APPROVED SOLUTION

Design Problem 4 – Condenser, Reflux Drum, Reflux Pump, and Reboiler Costs in Distillation

1. Objectives.
2. Problem Background and Statement.
3. Questions.
4. Suggestions, Specifications, and Constraints.
5. Submission requirements.

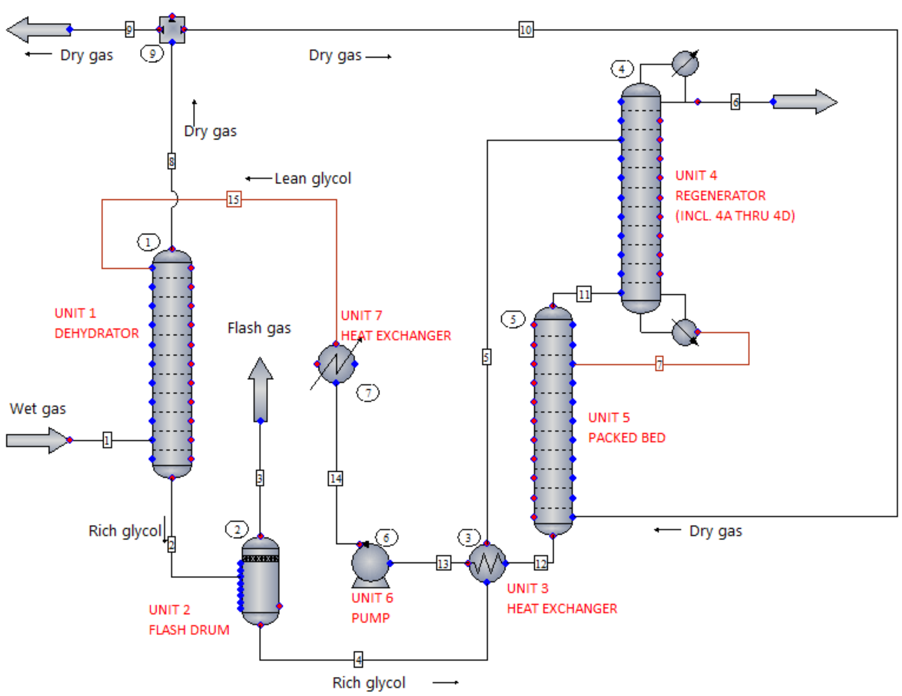
Objectives

1. Design a chemical process within realistic constraints.
2. Identify environmental and safety factors in a chemical process.
3. Introduce design heuristics for heat exchangers.

Problem Background and Statement

Natural gas is an important source of both fuel and chemicals. Natural gas is often found in the same geological formations as petroleum, so natural gas processing facilities are very common in oil-producing regions. For example, the Permian Basin in the southwest United States, which is a major petroleum producing region, there are approximately 330 active gas rigs [https://novilabs.com/permian-basin/], accounting for about 15% of U.S. production. With an area of about 75,000 square miles for the entire basin, which is about one natural gas rig every 10 miles in any direction.

Processing of natural gas after extraction involves a considerable amount of chemical engineering. The first step is usually the removal of water. A CHEMCAD flow diagram for a typical gas dewatering plant is shown below, and a working CHEMCAD file has been provided by your instructor.



The process works as follows: Wet natural gas (wet gas) enters absorber column (unit 1) at the lower left corner of the diagram, where it is contacted with water-lean triglycol (lean glycol). This step removes most of the water from the wet gas. The resulting dry gas product (dry gas) is then removed from the process in the upper left corner of the process. The water-rich triglycol (rich glycol) is then recycled through a series of water-removing steps. First, since the rich glycol contains volatile light ends such as methane, CO_2, and H_2S, these are partially removed in a flash drum (unit 2). The rich glycol is then preheated in an energy-recovery heat exchanger (unit 3) and then to the top stage of a distillation column (unit 4). The glycol emerges from the bottom of the distillation column (unit 4) and enters the top of a stripping column (unit 5) where it is contacted with some of the dry gas product which was split off from the original dehydrator (unit 1). The combination of units 4 and 5 serves to remove about 91% of the water, producing water-lean triglycol (lean glycol) at the bottom of the stripping column (unit 5). The lean glycol is still quite hot, so it is then sent back through the energy recovery heat exchanger (unit 3) where it is cooled off and then sent back to the dehydrator (unit 1), closing the recycle loop.

