Material Balances
Ethylene Oxide Production
ENGR 209

Ethylene oxide (EO) is used primarily as a chemical intermediate in making ethylene glycol and certain plastics. It is a major commodity chemical that is manufactured throughout the world.

Ethylene oxide is produced by the catalytic oxidation of ethylene over a silver-containing catalyst. A side reaction oxidizes ethylene to carbon dioxide and water.

$$C_2H_4 + 0.5O_2 \rightarrow C_2H_4O \qquad \zeta_1$$

$$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O \qquad \zeta_2$$

where ζ_i is the extent of reaction of reaction i. The selectivity of these reactions is determined by processing conditions. In the normal operating range for the catalyst (225 to 275°C), lower single-pass conversion favors ethylene oxide production. A simplified process flow diagram for an EO process is shown in Figure 1.

Process Description

Fresh ethylene (Stream 1) and air (Stream 2) are combined with a recycle stream containing unreacted ethylene, carbon dioxide, nitrogen, and traces of water vapor. The combined stream is fed to a reactor, operating between 225 and 275°C. The system pressure is 10 atm. The ethylene in the reactor feed (Stream 3) must be maintained between 5 to 10% for satisfactory catalyst operation. The single pass conversion in the reactor may be adjusted between 20 and 95% to optimize unit performance. All the oxygen in the feed reacts. The reactor effluent (stream 4) is cooled and sent to an absorber operating at 40°C. Essentially all the ethylene oxide is absorbed. Water is fed to the absorber in a 100:1 water:EO ratio. The water-EO mixture is distilled to obtain pure ethylene oxide product. The gas stream leaving the absorber is recycled. A portion of the recycle stream is purged so that excessive amounts of nitrogen and carbon dioxide do not build up in the system. Figure 1 shows a sketch of the process.

Reaction Information

The selectivity for ethylene oxide production is a function of single-pass conversion over the normal operating range. Selectivity data are provided in Table 1.

Operating Costs

Much of the expense in manufacturing ethylene oxide is associated with utility costs like compressing gases to reaction pressure and evaporating liquids for separation in distillation towers. These costs cannot be estimated well in a first chemical engineering course. Therefore, utility costs may be ignored this semester. The difference between product price and feedstock cost should be called revenue. It should not be called profit, since operating and other expenses have not been included.

ethylene cost = $ 0.55 /kg
ethylene oxide price = $ 0.98 /kg

Table 1: Reaction Selectivity Data

% Conversion	ζ_1 / ζ_2
20	6.0
30	5.9
40	5.8
50	5.6
60	5.2
70	4.4
80	3.6
85	2.4
90	1.2
95	0.0

Problem

You, the engineering team, are to optimize the operation of the EO process to produce 50,000 metric-tons/yr (50,000,000 kg/yr) to meet a contract with another company. Your goal is to minimize operating costs and maximize revenue. You are constrained by the selectivity of the reaction and by the operating requirement that reactor feed contain 5-to-10 % ethylene. The feed constraint can be met by adjusting the flow of the purge stream.

You may not use CAD software, but are encouraged to use spreadsheet calculations. You may write your own program if you prefer. If you write a program, any programming language is acceptable. Whether you use a spreadsheet or program, you must turn in hand calculations for one case to demonstrate that the program or spreadsheet is written correctly.

Market Research

Address the following questions as part of your report.

1. What other companies (largest 5) make this product?

2. How many and what size plants does each company have?

3. What percentage of the market would your plant represent?

4. What are the current prices of ethylene and ethylene oxide?
   (Hint: ICIS may help)

5. What is the economic impact on your optimum design if current market values are used rather than the projected values?

Other Information

You should assume that a year equals 8000 hours. This is about 330 days, which allows for periodic shut-down and maintenance of the equipment.

Additional information, *e.g.*, physical properties, may be found in standard references [1-4].

Group Formation

Professor VanAntwerp will assign you to diverse project teams of four students with the possibility of some teams of three.

Deliverables

Interim Report

An interim report is due September 28. This will be a concise report whose goal is the development of a base case EXCEL spreadsheet.

Final Report

Each team will be expected to prepare a written report recommending the best operating procedures for the EO process. This report is due at noon October 21. The report should follow the provided design-report guidelines. Data should be in the form of graphs and tables since this serves to both condense results and make them easily understandable. The appendix should include your spreadsheet or computer program and a hand calculation of a representative case.

References

1. Felder, R. M., Rousseau, R.W., and Bullard, L.G., *Elementary Principles of Chemical Processes,* 4th edition, Wiley, New York, 2016.

