National Exams May 2015

04-CHEM-A5, Chemical Plant Design and Economics

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. The questions are of equal value (20 points each).
5. Only the first five questions as they appear in the answer book(s) will be marked.
6. Most questions require an answer in essay format. Clarity and organization of the answer are important. Some of the questions require calculations – Please show all your steps.
7. State all assumptions clearly.

Q1. Process Flowsheet Diagram

Methyl tert-butyl ether (MTBE) was included in gasoline during the 1990s to boost octane and as an oxygenate to reduce ozone-generating emissions. Unfortunately, MTBE persisted in the natural environment and became a serious groundwater pollutant. To compensate for mandatory removal of MTBE in the early 2000s, refineries scaled up production of motor alkylate. Alkylation is a process whereby C_3 to C_5 olefins are reacted with isobutene to produce a paraffinic mixture that can be distilled to yield a gasoline blendstock or motor alkylate of high octane rating. A distillation module, known as an alkylate splitter, is used in the refinery to separate reactor effluent (various C_4 to C_{14} hydrocarbons) into two streams. The split is made between C_8 and C_{10} fractions to yield distillate suitable for automotive fuel (motor alkylate) and a bottom product for furnace fuel (heavy alkylate). Feed composition and product specifications are listed below:

		Composition (Mole Fraction)		
Component	Molecular Weight	Feed (Reactor Effluent)	Motor Alkylate	Heavy Alkylate
C_4H_{10}	58	0.008	0.01	
C_5H_{12}	72	0.051	0.06	
C_6H_{14}	86	0.029	0.03	
C_7H_{16}	100	0.032	0.03	
C_8H_{18}	114	0.730	0.79	0.11
C_9H_{20}	128	0.073	0.07	0.06
$C_{10}H_{22}$	142	0.043	0.01	0.41
$C_{11}H_{24}$	156	0.005		0.06
$C_{12}H_{26}$	170	0.007		0.08
$C_{13}H_{28}$	184	0.006		0.08
$C_{14}H_{30}$	198	0.009		0.11
$C_{15}H_{32}$	212	0.007		0.09
TOTAL		1.0000	1.00	1.00

This refinery module should be designed to process 650,000 m^3/yr of feed liquid. Prepare a flowsheet diagram for the process.

Q2. Cost Estimation

A carbon steel heat exchanger that costs $140,000 is expected to have a service life of 5 years before it requires replacement. If type 304 stainless steel is used, then the service life will be increased to 10 years. Which heat exchanger (carbon steel or stainless steel) is the most economical if the cost of capital is 12%? The material cost factor (f_m) of type 304 stainless steel relative to plain carbon steel is 1.3.

Values of Annual Capital Charge Ratio (ACCR) for Different Interest Rates

Interest Rate	ACCR: 10 Year Life	ACCR: 20 Year Life
10%	0.163	0.117
12%	0.177	0.134
15%	0.199	0.160
20%	0.239	0.205
25%	0.280	0.253
30%	0.323	0.302

Q3. Rate of Return

An oil company is offered a lease of a group of oil wells on which the primary reserves are close to exhaustion. The major condition of the purchase is that the oil company must agree to undertake a water-flood project at the end of 5 years to make possible secondary recovery. No immediate payment by the oil company is required. The relevant cash flows have been estimated as follows:

Year 0	Year 1-4	Year 5	Year 6-20	Investor's Rate of Return	Net Present Worth at 10%
0	$50,000	-$650,000	$100,000	?	$227,000

a) [10 points] Should the lease-and-flood arrangement be accepted?

b) [10 points] The company's Board of Directors understand and make it a policy to evaluate by the investor's rate of return. What is the investor's rate of return?

Q4. Selection of Materials of Construction

Suggest suitable materials of construction with brief explanation for the following applications:

a) **[3 points]** A 10,000 m^3 storage tank for toluene.
b) **[3 points]** A 5 m^3 tank for storing a 30% w/w aqueous solution of sodium chloride.
c) **[3 points]** A 2 m diameter, 20 m high distillation column, distilling acrylonitrile.
d) **[3 points]** A 100 m^3 storage tank for strong nitric acid.
e) **[4 points]** A 500 m^3 aqueous waste hold-up tank. The wastewater pH can vary from 1 to 12. The wastewater will also contain traces of organic material.
f) **[4 points]** A packed column (0.5 m diameter, 3 m high) absorbing gaseous hydrochloric acid into water. The column will operate at essentially atmospheric pressure.

Q5. Equipment Design

A light oil (flow rate = 1000 kg/hr, density = 0.9 g/cc, 1 mN.s/m^2) needs to be separated from water (flow rate = 5000 kg/hr, density = 1.0 g/cc, 1 mN.s/m^2). The oil is the light, dispersed phase and water is the heavy, continuous phase. The droplet diameter of light oil is 150 μm. Design a decanter settler including piping arrangement to accomplish this separation. Assume the following:

a) The dispersion band is 10% of the height of the decanter.
b) The oil-water interphase is halfway up the decanter.
c) The light oil take-off is at 90% of the height of the decanter.

Q6. Process Design Safety

A short safety checklist, covering the main items that should be considered in process design, is given below:

a) **[3 points]** Materials
b) **[3 points]** Reactors
c) **[3 points]** Pressure Systems
d) **[3 points]** Control Systems
e) **[3 points]** Storages
f) **[3 points]** General
g) **[2 points]** Fire Protection

List at least six factors that need to be considered within each item listed above for safe design of a chemical plant.