Exam Date & Time: 25-May-2023 (02:30 PM - 05:30 PM)

# MANIPAL ACADEMY OF HIGHER EDUCATION

VI SEMESTER B.TECH END SEMESTER EXAMINATIONS, May-June 2023

**DESIGN AND DRAWING OF CHEMICAL PROCESS EQUIPMENT [CHE 3251]**

**Marks: 50** **Duration: 180 mins.**

A

**Answer all the questions.**

Instructions to Candidates: Answer ALL questions Missing data may be suitably assumed

1) A) Estimate the thickness required for the component parts of the vessel (2.5 m ID and 3 m high). The vessel is to operate at a pressure of 14 bar (absolute) and temperature of 400°C. The material of construction will be plain carbon steel. Welds will be fully radiographed. A corrosion allowance of 3 mm should be used. The allowable design stress value = 100 N/mm$^2$.
HEAD: Ellipsoidal (2:1) and bolted cover with C=0.5 and $D_c$ = 2.7 m.
BOTTOM: Tori spherical (100-10) and Hemisphere.
Compare and discuss the results. (5)

B) A vacuum distillation column is to operate under a pressure of 150 mmHg. The column diameter is 1 m and the plate spacing 0.5 m. The material of construction is carbon steel and the maximum operating temperature 75 °C. If the vessel thickness is 15 mm, check if this is sufficient or not. (5)

2) A) A vessel is designed for an internal pressure 200 kg$_f$/cm$^2$. A spiral wound metal, fiber stainless steel gasket with inside diameter 40 cm and width 4 cm is used. Gasket factor is 4, while gasket seating stress is 750 kg$_f$/cm$^2$. Permissible stress for bolt material at atmospheric and operating condition is 1400 kg$_f$/cm$^2$. Check whether the gasket width is sufficient to keep it away from crushing out? (5)

B) While doing thermal design of a 2-4 STHE you end up with the following results:
Length of tubes = 10 m; No. of tubes = 500; Shell ID = 700 mm; $\Delta P_t$ = 55 kN/m$_2$ & $\Delta P_s$ = 5 kN/m$^2$; Available UOD = 600 W/m$^2$K; Required UOD = 1800 W/m$^2$K. Do you feel that this design is satisfactory? If not, what are the strategies will you incorporate to satisfy the design criteria? (5)

3) A) A 1-2 shell and tube heat exchanger is to be used for cooling amyl acetate from 70°C to 40°C at a rate of 30000 kg/h using raw water available at 20°C and leaving at 35°C. Find the value of heat transfer coefficient $h_o$ with the following data given. Correction factor $F_T$=0.88. The shell diameter given as 305 mm. Baffle spacing = 40% of shell ID. Properties of amyl acetate at 55 °C: $\rho$=880 kg/m$^3$, $c_p$=2.1 kJ/kgK, $\mu$=0.55 cP, k= 0.143 W/m K. (5)

B) 1-1 STHE is used to heat an organic liquid (50 m$^3$/h) from 10°C to 28°C, which passes through the tubes (30 steel tubes; 5cm ID; 5mm thick) of the exchanger. The density, viscosity, heat capacity and the thermal conductivity of the organic liquid are the same as water (1 g/cc; 1cP; 4.2 kJ/kg K and 0.54 W/ m K respectively). The shell-side fluid is water that enters with flow rate 3x10$^4$ kg/h and temperature 60°C. (5)

- Determine the tube side heat transfer coefficient.
- If the overall heat transfer coefficient is 500 W/m$^2$K, determine the length of the tubes.

4) It is proposed to use an existing distillation column, which is fitted with reflux condenser which has 300 vertical, 70 mm ID tubes, for separating benzene from a mixture of chlorobenzenes. The top product will be 3000 kg/h benzene and the column will operate with a reflux ratio of 5. Check whether (5)

A) flooding occurs or not. The condenser pressure will be 1 bar. Densities at benzene boiling point are $\rho_L$: 850 kg/m$^3$, $\rho_v$: 3 kg/m$^3$.

Useful Formula:

$$\left[u_v^{1/2}\rho_v^{1/4} + u_L^{1/2}\rho_L^{1/4}\right] < 0.6\,[g d_i(\rho_L - \rho_v)]^{1/4}$$

B) A water-cooled, 1-1 shell-and-tube freon condenser with in-tube condensation of R-22 @37°C ($c_{pL}$ = 1.31 kJ/kg K; $v_L$ = 8.4 x $10^{-4}$ m$^3$/kg; $v_g$ = 0.02 m$^3$/kg; $\mu_L$ = 1.86x$10^{-4}$ Pa.s; $\mu_g$ = 1.39x$10^{-5}$ Pa.s; $k_L$ = 0.082 W/m K; $\lambda$= 170 kJ/kg; Pr = 3) has to be designed. City water (Inlet and outlet temperatures are 18°C & 26°C respectively) is used as coolant. Determine the

- Tube side heat transfer coefficient using Cavallini and Zecchin theory. (5)
- Length of the condenser if the overall heat transfer coefficient is 250 W/ m$^2$K.

**Design parameters:**
Design cooling load: 150 kW; One tube pass; Pitch: 1" Square; Shell dia: 17"; Baffle Spacing: 35 cm; Number of Tubes: 200; Size of tubes: 0.75" OD & 0.68" ID; Vapor quality = 75%.

5) A forward-feed evaporator (triple effect) is used to evaporate a solution. Saturated steam at 9 atm abs is being used. The feed rate enters at 16 °C.
Assume $\Delta T_1$ = 28 K, $\Delta T_2$ = 23 K and $\Delta T_3$ = 42 K. (5)

A) Determine enthalpy of steam, vapor and liquid streams of each evaporator:

B) A forward-feed evaporator (triple effect) is being used to evaporate a solution containing 10 wt% solids to a concentrated solution of 50 wt%. The feed rate is 23000 kg/h. Using the following enthalpy values, calculate the steam and liquid flow rates of each evaporator. (5)

| **Enthalpies of each stream** | | |
|---|---|---|
| **Steam Enthalpies, kJ/kg** | **Vapor Enthalpies, kJ/kg** | **Liquid Enthalpies, kJ/kg** |
| | | @$T_F$, $h_F$ = 112 |
| @$T_{s1}$, $\lambda_{s1}$ = 2200 | @$T_1$, $H_1$ = 2684 | @$T_1$, $h_{L1}$ = 440 |
| @$T_1$, $\lambda_{s2}$ = 2243 | @$T_2$, $H_2$ = 2655 | @$T_2$, $h_{L2}$ = 364 |
| @$T_2$, $\lambda_{s3}$ = 2290 | @$T_3$, $H_3$ = 2601 | @$T_3$, $h_{L3}$ = 230 |

## Useful Energy Balance Equations:

- $F(h_F - H_1) + S\lambda_{s1} = L_1(h_{L1} - H_1)$
- $L_1(h_{L1} - \lambda_{s2} - H_2) + F\lambda_{s2} = L_2(h_{L2} - H_2)$
- $L_2(h_{L2} - \lambda_{s3} - H_3) + L_1\lambda_{s3} = L_3(h_{L3} - H_3)$

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