Seat No.: ________ Enrolment No.___________

# GUJARAT TECHNOLOGICAL UNIVERSITY

**BE - SEMESTER–VI • EXAMINATION – SUMMER • 2014**

**Subject Code: 160503** **Date: 23-05-2014**

**Subject Name: Process Equipment Design - I**

**Time: 10:30 am - 01:30 pm** **Total Marks: 70**

**Instructions:**

1. **Attempt all questions.**
2. **Make suitable assumptions wherever necessary.**
3. **Figures to the right indicate full marks.**

**Q-1** A horizontal 1-4 heat exchanger (condenser) is used to condense 45000 kg/hr of mixed light hydrocarbon vapors. The condenser to operate at 10 bar. The vapor will enter the condenser saturated at 60 °C and the condensation will be completed at 45 °C. The average molecular weight of vapor is 52. The enthalpy of the vapor is 596.5 kJ/kg and the condensate 247 kJ/kg. Cooling water is available at 30 °C and the temperature rise is limited to 10°C. Plant standards requires tubes of 20 mm od, 16.8 mm id, 4.88 m long of admiralty brass. Use square pitch tube arrangement with $p_t$=1.25$d_O$. The vapors are to be totally condensed and no sub cooling is required. Take temperature correction factor $F_t$=0.92. **14**

Based on overall heat transfer coefficient = 900 W/$m^2$°C, Calculate

(1) Number of tubes (2) Shell Diameter (3) Tube side heat transfer coefficient and (4) Shell side heat transfer coefficient

Physical properties of condensate at 47°C are:

$\mu_L$=0.16 mNs/m, $\rho_L$=551 kg/$m^3$, $k_L$=0.13W/m°C.

Specific heat of water at 35°C=4.18 kJ/kg C. Density of water = 993 kg/$m^3$,

Thermal conductivity of water = 0.628 W/m °C.

**Q-2** **A** Hexane at 37.8 °C is pumped through the system at a rate of 10.1 $m^3$/h. The tank is at atmospheric pressure. Pressure at the end of discharge line is 345 kPa g. The discharge is 3.05 m above the pump center line while the suction lift is 1.22 m above the level of liquid in the tank. The friction loss in suction line is 3.45 kPa and that in the discharge line is 37.9 kPa. The mechanical efficiency of the pump is 0.6. The density of hexane is 659 kg/$m^3$ and its vapor pressure at 37.8 C is 33.71 kPa. Calculate the power required by the centrifugal pump. **07**

**B** Calculate the Manometer reading generated by orifice meter based on following data: **07**

Name of the fluid: Water

Flow rate: 90000 kg/h

Inside diameter of pipe=154 mm

Operating temperature = 32 °C

Density of water = 995 kg/$m^3$ Viscosity of water = 0.765 cP

Manometer fluid = Mercury, Density of mercury = 13516.47 kg/$m^3$

Take $\beta$ = 0.5. $C_0$=0.6055

OR

**B** A three stage reciprocating compressor is used to compress 306 S$m^3$/h of methane from 0.95 atm a to 59 atm a. The inlet temperature is 26.7 °C. Specific heat ratio of methane is 1.31. Calculate (1) Power required for compression, if mechanical efficiency is 70% and (2) discharge temperature of gas after $1^{st}$ stage. **07**

**Q-3** A sieve tray tower is used for stripping methanol from a feed of dilute aqueous solution of methanol. The stripping heat is supplied by waste steam. **14**

Operating condition:

Vapor flowrate =3.0194 $m^3/s$, Liquid flowrate= 5.011*$10^{-3}$ $m^3/s$
Vapor composition= 20 mass% of methanol
Liquid composition=15 mass% of methanol
Liquid density=961 $kg/m^3$, Vapor density in given condition=0.65329 $kg/m^3$
Liquid surface tension= 40*$10^{-3}$ N/m
Temperature=368 K, Pressure=101325 Pa
Tray spacing = 0.5 m, hole diameter = 5mm, $A_h$=0.07894 $m^2$
Weir height= 50mm, Weir length = 0.77(Di)
For 85% flooding and 70% turn down ratio
Calculate (1) tower diameter and (2) Check weather weeping takes place or not.

OR

**Q-3** **A** 1. Discuss in brief the factors affecting selection of tray type. **04**
2. State the functions of down comer in distillation column. Explain the different types of down comers. **03**

**B** The feed and product composition for distillation column is given as below. **07**

| Component | Feed (mol%) | Distillate (mol%) | Residue (mol%) |
|---|---|---|---|
| n-butane | 37 | 95 | 16.3 |
| Iso-pentane | 32 | 5 | 41.6 |
| n-pentane | 21 | -- | 28.5 |
| n-hexane | 10 | -- | 13.6 |

$\alpha_{LK}$=2.567, $R_m$=1.4509.
Determine the number of theoretical stages required for R=3, by FUG method.

