04-CHEM-A5, CHEMICAL PLANT DESIGN AND ECONOMICS

December 2015

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. Consider a process for producing benzene (C_6H_6) from toluene (C_7H_8) by hydrodealkylation. The homogeneous gas-phase reactions of interest are as follows:

$$C_7H_8 + H_2 \rightarrow C_6H_6 + CH_4 \qquad 2\,C_6H_6 \rightleftharpoons C_{12}H_{10} + H_2$$

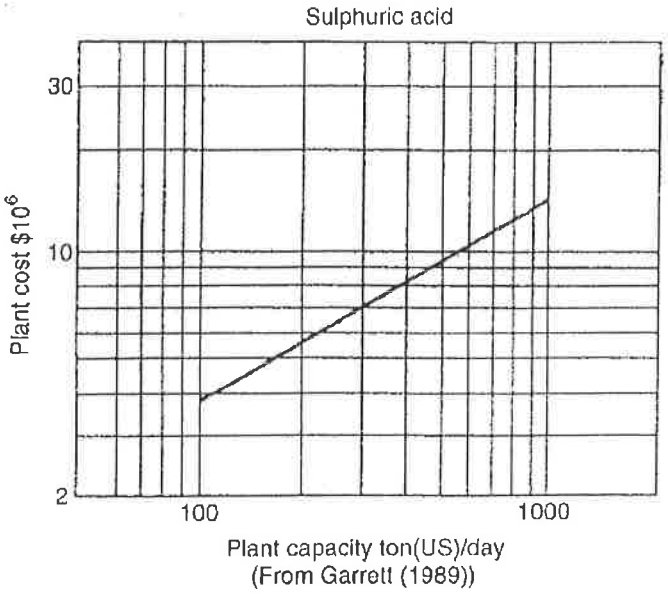
These reactions take place in the range between 620 °C and 705 °C and at a pressure of about 33 atm. An excess of hydrogen (a 5:1 ratio) is needed to prevent coking, and the reactor effluent gas must be rapidly quenched to 620 °C in order to prevent coking in the heat exchanger following the reactor. The production rate of benzene is 265 moles/hr and product purity of benzene is 99.97%. Raw materials for the reactions are pure toluene at ambient conditions, and H_2 stream containing 95% H_2 and 5% CH_4 at 38 °C and 37 atm. Develop a process flowsheet and discuss the various process alternatives.

BOILING POINT DATA:

Hydrogen (H_2) = - 253 °C Methane (CH_4) = - 162 °C Benzene (C_6H_6) = 80 °C

Toluene (C_7H_8) = 111 °C Diphenyl ($C_{12}H_{10}$) = 255 °C

Q2. Obtain a rough estimate of the cost of a plant to produce 750 tonnes per day of sulfuric acid from sulfur. The Chemical Engineering Cost Index for January 1987 is 343 and June 2015 is 558.



Q3. Rate of Return

A chemical plant is producing 10,000 metric tons per year of a product. The overall yield is 70% by weight (0.7 kg of product per with kg of raw material). The raw material costs $500/metric ton, and the product sells for $900/metric ton. A process modification has been devised that will increase the yield to 75%. The additional investment required is $1,250,000, and the additional operating costs are negligible. Is the modification worth making?

Q4. Selection of Materials of Construction

The conditions that cause corrosion can arise in a variety of ways. Give brief explanation for the materials used in the following categories of corrosion:

a) **[4 points]** General wastage of material (uniform corrosion)
b) **[3 points]** Galvanic corrosion
c) **[3 points]** Pitting (localized corrosion)
d) **[3 points]** Stress corrosion
e) **[4 points]** High-temperature oxidation and sulfidation
f) **[3 points]** Intergranular corrosion (at grain or crystal boundaries)