2. Felder, R. M. and Rousseau, R.W., *Elementary Principles of Chemical Processes*, 3rd edition, Wiley, New York, 2003.

3. Reid, R. C., J. M. Prausnitz and B. E. Poling, *The Properties of Gases and Liquids,* 4th edition, McGraw Hill, New York, 1987.

4. Perry, R. H. and D. Green, eds., *Perry's Chemical Engineers' Handbook*, 7th edition, McGraw-Hill, New York, 1997.

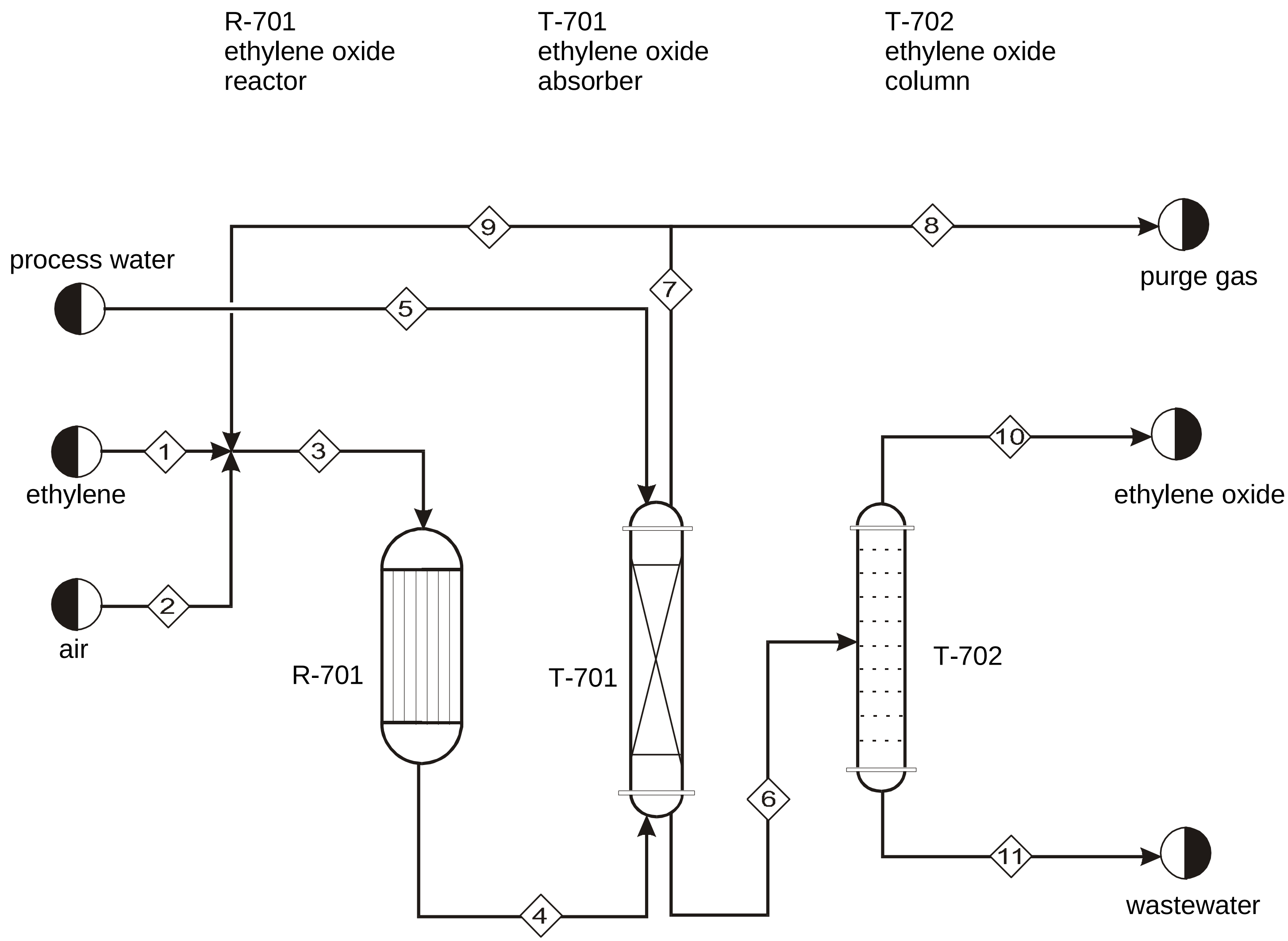

Figure 1: Ethylene Oxide Process