In this project, you will determine the purchased equipment costs for this natural gas drying facility. Your task is to complete the design (sizing and pricing) of the regenerator section of the process, unit 4 in the flowsheet. Unit 4 includes the shell and trays, condenser, reflux drum, reflux pump, and reboiler. You will combine your pricing results with the prices of the other equipment determined previously to obtain the *total purchased equipment cost* of the process.

Questions:

1. **5 Points.** Run the CHEMCAD sizing and costing tools to determine the cost of the regenerator column (Unit 4A).

2. **10 Points.** Use CHEMCAD and the 3-step exchanger design method to find the heat transfer coefficient, area, and cost of the regenerator condenser (Unit 4B).

3. **5 Points.** Use the CHEMCAD sizing and costing tools to determine the cost of the regenerator reflux drum (Unit 4C).

4. **5 Points.** Use CHEMCAD to determine the cost of the reflux pump (unit 4D).

5. **5 Points.** Use CHEMCAD and design heuristics to determine the cost of the regenerator reboiler (unit 4E).

6. **10 Points.** A partially completed table entitled “Table DP4-1 - Summary of Purchased Equipment Costs” is given below. Complete the table by using CHEMCAD cost tools to determine the purchase cost of each component of the regenerator (Units 4A through 4E). Report the purchased equipment costs in *February 2024* dollars.

7. **5 Points.** Environmental: This process is to be built in the Finger Lakes Region of New York State, where the ground water is relatively clean. What information would be required to provide an environmental assessment of the project? Where is this information found? What does it say?

8. **5 Points.** Safety: Suppose that you had to create an NFPA-704-format "fire diamond" for triglycol and natural gas. What entries would you use for each sector of the diamonds?

Answers to Questions 7 and 8 can be found in the attached form on the last page of this document.

Suggestions, Specifications, and Constraints

- Find the CHEMCAD file in Canvas and make sure it works.
- Note the numbering in the flow sheet. You are *not* required to size units 1-3 or 5-7. They have already been sized, and the resulting prices for February 2024 entered in Table DP4-1.
- All equipment is made from carbon steel.
- The design pressure is required for vessel and column sizing. Use a design pressure of twice the process maximum.
- The regenerator distillation column (Unit 4A) uses sieve trays. Use CHEMCAD defaults for all other required column data.
- The reboiler, condenser, and reflux pump on the regenerator are not directly accessible in the CHEMCAD distillation column unit op. The heat exchangers visible in the flowsheet are only visuals. To manipulate feeds and to design the actual heat exchangers, they *must* be redrawn as separate units on your flow sheet.
- To obtain the vapor feed to the condenser, component flow rates can be copied and pasted from the appropriate tray in the column. Fluid traffic inside a distillation column is obtained in Home→Reports→Distillation/Tray composition. Your instructor will demonstrate this in class.
- The condenser is TEMA Type AEL and the reboiler is kettle-type (TEMA shell K).
- Use the three-step method to design to condenser.
- Do not use the 3-step method for the reboiler design. Instead, use "heuristics," or "rules of thumb." Heuristics for heat exchangers are in your textbook on page 970. The reboiler heat transfer coefficient is given in the paragraph beginning "Heat-transfer coefficients…" Enter the textbook value for U into the appropriate field in the heat exchanger box. CHEMCAD will then calculate the required area and use the resulting area and then use it for determining the cost.
- Cooling water for the condenser is available at 65 ºF and 40 psia and must be returned at or below 70 ºF. Cooling water enters the condenser tube-side.
- Saturated steam for the reboiler is available at 3550 kPa (absolute) and must be returned at a quality of 50% or greater (vapor fraction = 0.50 or higher). Steam enters the reboiler tube-side.

Submission Requirements

1. PDF of completed Table DP4-1 with signed cover Sheet.
2. Answers to Questions 1-8. Questions 1-5 are answered electronically by completing your CHEMCAD design. Question 6 is completing the table. Questions 6-8 are typewritten and submitted electronically with your PDF.
3. Electronic copy of completed CHEMCAD file on SharePoint directory.
4. All work is due NLT 1435 hours (End of lab hour).

Table DP4-1 - Summary of Purchased Equipment Costs

Unit Number	*Name*	*Purchased Cost*
1	**Dehydrator**	$644,558
2	**Flash Drum**	$103,337
3	**Heat Exchanger**	$71,129
4A	Regenerator Column	$53,318
4B	Regen. Condenser	$6,474
4C	Regen. Reflux Drum	$105,097
4D	Regen. Reflux Pump	$64,858
4E	Regen. Reboiler	$31,959
5	**Packed Bed, w/packing**	$30,986
6	**Pump**	$9,801
7	**Heat Exchanger**	$5,167
Purchased Equipment Cost (PEC)		$1,126,748

Cadet prices should be with $1,000 of these values.