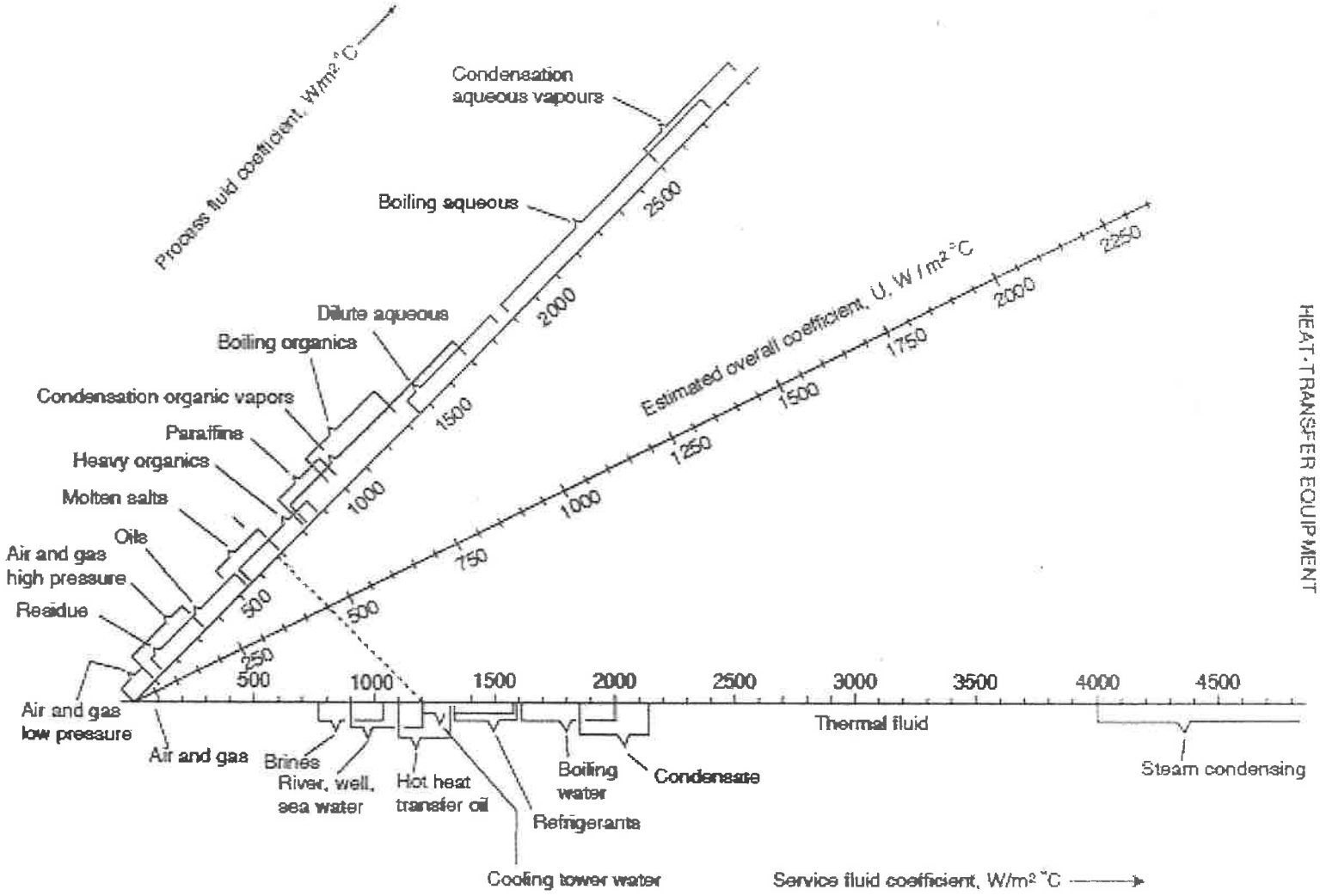
Q5. General process hazards are factors that play a primary role in determining the magnitude of the following an incident.

a) **[7 points]** List six general process hazard factors.

Special process hazards are factors that are known from experience to contribute to the probability of an incident involving loss.

b) **[13 points]** List twelve general process hazard factors.

Q6. An evaporator concentrates 4000 kg per hour of apple juice by removing 40% of the water content. Low-pressure steam at 120 °C is available as a heat source. The evaporator is run under a slight vacuum such that the temperature of the boiling apple juice concentrate is maintained at 100 °C. The latent heat of vaporization of apple juice at 100 °C is 2200 kJ/kg. Using the figure below, estimate the heat exchange area required to accomplish this concentration.


Process fluid coefficient, W/m² °C
Condensation aqueous vapours
Boiling aqueous
Dilute aqueous
Boiling organics
Condensation organic vapors
Paraffins
Heavy organics
Molten salts
Oils
Air and gas high pressure
Residue
Air and gas low pressure
Air and gas
Brines
River, well, sea water
Hot heat transfer oil
Cooling tower water
Refrigerants
Boiling water
Condensate
Thermal fluid
Steam condensing
Estimated overall coefficient, U, W/m² °C
Service fluid coefficient, W/m² °C
HEAT-TRANSFER EQUIPMENT