14CH602

Hall Ticket Number:

III/IV B.Tech (Regular) DEGREE EXAMINATION

April, 2018 | **Chemical Engineering**

Sixth Semester | **Chemical Process Equipment Design-I**

Time: Three Hours | **Maximum :** 60 Marks

Answer Question No.1 compulsorily. (1X12 = 12 Marks)

Answer ONE question from each unit. (4X12=48 Marks)

1. Write short notes on the following(1X12=12 Marks)

a. What is stripping factor?
b. Differentiate between block and process flow diagrams.
c. Define Safety and Health hazards.
d. What is HAZOPS study?
e. Define cavitation and NPSH?
f. What are +Ve displacement pumps?
g. Differentiate between constant volume filtration and constant pressure filtration.
h. Give the equation for calculating hydraulic mean diameter for annulus of a double pipe heat exchanger used for heat transfer coefficient calculation.
i. When overall heat transfer coefficient is used?
j. What do you mean by flooding and coning in plate columns?
k. Define ‘q’value used in binary distillation design.
l. Expand UVCE and BLEVE.

UNIT I

2. a) List out the sequential steps involved in development of a project and explain them in detail. **6M**
b) Explain with detail about Practical considerations in Design. **6M**

(OR)

3. a) Discuss in detail, the factors to be considered in comparison of different process. **6M**
b) What is feasibility survey? What are the items that should be considered in making a feasibility survey? **6M**

UNIT II

4. a) Derive the expression for calculation of total mechanical energy balance to a compressible fluid, assuming ideal gas law holds good. State the assumptions clearly. **6M**
b)A pump is discharging water at the rate of 600 m^3/hr under a pressure of 5kgf/cm^2; The head developed by the pump is to be calculated from the following data:
Gauge pressure in the suction pipe =200 mm Hg.
Vertical distance between the suction and discharge pressure gauge = 415 cm.
Internal diameter of suctionpipe is 350 mm.Internal diameter of Discharge pipe is 300 mm. **6M**

(OR)

5. a) Derive constant pressure filtration model **5M**
b) The following relation between specific resistance and pressure drop has been determined as: $\alpha = 8.8 \times 10^{10}[1 + 3.36 \times 10^{-4}(\Delta p \ in \ lb/ft^2)^{0.86}]$
This relation is valid over a pressure range of 0 to 1000 lbf/in^2. A slurry of this material yielding 4lb of cake solid per cubic filtrate is to be filtered at a constant pressure drop of 75lbf/in^2 and 70 °F. The resistance of filter medium R_m= 1.2 x10^{10} per ft. Determine square feet of the filter surface area required to give 1400 gal of filtrate in a 1-hr-filtration? $\mu_{filtrate}$ =6.6 x 10^{-4}lb/ft-s **7M**

UNIT III

6. a) With a neat diagram, show the construction details of a 1-1 shell and tube heat exchanger. **6M**

b) Methanol flowing in the inner pipe of a double pipe exchanger is cooled with water flowing in the annulus. The inner pipe ID is 25 mm and OD is 28 mm. The thermal conductivity of steel is 46 $Wm^{-1}K^{-1}$. The individual coefficients are given in the following table. What is the overall coefficient based on the outside area of the inner pipe? Alcohol coefficient =1020; Water coefficient = 1700; Inside fouling factor = 5680 ; Outside fouling factor = 2840 Wm^{-2} K^{-1} **6M**

(OR)

7. a) Develop the expression for overall heat transfer coefficient. **4M**

b) A chemical plant produces 400 metric tonnes of H_2SO_4 per day. It is cooled from 60°C to 40°C by 400 metric tonnes of H_2O per day which has an initial temperature of 15°C. A counter flow cooler consisting of concentric pipes 12.5 mm thick is to be used. The inner pipe through which the acid flows is 7.5 cm bore and the outer one is 12.5 cm bore. The outside dia. of the pipe is 10cm.k (of pipe) =40. Calculate the length of the pipe required.

Properties (@ the mean temperature):	**Acid**	**Water**
Density (kg/m^3)	1800	998.2
C_p-> (kcal/kg °C)	0.35	1.0
k ->(kcal/hrm°C)	0.26	0.575
μ->(kg/m.hr)	40.3	3.96

8M

UNIT IV

8. a) What is meant by minimum and actual reflux ratio? **2M**

b)A mixture of water and ethyl alcohol containing 0.35 mole fraction of ethanol is continuously distilled in a plate fractionating columns to give a product of 0.75 mole fraction of alcohol and a waste of 0.04 mole fraction of alcohol. Determine the number of theoretical and actual plates required, if the feed is liquid at its bubble point and a reflux ratio of 2.5 is used. The efficiency of the plate is 70%. **10M**

Equilibrium data:

%X:	1.9	7	9.6	12.4	23	33	51	67	75	89
% Y:	17	39	44	47	54	58	66	73	78	89

(OR)

