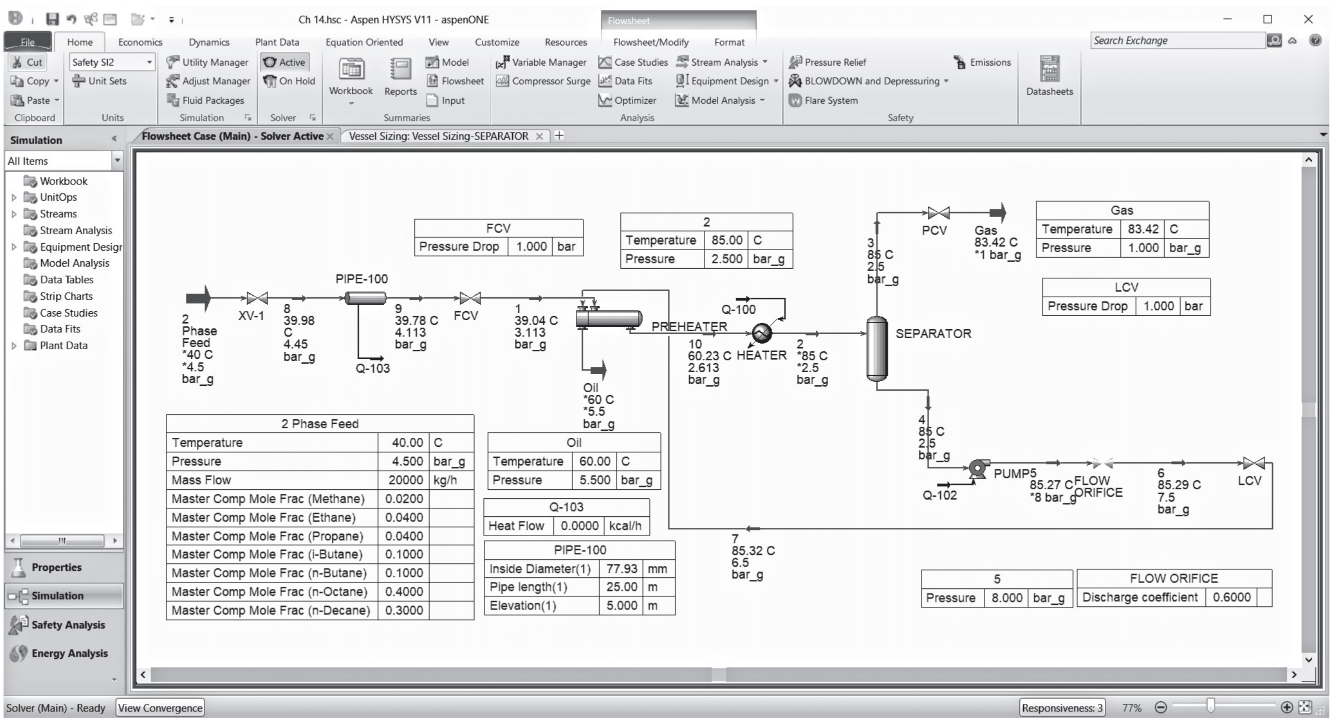


Chapter 16

ASPEN HYSYS DYNAMICS (PROJECT PROBLEM)

