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

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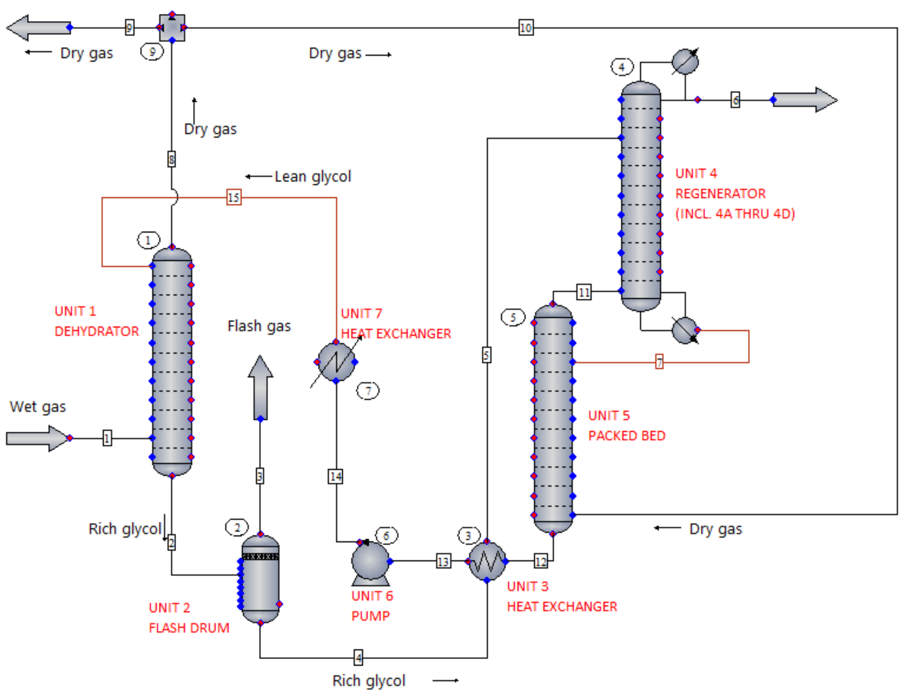
Objectives

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, in 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, this is about one natural gas rig every 10 miles in any direction.

Processing of natural gas after extraction from the ground involves a considerable amount of chemical engineering. The first step is usually the removal of water. The CHEMCAD process flow diagram shown below simulates a typical gas dewatering plant. A working CHEMCAD file containing this design has been provided in Canvas.



The process works as follows: Wet natural gas (wet gas) enters the 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 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 below. This table is also provided as a fillable form in Canvas. Complete the table by entering your results from questions 1-5 for units 4A through 4E. Ensure that the costs are referenced to *February 2024*.
7. **5 Points.** Environmental: This process is to be built in the Finger Lakes Region of New York State, a major gas-producing region, where the ground water is relatively clean. Using the Safety Data Sheets (SDS) provided in Canvas, determine what information would be required to provide a preliminary environmental assessment of the project? Where is this information found in the SDS? 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. Use the provided SDSs to determine the entries would you use for each sector of the diamonds. One set of entries is required for tryglycol and one for natural gas. Use the hazard assessment guidelines in the FE Reference Manual to interpret each of the entries.

Suggestions, Specifications, and Constraints

- Download the CHEMCAD file from 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. Use the fillable form found in Canvas to satisfy this requirement.
2. Questions 7 and 8 require typewritten responses entered into the fillable form found in Canvas.
3. Electronic copy of completed CHEMCAD file uploaded to Canvas.
4. All work is due NLT 1435 hours (End of lab hour).

Table DP4-1 - Summary of Purchased Equipment Costs

Equipment Number	*Name*	*Purchased Cost*
1	**Dehydrator**	$644,558
2	**Flash Drum**	$103,337
3	**Heat Exchanger**	$71,130
4A	Regenerator Column	________
4B	Regen. Condenser	________
4C	Regen. Reflux Drum	________
4D	Regen. Reflux Pump	________
4E	Regen. Reboiler	________
5	**Packed Bed, w/packing**	$30,986
6	**Pump**	$9,801
7	**Preheater**	$5,167
Purchased Equipment Cost (PEC)		________