9. a)Compare and contrast plate and packed columns. **6M**

b) It is desired to absorb 80% of the Acetone in a gas containing 1mole % Acetone in air in a counter current stage tower. The total inlet gas flow to the tower is 30 kg mole/hr, and the total inlet pure water flow to be used to absorb Acetone is 90 kg mole/hr. The equilibrium relation is $Y = 2.53\ X$, where '*Y'* and '*X'* are mole fractions of Acetone in gas and liquid phases respectively. Determine the number of theoretical plates required. Assume dilute solution concept. **6M**

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Time: Three Hours **Maximum :** 60 Marks

Answer Question No.1 compulsorily. (1X12 = 12 Marks)

Answer ONE question from each unit. (4X12=48)

Write short notes on the following (1X12=12 Marks)

a. **What is stripping factor?**
Stripping factor is defined as the ratio of slope of equilibrium line to the slope of operating line**.**
S = (mG)/L

b. **Differentiate between block and process flow diagrams.**
Block diagram is a diagram of a system in which the principal parts or functions are represented by blocks connected by lines that show the relationships of the blocks.
A data flow diagram (DFD) is a graphical representation of the "flow" of data through an information system, modeling its process aspects.

c. **Define Safetyand Health hazards.**
A highly toxic material that causes immediate injury is classified as a ***safety hazard.***
A material whose effect is only apparent after long exposure at low concentrations is considered as an industrial ***health and hygiene hazard***.

d. **What is HAZOPS study?**
The ***hazard and operability study*** is a systematic technique for identifying all plant or equipment hazards and operability problems.

e. **Define cavitation and NPSH**
Cavitaion is the forming of bubbles in the suction pipe when the -ve pressure developed at the eye of the impeller is lower than the saturation pressure of the fluid to be pumped causing it to boil, and the bursting of those bubbles in the vanes where the pressure is higher.
Net Positive Suction Head or NPSH for pumps can bedefined as the difference between liquid pressure at pump suction and liquid vapor pressure, expressed in terms of height of liquid column.

f. **What are positive displacement pumps?**
A **positive displacement pump** makes a fluid move by trapping a fixed amount and forcing (displacing) that trapped volume into the discharge pipe.

g. **Differentiate between constant volume filtration and constant pressure filtration.**
In the early stages of a filtration cycle, the cake is thin and the resistance offered to the flow is virtually constant and so filtration proceeds at a ***constant rate or constant volume***.
Once the initial cake has been built up, flow occurs under a ***constant-pressure*** differential.

h. **Give the equation for calculating hydraulic radius for annulus of a double pipe heat exchanger used for heat transfer coefficient calculation.**

$$D_{eh} = \frac{\left(D_i^2 - d_0^2\right)}{d_0}$$

i. **When overall heat transfer coefficient is used?**
The overall heat transfer coefficient takes into account the individual heat transfer coefficients of each stream and the resistance of the pipe material.

j. **What do you mean by flooding and coning in plate columns?**
At very high rates of gas flow the liquid stops flowing and the liquid fill the entire space between the trays. This condition is called flooding.
If liquid rates are too low this is a condition in which the rising vapor pushes the liquid back from the

top of the hole and passes upward with poor liquid contact. This condition is called coning.

k. **Define ‘q’ value used in binary distillation design.**
q is the heat required to vaporise 1 mol of feed/ molar latent heat of feed

l. **Expand UVCE and BLEVE.**
UVCE-***Unconfined-vapour-cloud explosion,*** BLEVE-***Boiling-liquid-expanding-vapour explosion.***

UNIT – I

2. a) List out the sequential steps involved in development of a project and explain them in detail. 5M

1. Inception
2. Preliminary evaluation of economics and market
3. Development of data necessary for final design
4. Final economic evaluation
5. Detailed engineering design
6. Procurement
7. Erection
8. Startup and trial runs
9. Production

Thedevelopmentofaprocessdesign,involvesmanydifferentsteps.

1. The first is theinceptionofthebasicidea.Thisideamayoriginateinthesalesdepartment,asaresultofacustomerrequest,ortomeetacompetingproduct.Itmayoccurspontaneouslytosomeonewhoisacquaintedwiththeaimsandneedsofaparticularcompany or itmaybetheresultofanorderlyresearchprogramoranoffshootofsuchaprogram.Theoperatingdivisionofthecompanymaydevelopanewormodifiedchemical,generallyasanintermediateinthefinalproduct.Theengineeringdepartmentofthecompanymayoriginateanewprocessormodifyanexistingprocesstocreatenewproducts.

2. Iftheinitialanalysisindicatesthattheideamayhavepossibilitiesofdevelopingintoaworthwhileproject,apreliminaryresearchorinvestigationprogramisinitiated. A generalsurveyofthepossibilitiesforasuccessfulprocessismadeconsideringthephysicalandchemicaloperationsinvolvedaswellastheeconomicaspects.Nextcomestheprocess-researchphaseincludingpreliminarymarketsurveys,laboratory-scaleexperiments,andproductionofresearchsamplesofthefinalproduct.