Price of condenser increased after tubes are lengthened.

Assume design pressure of 1220 psia.

Price quoted is for horizontal vessel with design pressure of 1220 psia.

Additional Notes for Instructor Use Only (Cadets do not need this information):

Unit 5:

- Specify 25-mm ceramic berl saddles for packing.
- Used the Billet-Shultes correlation for sizing.
- HETP is less than 3 feet (PTW p. 775)
- Cost of packing is about $1000 (PTW p. 795).
- Actual cost is closer to $7,714 in March 2016.

Unit 7:

- The heat exchanger cost is $3500 in March 2016
- Based on 3-step design with steam as utility fluid.

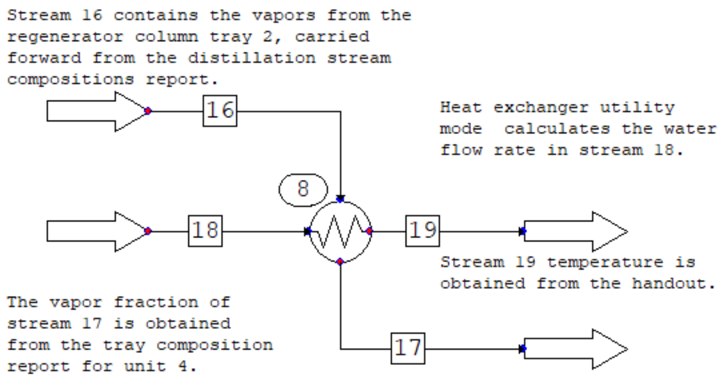
Unit 4:

- Distillation column sized at 500 psia

Condenser design:

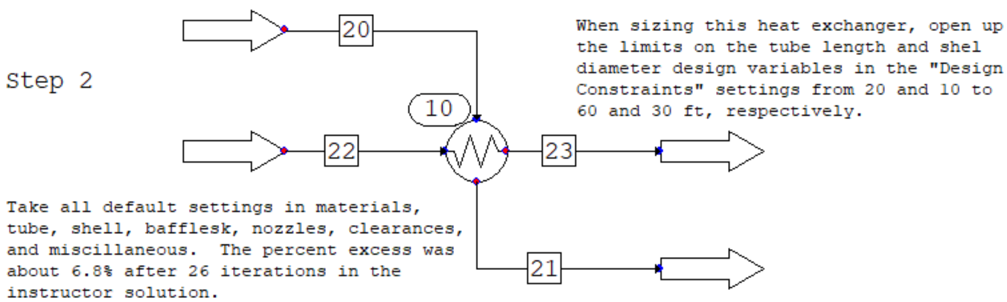
1. Obtain T, P, and composition for stream 16 from "Tray Composition" reporton the regenerator column (Unit 4).
2. The heat exchanger is set to utility mode to calculate the flow rate of stream 18. This requires two specifications.
3. For the 1st spec, use the water outlet temperature given in the handout.
4. For the 2nd spec, obtain vapor fraction of stream 17 from the tray 2

Step 1



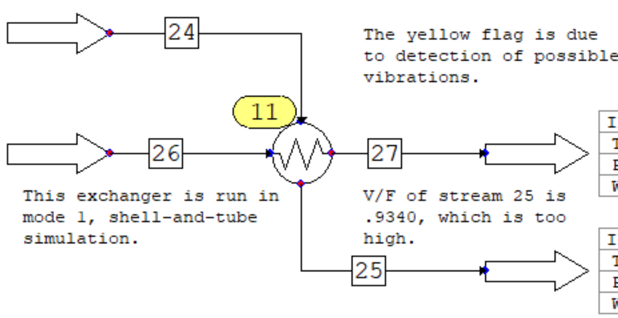
5. Copy and paste the heat exchanger to create a second heat exchanger.
6. Run sizing on the second heat exchanger, taking all defaults.

Step 2



5. Copy and paste the second heat exchanger to create a third heat exchanger.
6. Run exchanger 3 in simulation mode with the costing tool activaed.

