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1960 Problem Production of Ethyl Chloride

FOREWORD

In 1960 a committee from the Stauffer Chemical Company, Richmond, California, was responsible for the problem. The committee members were R. G. Campbell, chairman; T. C. S. Dao; H. T. Fullam; G. E. Klingman; and C. L. Stoner. Fifty-six solutions were received from thirty-two schools.

The A. McLaren White Award, first prize of \$200, went to Neil Adrien Dougharty, Lamar State College of Technology; the A. E. Marshall Award, second prize of \$100, to Carroll Thomas Science, University of Oklahoma; the third prize of \$50 to Richard John Hampton, McGill University; and honorable mention to Ray James Comeaux, Lamar State College of Technology; William B. Lumpkin, Oklahoma State University; and Allan Sass, Cooper Union. The first-prize-winning solution follows on page 32.

TO THE CONTESTANT

The chemical engineer is often called upon to compare the economics of process alternatives. The problem presented here is a practical one of a type frequently encountered in the chemical industry; it involves both process design and economic considerations.

Ethyl chloride is a multimillion-pound-per-year product in this country, most of it being used in the production of antiknock fluid, tetraethyl lead. Some ethyl chloride is produced by reacting ethanol with hydrochloric acid, a small amount results as a by-product of other reactions, but most of it is produced through the reaction of ethylene and anhydrous hydrogen chloride in the presence of a catalyst in a liquid phase system.

INTRODUCTION

A suggested flowsheet is given showing principal streams. A nonvolatile catalyst is present in the reactor, R-1, in which all the chemical reaction that occurs takes place.

This reaction is exothermic. In this suggested case the reactor contents are held at 120° F. by

allowing the heat of reaction to vaporize liquid ethyl chloride under the equilibrium pressure of the reaction system. Heat exchangers H-1 and H-2 liquify the vaporized product and return sufficient crude ethyl chloride to the reactor to maintain the liquid level in the reactor. The remaining ethyl chloride is purified for production by the fractionating column, C-1. This column removes hydrogen chloride, ethane, and ethylene from the product. These gases, along with some ethyl chloride, are recycled to the reactor.

If the water-cooled exchanger is found to condense sufficient ethyl chloride for the production of the plant, only this ethyl chloride will be distilled in C-1. If this exchanger does not condense sufficient ethyl chloride, the deficit will have to be made up with ethyl chloride from the refrigeration-cooled exchanger.

STATEMENT OF PROBLEM

This problem involves an economic comparison of two different ethylene feed-gas streams.

You will have a 92.5 mole % ethylene and 7.5 mole % ethane gas stream available to you at 4.3¢/lb. of contained ethylene or a 97.5 mole % ethylene and 2.5 mole % ethane gas stream

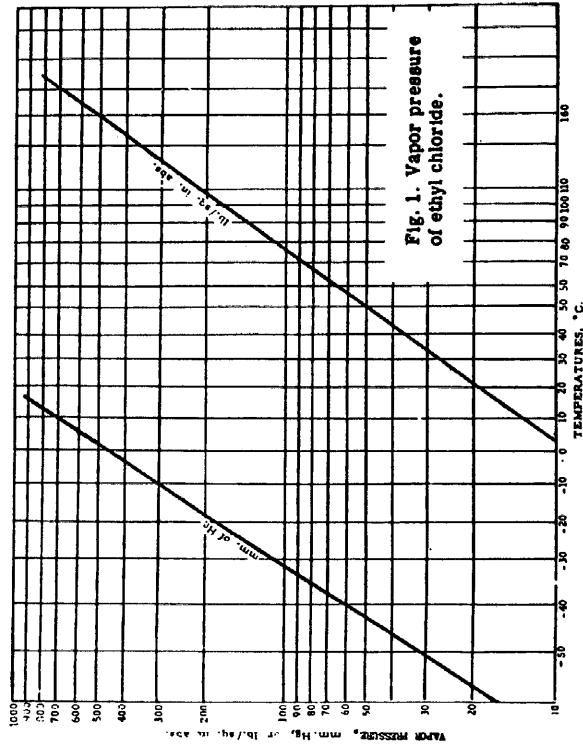


Fig. 1. Vapor pressure of ethyl chloride.

