

**16-CHEM-A5, CHEMICAL PLANT DESIGN and ECONOMICS**

MAY 2019

3 hours duration

**NOTES**

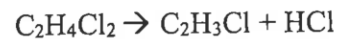
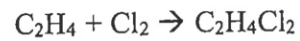
1. If doubt exists as to the interpretation of any question, the candidate is urged to submit with the answer paper, a clear statement of any assumptions made.
2. The examination is a **CLOSED BOOK EXAM**. One aid sheet allowed written on both sides.
3. Candidates may use approved **Sharp/Casio** calculator.
4. **Five (5) questions** constitute a complete exam paper.
5. The questions are of equal value (**20 points each**).
6. Only the **first five questions** as they appear in the answer book(s) will be marked.
7. Clarity and organization of the answer are important. For questions that require calculations, please show all your steps.
8. State all assumptions clearly.

Q1. Vinyl chloride ( $C_2H_3Cl$ ) can be manufactured by at least three different reaction paths as shown below:

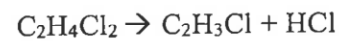
Path #1 → From acetylene and hydrogen chloride



Path #2 → From ethylene and chlorine via dichloroethane



Path #3 → From ethylene, oxygen and hydrogen chloride via dichloroethane



The market value and molar masses of all the materials involved are listed below:

Material	Molar Mass (kg/kmol)	Market Value (\$/kg)
Acetylene ( $C_2H_2$ )	26	1.0
Chlorine ( $Cl_2$ )	71	0.23
Ethylene ( $C_2H_4$ )	28	0.53
Hydrogen Chloride (HCl)	36	0.39
Vinyl Chloride ( $C_2H_3Cl$ )	62	0.46

There is no cost for oxygen because it is obtained from the atmosphere.

- a) [8 points] Which reaction path makes most sense on the basis of raw material costs, product and by-product?

You are asked to devise a process from the above three reaction paths that uses ethylene and chlorine as raw materials and produces no by-products other than water.

- b) [12 points] Is the process with no by-products other than water economically attractive?

Q2. In liquid-liquid extraction, solvents like water, ethylene glycol, chloroform, benzene, ethyl acetate, etc., are contacted with feed mixture to separate the desired product. The desired product is transferred to liquid solvent and then separated from the solvent by unit operations like distillation. Supercritical extraction (SCE) is a liquid-liquid extraction technique where a supercritical fluid (SCF) like CO<sub>2</sub> is used as a solvent. List and describe the advantages and disadvantages of supercritical extraction over conventional unit operations.

Q3. Monoethanolamine (MEA) reacts with ammonia and hydrogen to produce ethylenediamine (EDA), which is used in the manufacture of chelating agents and carbamate fungicides. The reaction occurs in gas phase over a catalyst at temperatures below 300 °C and pressures in excess of 245 atmospheres. The products and composition of the reaction between MEA, ammonia and hydrogen are listed below:

Ethylenediamine (EDA) → 74%

Diethyltriamine (DETA) → 8%

Piperazine (PIP) → 4%

Aminoethylpiperazine (AEP) → 10%

Hydroxyethylpiperazine (HEP) → 4%

The following data is available:

Fixed Capital Cost → \$10.3 Million

Interest Rate → 10% per year

Utility Costs per Kg of Total Products:

Electricity →  $3.56 \times 10^6$  J @  $4.17 \times 10^{-7}$  cents/J

Steam at 1 atm → 18.1 kg @ 0.0113 cents/kg

Water →  $0.1528$  m<sup>3</sup> @ 3.17 cents/m<sup>3</sup>

Operating Labor Rate → \$8.61/hr

Land Cost → 1.5% of Depreciable Capital Cost

Land Development Cost → 2.1% of Depreciable Capital Cost

Total Raw Material Cost → 80 cents/kg

If the production rate is 10,000 metric tons per year and the plant is to operate 8000 hours (333 days) each year without interruption, what is the production cost per kilogram of total product?

**Q4.** A chemical plant with a fixed capital investment of \$100 million generates an annual gross profit of \$50 million. The rate of corporate income tax is 35%. Calculate the depreciation charge, taxes paid, and after-tax cash flows for the first 10 years of plant operation using the following:

- (a) [10 points] Straight-line depreciation over 10 years.
- (b) [10 points] Modified Accelerated Cost Recovery System (MACRS) depreciation with a 7-year recovery period.

Assume the plant was built at time zero, begins operation at full rate in year one, and taxes must be paid based on the previous year's income.

- Q5.** The purpose of chemical processes is to make chemicals in a profitable yet sustainable manner. Therefore, chemical processes should be designed such that it retains the capacity of ecosystems to support both industrial activity and life into the future. When developing a design, it helps if it is recognized there is a hierarchy that is intrinsic to chemical processes. List and describe ten important hierarchical elements or components that are intrinsic to a chemical process.
- Q6.** A pharmaceutical plant manufacturing bulk drugs uses acetone for final purification of a product. After filtration, the wet cake is dried in a fluidized-bed dryer in which nitrogen is used as a drying medium. The off gases from the dryer is saturated nitrogen with vapor of water and acetone at near atmospheric pressure and 75-90 °C. Local pollution control authority requires that the emissions from the dryer must contain acetone below 200 ppm. Prepare a piping and instrumentation diagram (P&ID) for volatile organic compound (VOC) emission control scheme.