04-CHEM-A5, CHEMICAL PLANT DESIGN and ECONOMICS

December 2016

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. Monochlorodecane (MCD) is to be produced from decane (DEC) and chlorine via the following reaction:

$$C_{10}H_{22}\ (DEC) + Cl_2 \rightarrow C_{10}H_{21}Cl\ (MCD) + HCl$$

A side reaction occurs in which dichlorodecane (DCD) is produced by the following reaction:

$$C_{10}H_{21}Cl\ (MCD) + Cl_2 \rightarrow C_{10}H_{20}Cl_2\ (DCD) + HCl$$

The byproduct, DCD, is not required for this project. Hydrogen chlorine (HCl) can be sold to a neighbouring plant. Assume at this stage all separations can be carried out by distillation. Information on chemicals involved in this project are given below.

Material	Molecular Weight	Normal Boiling Point (K)	Value ($/kg)
HCl	36	188	0.35
Chlorine	71	239	0.21
Decane	142	447	0.27
MCD	176	488	0.45
DCD	211	514	0.0

(a) **[12 points]** Determine alternative recycle structures for the process by assuming different levels of conversion of raw materials and different excesses of reactants.

(b) **[3 points]** Which structure is most effective in suppressing the side reaction?

(c) **[5 points]** What is the minimum selectivity of decane that must be achieved for profitable operation?

Q2. An existing distillation column is to be revamped to increase its capacity by replacing the existing trays with stainless steel structured packing. The column shell is 46 m high, 1.5 m diameter, and currently fitted with 70 sieve trays with a spacing of 0.61 m. The existing trays are to be replaced with a stainless steel structured packing with a total height of 30 m. Estimate the cost of the project using tables given below.

Table 2.1 Typical equipment capacity delivered capital cost correlations.

Equipment	Material of construction	Capacity measure	Base size Q_B	Base cost C_B (S)	Size range	Cost exponent M
Agitated reactor	CS	Volume (m^3)	1	1.15×10^4	1–50	0.45
Pressure vessel	SS	Mass (t)	6	9.84×10^4	6–100	0.82
Distillation column (Empty shell)	CS	Mass (t)	8	6.56×10^4	8–300	0.89
Sieve trays (10 trays)	CS	Column diameter (m)	0.5	6.56×10^3	0.5–4.0	0.91
Valve trays (10 trays)	CS	Column diameter (m)	0.5	1.80×10^4	0.5–4.0	0.97
Structured packing (5 m height)	SS (low grade)	Column diameter (m)	0.5	1.80×10^4	0.5–4.0	1.70
Scrubber (Including random packing)	SS (low grade)	Volume (m^3)	0.1	4.92×10^3	0.1–20	0.53
Cyclone	CS	Diameter (m)	0.4	1.64×10^3	0.4–3.0	1.20
Vacuum filter	CS	Filter area (m^2)	10	8.36×10^4	10–25	0.49
Dryer	SS (low grade)	Evaporation rate (kg $H_2O \cdot h^{-1}$)	700	2.30×10^5	700–3000	0.65
Shell-and-tube heat exchanger	CS	Heat transfer area (m^2)	80	3.28×10^4	80–4000	0.68
Air-cooled heat exchanger	CS	Plain tube heat transfer area (m^2)	200	1.56×10^5	200–2000	0.89
Centrifugal pump (Small, including motor)	SS (high grade)	Power (kW)	1	1.97×10^3	1–10	0.35
Centrifugal pump (Large, including motor)	CS	Power (kW)	4	9.84×10^3	4–700	0.55
Compressor (Including motor)		Power (kW)	250	9.84×10^4	250–10,000	0.46
Fan (Including motor)	CS	Power (kW)	50	1.23×10^4	50–200	0.76
Vacuum pump (Including motor)	CS	Power (kW)	10	1.10×10^4	10–45	0.44
Electric motor		Power (kW)	10	1.48×10^3	10–150	0.85
Storage tank (Small atmospheric)	SS (low grade)	Volume (m^3)	0.1	3.28×10^3	0.1–20	0.57
Storage tank (Large atmospheric)	CS	Volume (m^3)	5	1.15×10^4	5–200	0.53
Silo	CS	Volume (m^3)	60	1.72×10^4	60–150	0.70
Package steam boiler (Fire-tube boiler)	CS	Steam generation ($kg \cdot h^{-1}$)	50,000	4.64×10^5	50,000–350,000	0.96
Field erected steam boiler (Water-tube boiler)	CS	Steam generation ($kg \cdot h^{-1}$)	20,000	3.28×10^5	10,000–800,000	0.81
Cooling tower (Forced draft)		Water flowrate ($m^3 \cdot h^{-1}$)	10	4.43×10^3	10–40	0.63

CS = carbon steel; SS (low grade) = low-grade stainless steel, for example, type 304; SS (high grade) = high-grade stainless steel, for example, type 316

Table 2.8 Modification costs for distillation column retrofit[17].

Column modification	Cost of modification (multiply factor by cost of new hardware)
Removal of trays to install new trays	0.1 for the same tray spacing 0.2 for different tray spacing
Removal of trays to install packing	0.1
Removal of packing to install new trays	0.07
Installation of new trays	1.0–1.4 for the same tray spacing 1.2–1.5 for different tray spacing 1.3–1.6 when replacing packing
Installation of new structured packing	0.5–0.8

Q3. The transfer of heat to and from process fluids is an essential part of most chemical processes.

(a) [11 points] List the steps involved in a typical design procedure for a heat exchanger.

Cyclones are the principal type of gas-solids separators employing centrifugal force and widely used in the chemical industry.

(b) [9 points] List the steps involved in a general design procedure for a cyclone separator.

Q4. Plastics are being increasingly used as corrosion-resistant materials in construction of chemical plants. They are also widely used in food processing and biochemical plants. List the properties and typical areas of use of the following plastics used for chemical plant:

a) [3 points] Polyvinyl Chloride or PVC

b) [2.5 points] Polyolefins

c) [3 points] Polytetrafluoroethylene or PTFE

d) [2.5 points] Polyvinylidene Fluoride or PVDF

e) [6 points] Glass-Fiber Reinforced Plastics or GRP

f) [3 points] Rubber

Q5. One of the principal approaches to making a process inherently safe is to limit the inventory of hazardous material. The inventories to be avoided most of all are flashing flammable or toxic liquids, i.e., liquids under pressure above their atmospheric boiling points.

a) **[9 points]** List 7 common changes that should be considered to improve inherent safety in reactors.

b) **[4 points]** List 3 common changes that should be considered to improve inherent safety in distillation.

c) **[4 points]** List 4 common changes that should be considered to improve inherent safety in heat transfer operations.

d) **[3 points]** List 3 common changes that should be considered to improve inherent safety in storage.

Q6. List the following:

a) [4.5 points] 5 main factors to consider when selecting a screening or sieving equipment.

b) [5.5 points] 6 principal design and operating factors to consider when using a centrifugal filter.

c) [6.5 points] 7 main factors to consider when selecting an evaporator.

d) [3.5 points] 4 main factors to consider when selecting equipment for movement and storage of solids.