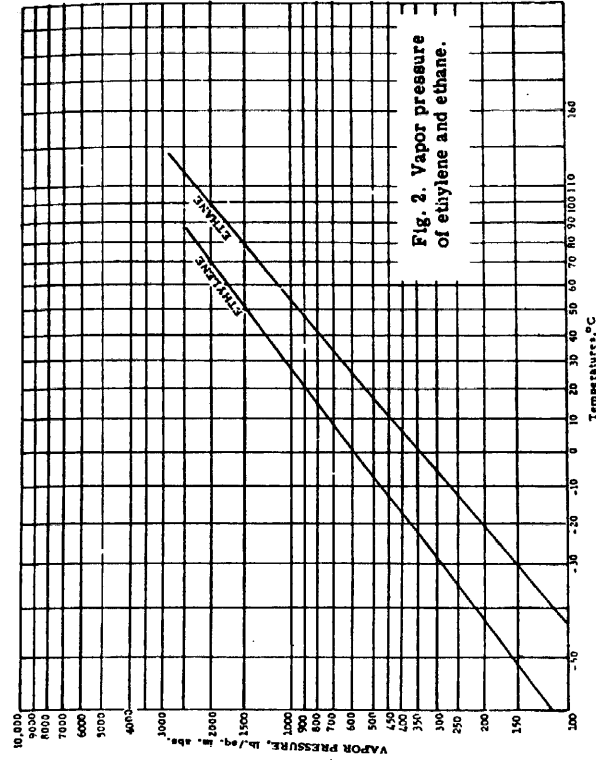


Fig. 2. Vapor pressure of ethylene and ethane.

available at 4.5¢/lb. of contained ethylene. The ethane content will not be considered as having any value. You, as a process design engineer, must determine which stream is more economical to use as a source of ethylene.

The underflow rate of column C-1 is to be at a rate of 2,350,000 lb. of ethyl chloride/month when the plant is operating 100% of the time.

The following list of conditions and simplifying assumptions is recommended:

1. The vent losses of hydrogen chloride and ethylene are each 2.5% of the quantity introduced to the reactor in the feed streams.
2. The vent gas has been cooled to such a temperature in H-2 that the loss of ethyl chloride in this stream is 1.0% of that which was produced in the reactor, R-1.
3. Equal moles of ethylene and hydrogen chloride are fed to R-1 through the fresh feed streams.
4. No by-products are produced.
5. The catalyst in R-1 exerts no physical effect on the system.
6. Ethylene and hydrogen chloride feed streams enter the reactor at 25°C.
7. The heat of reaction for ethylene and hydrogen chloride as gases at 25°C. to form

liquid ethyl chloride at 25°C. may be assumed to be 40,000 B.t.u./lb.-mole reacting.

8. The process streams leaving H-1 and H-4 are at 95° F.

9. Cooling water is available at 85° F. To avoid scaling, do not allow it to leave the exchanger at a temperature higher than 110° F.

10. The mean temperature difference (MTD) correction factor for H-1 is 0.95.

11. The cost of cooling water is 2.63¢/1,000 gal. pumped including all costs.

12. The cost of refrigeration is 4¢/(hr.)(ton) at -50°C., 3¢/(hr.)(ton) at -20°C., and 2¢/(hr.)(ton) at 10°C. H-2 temperature including all costs.

The refrigerant in H-2 is a liquid boiling at constant temperature in the exchanger shell. The refrigerant temperature should be 10°C. below the temperature required by the process. The cost of the refrigeration used can be obtained by extrapolation or interpolation of the cost-temperature data given above.

13. Use the following over-all heat transfer coefficients for the outside surface of the heat exchanger tube:

Condensing: 120 B.t.u./hr.(sq. ft.)(° F.)

Liquid cooling: 60 B.t.u./hr.(sq. ft.)(° F.)

Gas (vapor) cooling: 30 B.t.u./hr.(sq. ft.)(° F.)