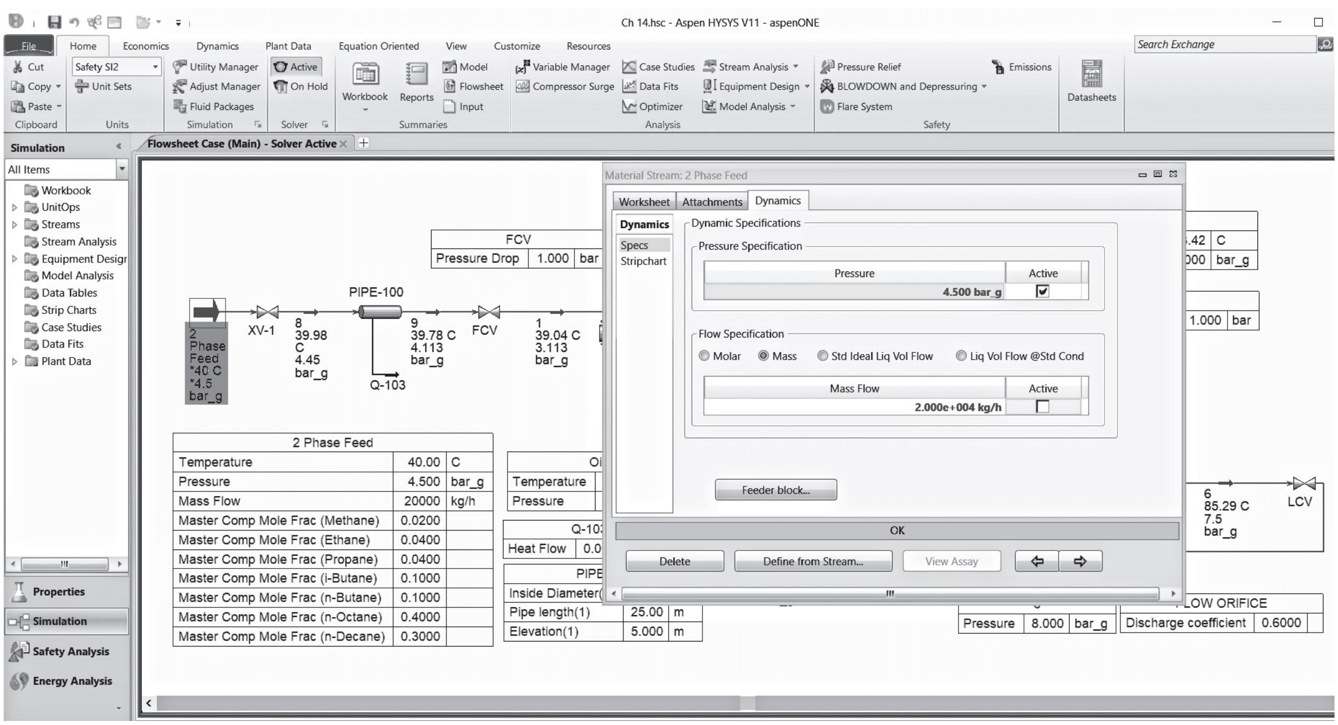
We have already designed a typical oil and gas separation facility in chapter 12.
In this chapter, we are going to convert that steady-state model into a dynamic model.

Figure 16.1: Model



Make sure the Aspen HYSYS model is converged.
Boundary conditions specifications must be pressure active only.

