04-CHEM-A5, CHEMICAL PLANT DESIGN and ECONOMICS

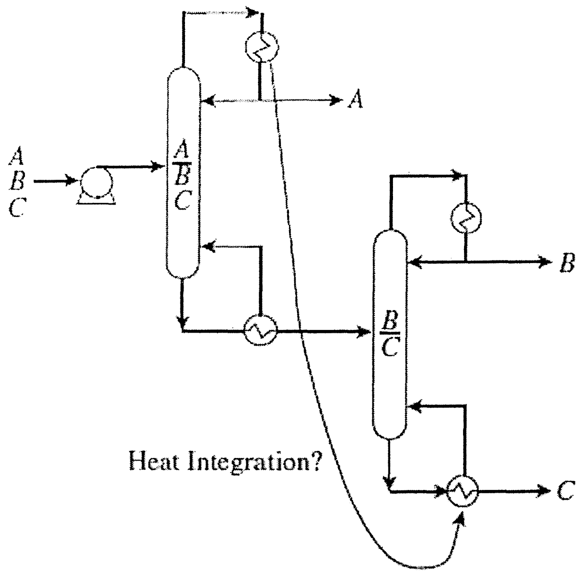
May 2016

3 hours duration

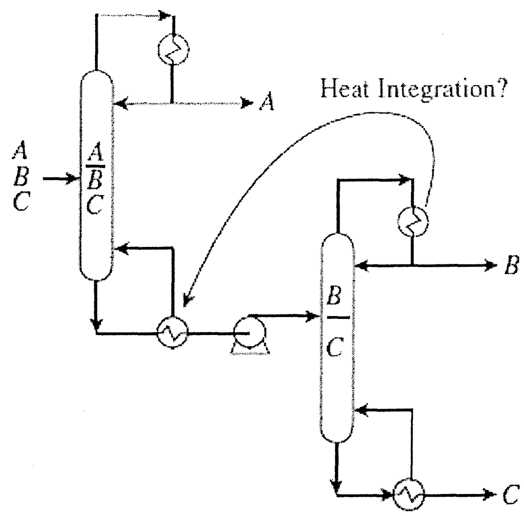
NOTES

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. Two simple distillation columns have been sequenced to be in the direct sequence, and opportunities for heat integration between the two columns are to be explored as shown below:



(a) Forward heat integration.



(b) Backward heat integration.

The operating pressures of the two columns need to be chosen to allow heat recovery. Data for Column #1 and Column #2 at various pressures are given below:

COLUMN #1

Pressure (bar)	Condenser Temperature (°C)	Reboiler Temperature (°C)	Condenser Heat Duty (kW)	Reboiler Heat Duty (kW)
1	90	120	3000	3000
2	130	160	3600	3600
3	140	170	4000	4000
4	160	190	4300	4300

COLUMN #2

Pressure (bar)	Condenser Temperature (°C)	Reboiler Temperature (°C)	Condenser Heat Duty (kW)	Reboiler Heat Duty (kW)
1	110	130	5000	5000
2	130	153	6000	6000
3	150	175	6300	6300
4	163	190	6500	6500
5	170	200	6600	6600

Medium-pressure steam is available for reboiler heating at 200°C. Cooling water is available for condenser, to be returned to the cooling tower at 30°C. Assuming a minimum permissible temperature difference for heat transfer of 10°C, determine the minimum heating and cooling requirements for the following:

(a) **[6 points]** Both columns operating at 1 bar

(b) **[7 points]** Forward heat integration

(c) **[7 points]** Backward heat integration

Q2. A firm is evaluating two competing projects. The first is a new inorganic chemicals plant, while the second is the expansion of a textile fibers facility. The process engineers have estimated the projected annual revenue, total capital investment, and total annual cost (without capital recovery) for each project as follows:

	Cost of Inorganic Chemicals Plant	Cost of Textile Fibers Plant Expansion
Projected Revenue	\$33,700,000	\$30,900,000
Total Capital Investment	\$52,500,000	\$57,300,000
Total Annual Cost	\$25,100,000	\$21,500,000

Both the new and expanded plants would have an estimated life of 20 years. The firm's marginal acceptable rate of return is 12.5% before tax, and its marginal federal and provincial income tax rate is 52%. Assuming straight-line depreciation with zero salvage and that 100% of the investment is depreciable, calculate the net present worth of each project.

Q3. There are several processes involved in the treatment of drinking water, but three of the most important ones are associated with removal of suspended matter, which is known as turbidity. Turbidity removal is brought about by adding chemicals that cause small suspended solids to clump together (coagulation), forming larger particles that can be removed through settling (sedimentation). The few particles that remain after sedimentation are filtered out in sand, carbon, or coal filters (filtration). In general, as the dosage of the chemicals is increased, more coagulation occurs (up to a point), so there is increased removal of particles through the settling process. This means that fewer particles have to be removed through filtration, which means the filter will not have to be cleaned as often through backwashing. To minimize the total cost associated with coagulation and filtration, it is necessary to obtain a relationship between the coagulant dosage and water turbidity after coagulation and sedimentation, but before filtration. This relationship is

$$\mathbf{T = 37.0893 - 7.739\,F + 0.7263\,F^2 - 0.0233\,F^3}$$

where T → turbidity of settled water

F → coagulant dosage in mg per liter

The backwash data can be described by the equation

$$B = -0.549\ F + 1.697\ T$$

where B → backwash water rate in m^3 per 1000 m^3 of product water

The cost of water is \$0.0608/m^3 and the chemical cost of coagulation is \$0.183 per kg of coagulant.

(a) **[13 points]** What dosage of coagulant will result in minimum total cost (coagulation and filtration) per 1000 m^3 of product water? What is this minimum total cost?

(b) **[7 points]** The plant was using 12 mg/liter of coagulant dosage and an average flow rate of 189,250 m^3/day. What will be the percentage saving in total cost if the plant switched to the coagulant dosage from part (a)?

Q4. Choose a suitable material of construction for a 50 mm pipe operating at 2 bar pressure and carrying the following:

a) **[2 points]** 98% by weight sulfuric acid at 70 °C
b) **[2 points]** 5% by weight sulfuric acid at 30 °C
c) **[2 points]** 30% by weight hydrochloric acid at 50 °C
d) **[2 points]** 5% aqueous sodium hydroxide solution at 30 °C
e) **[2 points]** Concentrated sodium hydroxide solution at 50 °C
f) **[2 points]** 5% by weight nitric acid at 30 °C
g) **[2 points]** Boiling concentrated nitric acid
h) **[2 points]** 10% by weight sodium chloride solution
i) **[2 points]** A 5% by weight solution of cuprous chloride in hydrochloric acid
j) **[2 points]** 10% by weight hydrofluoric acid

Q5. Continual monitoring of equipment and plant is standard practice in chemical process plants. Equipment deteriorates and operating conditions may change. During startup and shutdown, stream compositions and operating conditions are much different from those under normal operations, and their possible effect on safety must be taken into account.

a) **[13 points]** List 10 common safety questions that need to be checked in order to safely expedite startup of a chemical process plant.

b) **[7 points]** List 5 common safety questions that need to be checked in order to safely shutdown a chemical process plant.

Q6. List the following:

a) **[3.5 points]** 7 main factors to be considered when selecting a dryer

b) **[4 points]** 8 principal factors to be considered when selecting a filtration equipment

c) **[3 points]** 6 main factors to be considered when selecting equipment for crushing and grinding

d) **[2.5 points]** 5 main factors to be taken into account when choosing equipment for mixing liquids

e) **[7 points]** A general overall procedure for designing a chemical reactor