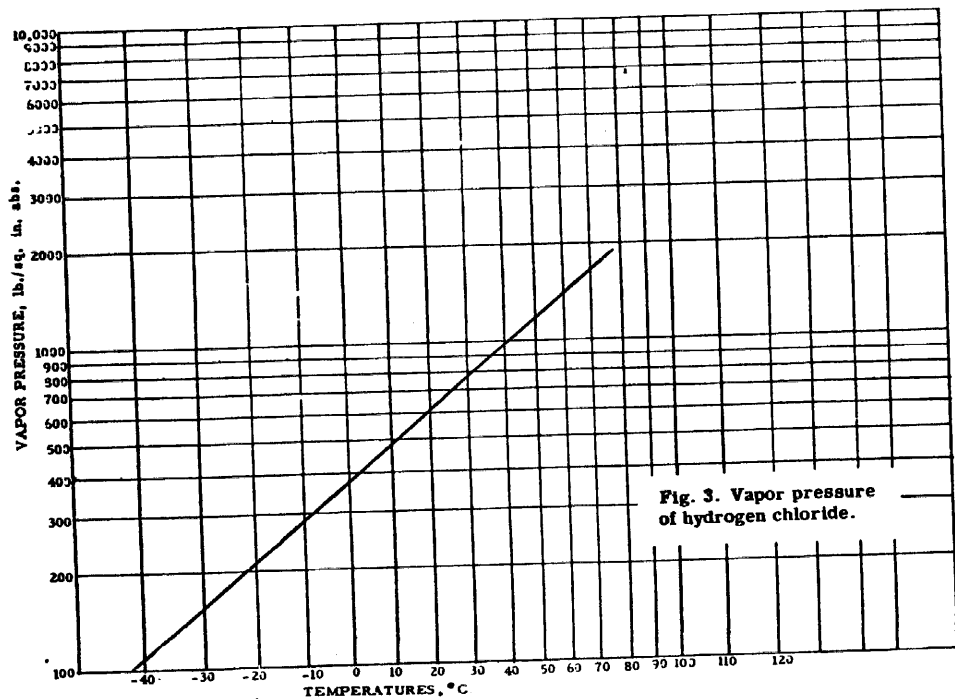


Fig. 3. Vapor pressure of hydrogen chloride.

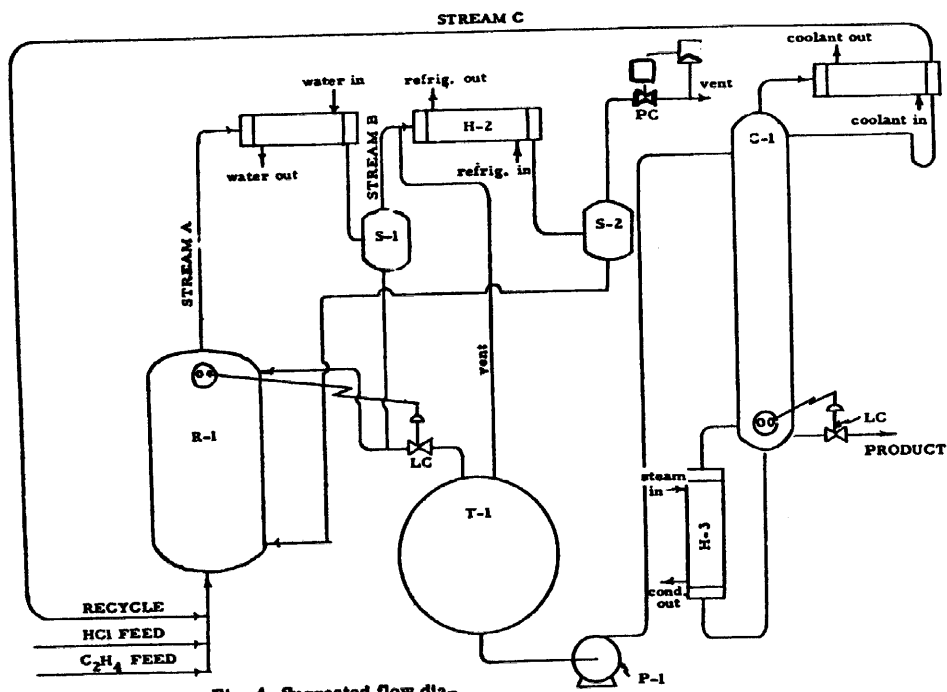


Fig. 4. Suggested flow diagram, ethyl chloride plant.