**Q-4** **A** Discuss in brief Random and Regular packing. **07**
**B** Explain the important industrial applications of liquid-liquid extraction. **07**

OR

**Q-4** **A** 1)Explain advantages and disadvantages of vacuum distillation **03**
2)Define: Weeping, Entrainment, Coning and Flooding in distillation column **04**
**B** Explain Tinker's flow model **07**

**Q-5** Venturi scrubber is used for absorbing $NO_x$ gases from the exit gas stream of nitric acid plant by using 10% NaOH solution (by mass). The data for the scrubber is as follows. **14**
Volumetric flow rate of exist gas stream = 40,540 $Nm^3/h$
Discharge pressure of gas from venturi = Atmospheric
Temperature of gas mixture, entering the venturi scrubber = 50 $^0C$
$NO_x$ concentration in the exist gas stream = 2000 ppm (or mg/kg)
Solvent = 10% NaOH Solution
Solvent to gas ratio = 1.5 $L/m^3$
Throat velocity of gas phase = 100 m/s
Average molar mass of flue gas = 28.43 kg/kmol
Density of 10% NaOH Solution = 1075 $kg/m^3$
Equilibrium mass of $NO_x$ per 100 mass of$H_2O$ = 0.025
Determine: (i) throat diameter of venturi scrubber (ii) % removal $NO_x$ gases (iii) consumption of NaOH and (iv) pressure drop in venturi scrubber.

OR

**Q-5** A feed stream having flow rate of 200 kg/h and containing 20 mass % acetic acid in water is to be extracted at 25 $^0C$ with 400 kg/h of recycled MIBK (Methyl IsoButyl Ketone) that contains 0.1 % acetic acid and 0.01 % water. The aqueous raffinate is extracted down to 1 % acetic acid. Calculate (i) $N_{toR}$ considering MIBK and water as partially miscible liquids and (ii) $N_{toR}$ considering MIBK and water as completely immiscible liquids and equilibrium curve as straight line (in terms of mass ratio concentration).

Data for equilibrium curve:

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| X | 0 | 0.0285 | 0.117 | 0.205 | 0.262 | 0.328 | 0.346 |
| Y | 0 | 0.0187 | 0.089 | 0.173 | 0.246 | 0.308 | 0.336 |

Data for operating curve:

| | | | | |
|---|---|---|---|---|
| $X_S$ | 0.2 | 0.14 | 0.08 | 0.01 |
| $Y_{S+1}$ | 0.085 | 0.06 | 0.035 | 0.001 |

Data in terms of mass ratio:

| | | | | |
|---|---|---|---|---|
| X′ (kg of Acetic acid/kg of water) | 0 | 0.0299 | 0.1364 | 0.2708 |
| Y′ (kg of Acetic acid/kg of MIBK) | 0 | 0.0196 | 0.1039 | 0.2354 |

## Design Formulae:

(A) Heat Exchanger Design:

1. Tube bundle diameter, $D_b = d_0 \left[\frac{N_t}{k_1}\right]^{1/n_1}$

2. For square pitch arrangement with $P_t=1.25d_0$

| No of tube side passes | 1 | 2 | 4 | 6 | 8 |
|---|---|---|---|---|---|
| $k_1$ | 0.215 | 0.156 | 0.158 | 0.0402 | 0.0331 |
| $n_1$ | 2.207 | 2.291 | 2.263 | 2.617 | 2.643 |

3.Shell side condensation coefficient for horizontal position:

$$h_{co} = 0.95 k_L \left[\frac{\rho_L(\rho_L - \rho_v)g}{\mu_L \tau_h}\right]^{1/3} N_r^{-1/6}$$

Where $\tau_h = \frac{W_c}{L N_t}$ $\quad N_r' = D_b/p_t \quad N_r = 2/3\, N_r'$

4.Tube side heat transfer coefficient:

For Nre>4000,

$$Nu = C\ Re^{0.8} Pr^{0.33} \left(\frac{\mu}{\mu_w}\right)^{0.14}$$

Where C=0.021 for gases, 0.023 for non viscous liquids, 0.027 for viscous liquids.