Figure 16.2: Dynamic specification



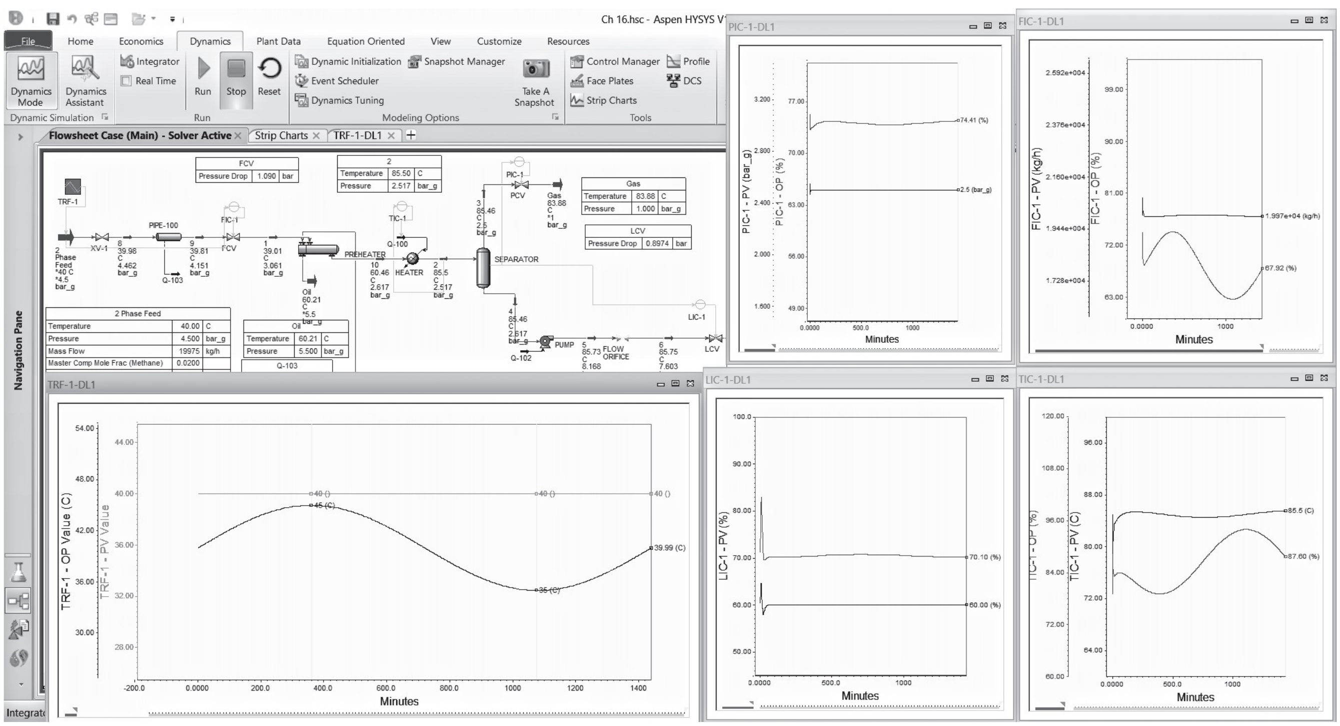
There is a set of preliminary tuning parameters suggested. The same shall be used in this example.

Figure 16.29: Tuning parameters

System	K_c	τ_i (minutes)	τ_d (minutes)
Flow	0.1	0.2	0
Level	2	10	0
Pressure	2	2	0
Temperature	1	20	0

The temperature fluctuation is 24 hours for 2 Phase Feed stream is given in the below plot. And also, the impact of the same on the other 4 controllers are provided.

Figure 16.63: Model analysis



Chapter 17

TYPICAL INTERVIEW QUESTIONS

The following are the most commonly asked technical questions in a process engineering interview. The reader is expected to write down all the answers for the same.

1. Please introduce yourself.
2. What is your present job profile?
3. Why do you want to switch jobs?
4. Why do you think this company (where you have applied) is better suited for your career goals?
5. What is your favorite topic in chemical engineering? Why?
6. Have you designed a process plant before?
7. How good are you with MS Excel?
8. How to carry out heat exchanger sizing?
9. What do you mean by pump hydraulic power?
10. What is $NPSH_{available}$?
11. Explain control valve sizing procedure.
12. What is cavitation in control valves?
13. What are the different standards used in the process industry?
14. What are the different types of PSVs?
15. Explain Table 1 of API 520 Part 1.
16. Explain different line sizing criteria.
17. What is the L/D ratio of horizontal separator?

235. Explain the distillation column control system. (Ingenero India)
236. What are the causes of Overpressure in the column? (Ingenero India)
237. What are the pump overpressure causes? (Ingenero India)
238. Explain every unit of the refinery in with its significance.
239. What are the simulation steps for distillation column sizing?
240. Explain TEMA and the significance of its parameters.
241. What is the significance of ϱv^2 in the heat exchanger?
242. What is better; crossflow or counter-current flow in a heat exchanger?