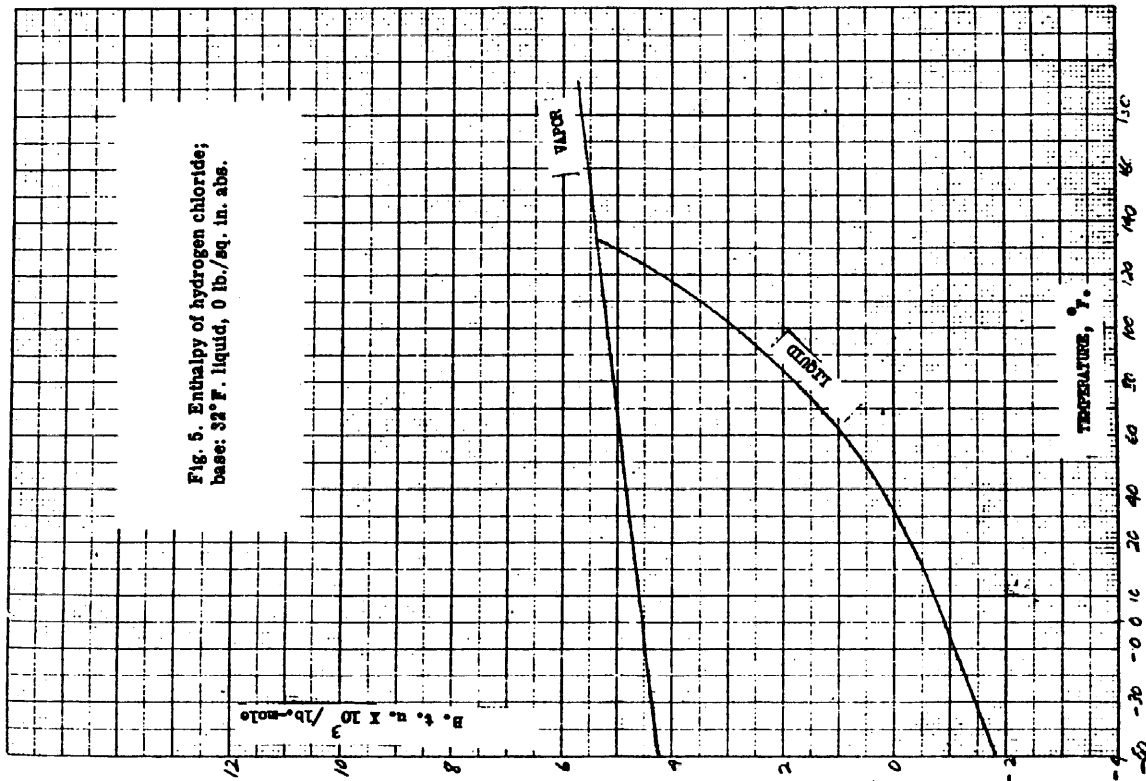


Fig. 5. Enthalpy of hydrogen chloride;
base: 32°F. liquid, 0 lb./sq. in. abs.

One should keep in mind that the quantity of vapor is constantly decreasing as the process stream flows through the exchanger.

14. The ethane, ethylene, and hydrogen chloride gas stream (stream C) recycling from H-4 is saturated at R-1 pressure plus 4 lb./sq. in. with ethyl chloride vapor.

15. Assume Dalton's and Raoult's laws hold for all components in the system.

16. There is no pressure drop in heat exchangers or pipe lines.

17. Assume that there is no heat loss or gain to or from the surroundings involved in any part of the system.

18. Assume that the cost of installing and operating C-1, H-3, and H-4 is the same for both cases.

19. Assume that the cost of pipelines, insulation, instrumentation, labor, maintenance materials, supplies, and laboratory expenses is the same for both ethylene feed streams.

20. Assume the following installed costs for the heat exchangers H-1 and H-2:

Outside area, sq. ft.	H-1	H-2
100	1,800	2,600
200	2,880	4,000
500	6,350	7,850
1,000	11,650	13,900

Outside area, sq. ft.	H-1	H-2
2,000	21,600	25,400
5,000	50,000	59,400

In determining the cost of using H-1 and H-2, use a straight-line amortization rate of ten years. Property taxes and fire insurance may be taken as 2.3%/year of the capital cost.

H-1 and H-2 will not be an exact size such as 500 or 2,000 sq. ft. To find the exchanger cost, interpolate or extrapolate the cost-area data given above.

REPORT

You should prepare a formal report giving your findings on the relative economics of the two cases. All your calculations should be included along with a simplified flowsheet giving heat and material balances for each pertinent stream.

REFERENCE

Perry, John H., ed., "Chemical Engineers' Handbook," 3 ed., pp. 585-587, 257-259, McGraw-Hill Book Company, Inc., New York (1950).