(B) Power required by centrifugal pump: $P = \frac{H q_v \rho}{3.67 * 10^5 \eta}$

(C) Orifice meter:

$$m = C_0 Y A_0 \sqrt{\frac{2 g_c \Delta P \rho}{1-\beta^4}}$$

(D) Compressor:

1.Power required for each stage:

$$P_0 = \frac{2.78 \times 10^{-4}}{\eta} \frac{k}{k-1} q_{v1} P_1 \left[\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} - 1\right]$$

2.Temperature-Pressure relations:

$$T_2 = T_1 \left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}}$$

(E) Distillation Column:

1.Flooding velocity $v_F = C_f \left(\frac{\sigma}{0.02}\right)^{0.2} \left(\frac{\rho_L - \rho_v}{\rho_v}\right)^{0.5}$

2.Minimum vapor velocity to avoid weeping:

$$v_{h\,min} = \frac{K - 0.9(25.4 - d_h)}{\sqrt{\rho_v}}$$

3.Weir crest of liquid mm, $h_{ow} = 750\left(\frac{L_m}{\rho_L l_w}\right)^{2/3}$

4.FUG Method:

Fenskey's Equation:

$$N_m = \frac{log\left[\left(\frac{x_{LK}}{x_{HK}}\right)_d \left(\frac{x_{HK}}{x_{LK}}\right)_b\right]}{log \propto_{LK}}$$

Gilliland's Correlation:

$$f(N) = \frac{N - N_m}{N + 1} = 1 - exp\left[\left(\frac{1 + 54.4\Psi}{11 + 117.2\Psi}\right)\left(\frac{\Psi - 1}{\Psi^{0.5}}\right)\right]$$

Where $\Psi = \frac{R - R_m}{R + 1}$

(F) Venturi scrubber:

1.Fractional solute removal = $\frac{y_1 - y_2}{y_1} = \eta \frac{(1 - mx_2 / y_2)}{\left(1 + \frac{mG_M}{L_M}\right)}$

2.Mass transfer efficiency = $\eta = 1 - e^{-N_G}$

3.Number of overall gas-phase mass transfer units $N_G = (K_G aRT / p_t)/\theta_c$

4.Venturi pressure drop $\Delta P = 2.584 \times 10^{-3} v_G^{\,2} \rho_G A_{th}^{\,0.133} (L' / G')^{0.78}$

(G) Extractor Design:

Number of overall mass transfer units based on raffinate phase:

1. For partially miscible system: $N_{toR} = \int_{X_{NP}}^{X_F} \frac{dX}{X - X^*} + \frac{1}{2}\ln\left(\frac{1 - X_{NP}}{1 - X_F}\right) + \frac{1}{2}\ln\left(\frac{X_{NP}(r-1)+1}{X_F(r-1)+1}\right)$

2. For completely immiscible system:

$$N_{toR} = \frac{\ln\left[\left(\frac{X'_F - Y'_S / m'}{X'_{NP} - Y'_S / m'}\right)\left(1 - \frac{1}{\varepsilon}\right) + \frac{1}{\varepsilon}\right]}{\left(1 - \frac{1}{\varepsilon}\right)}$$

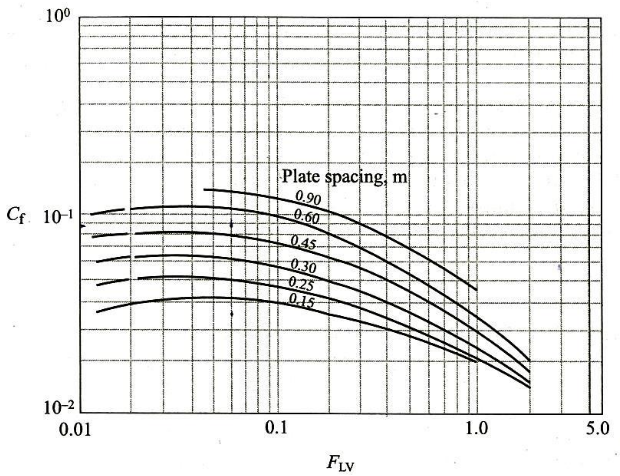


Figure 1: Flooding velocity (sieve tray)

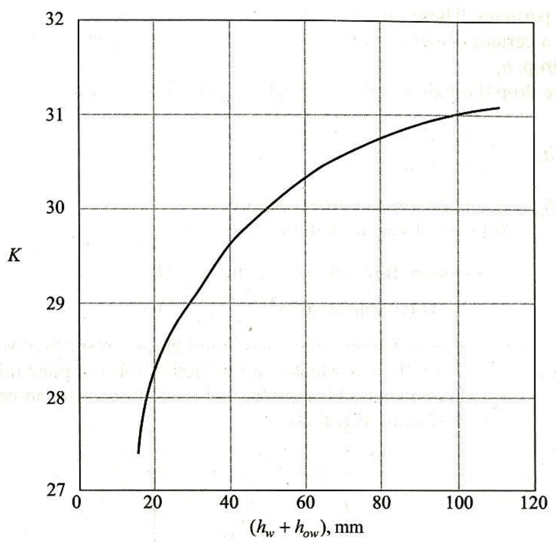


Figure 2: Weep point correlation