Step 3



ID	27
T	69.59 F
P	38.47 psia
W	119788.86 lb/h

ID	25
T	165.01 F
P	13.87 psia
W	7489.36 lb/h

7. Verify that the outlet temperatures on exchanger 3 meet specs.

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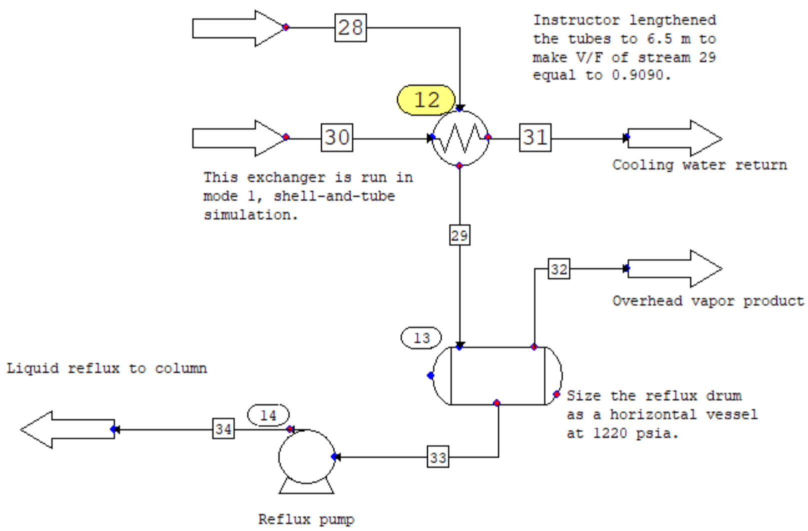
Reflux drum design:

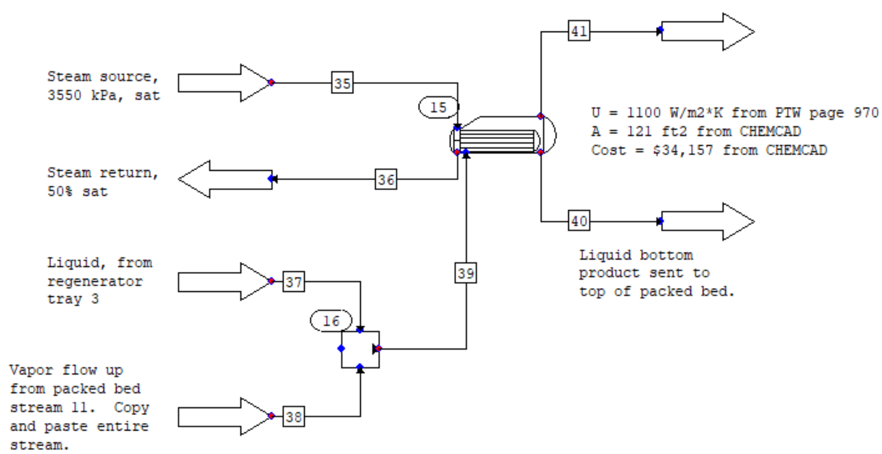
5. Copy and paste the 3rd heat exchanger creating a 4th heat exchanger.
6. In CCTherm, create a copy of the design case and rename it "rating."
7. Lengthn the tubes and continue to adjust them until V/F meets spec.
8. Add the flash drum to separate the vapor and liquid phases.
9. Size the drum and determine its cost.



10. The condenser heat exchanger has pressure drop. Before the reflux can be re-introduced to the column, the relux must be brought back up to the column pressure on the top tray. Add the reflux pump (unit 4e) to re-pressurize the reflux so that is can re-enter the column.

Reboiler design:

11. Build this process with a mixer. The bottom of the column has two feeds, one coming from the reboiler containing the boilup vapors, and the other from the packed bed, stream 11. Use the mixer to add an extra feed.



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Purchased Equipment Cost (PEC)		$1,126,748

Answer Question 7 here:

Environmental information is found in Section 12 of the SDS.

For natural gas, no information is available for ecotoxicity, persistence and degradability, bioaccumulation, or mobility in soil. Anecdotally, methane is considered to be a potent greenhouse gas.

For trigycol, chronic and acute toxicity to fish, daphnia and other aquatic invertebrates is low. Toxicity to algae and sewage bacteria are low.

Answer Question 8 here:

Methane: No special hazards listed.
Health: 2 - Exposure to this molecules could lead to temporary incapacitation or residual injury.
Fire: 4 - This means this molecule rapidly vaporizes and burns readily.
Reactivity (Instability): 0 - This means this molecule is normally stable.

Triglycol: No special hazards listed.
Health: 1 - Exposure can lead to significant irritation.
Fire: 1 - Requires preheating for ignition.
Reactivity (Instability): 0 - This molecule is normally stable.