3. Whenthepotentialitiesoftheprocessarefairlywellestablished,theprojectisreadyforthedevelopmentphase.Atthispoint,apilotplantoracommercialdevelopmentplantmaybeconstructed.Apilotplantisasmall-scalereplicaofthefull-scalefinal plant. A commercial-developmentplantisusuallymadefromoddpiecesofequipmentwhicharealreadyavailableandisnotmeanttoduplicatetheexactsetuptobeusedinthefull-scaleplant.Designdataandotherprocessinformationareobtainedduringthedevelopmentstage.Thisinformationisusedasthebasisforcarryingouttheadditionalphasesofthedesignproject.Acompletemarketanalysisismade,andsamplesofthefinalproductaresenttoprospectivecustomerstodetermineiftheproductissatisfactoryandifthereisareasonablesalespotential.

4. Capital-costestimatesfortheproposedplantaremade.Probablereturnsontherequiredinvestmentaredetermined,andacompletecost-and-profitanalysisoftheprocessisdeveloped.Itisatthispointthattheengineers’preliminarydesignworkalongwiththeoralandwrittenreportswhicharepresentedbecomeparticularlyimportantbecausetheywillprovidetheprimarybasisonwhichmanagementwilldecideiffurtherfundsshouldbeprovidedfortheproject.

5. Iftheeconomicpictureisstillsatisfactory,thefinalprocess-designphaseisreadytobegin.Allthedesigndetailsareworkedoutinthisphaseincludingcontrols,services;pipinglayouts,firmpricequotations,specificationsanddesignsforindividualpiecesofequipment,andalltheotherdesigninformationnecessaryfortheconstructionofthefinalplant.Acompleteconstructiondesignisthenmadewithelevationdrawings,plant-layoutarrangements,andotherinformationrequiredfortheactualconstructionoftheplant.

6, 7, 8 & 9. Thefinalstageconsistsofprocurementoftheequipment,constructionoftheplant,startupoftheplant,overallimprovementsintheoperation,anddevelopmentofstandardoperatingprocedurestogivethebestpossibleresults.

Scheme: Listing-2M, Explanation of each step-5M.

b) Explain with detail about Practical considerations in Design.

The chemical engineer must consider the practical limitations involved in a design. The practical engineer understands the physical problems which are involved in the final operation and maintenance of the designed equipment. In design work, theoretical and economic principles must be combined with an understanding of the common practical problems that will arise when the process finally comes to life in the form of a complete plant or a complete unit.

- The exact calculated pipe size may not be used in the final design. Size may be chosen on the market availability.
- In developing the plant layout, crucial control valves must be placed where they are easily accessible to the operators.
- Sufficient space must be available for maintenance personnel to check, take apart, and repair equipment.
- Multiple feed plate locations may be considered in a distillation column.

Scheme: Explanation of practical consideration-5M

(OR)

3. a) Discuss in detail, the factors to be considered in comparison of different process.

In a design project it is necessary to determine the most suitable available process for obtaining a desired product. The following items should be considered in a weighted comparison of the essential variable items:

1. Technical factors
    a. Process flexibility
    b. Continuous operation
    c. Special controls involved
    d. Commercial yields
    e. Technical difficulties involved
    f. Energy requirements
    g. Special auxiliaries required
    h. Possibility of future developments
    i. Health and safety hazards involved
2. Raw materials
    a. Present and future availability
    b. Processing required
    c. Storage requirements
    d. Materials handling problems
3. Waste products and by-products
    a. Amount produced
    b. Value
    c. Potential markets and uses
    d. Manner of discard
    e. Environmental aspects
4. Equipment
    a. Availability
    b. Materials of construction
    c. Initial costs
    d. Maintenance and installation costs
    e. Replacement requirements
    f. Special designs
5. Plant location
    a. Amount of land required
    b. Transportation facilities
    c. Proximity to markets and raw-material sources
    d. Availability of service and power facilities
    e. Availability of labor
    f. Climate
    g. Legal restrictions and taxes

6. Costs
   a. Raw materials
   b. Energy
   c. Depreciation
   d. Other fixed charges
   e. Processing and overhead
   f. Special labor requirements
   g. Real estate
   h. Patent rights
   i. Environmental controls
7. Time factor
   a. Project completion deadline
   b. Process development required
   c. Market timeliness
   d. Value of money
8. Process considerations
   a. Technology availability
   b. Raw materials common with other processes
   c. Consistency of product within company
   d. General company objectives

Scheme: Factors to be considered in comparison of processses-6M

b) What is feasibility survey? What are the items that should be considered in making a feasibility survey?

Before any detailed work is done on the design, the technical and economic factors of the proposed process should be examined. The various reactions and physical processes involved must be considered, along with the existing and potential market conditions for the particular product. This is known as feasibility survey.

List of items that should be considered in making a feasibility survey:

1. Raw materials (availability, quantity, quality, cost)
2. Thermodynamics and kinetics of chemical reactions involved (equilibrium, yields, rates, optimum conditions)
3. Facilities and equipment available at present
4. Facilities and equipment which must be purchased
5. Estimation of production costs and total investment
6. Profits (probable and optimum, per pound of product and per year, return on investment)
7. Materials of construction
8. Safety considerations
9. Markets (present and future supply and demand, present uses, new uses, present buying habits, price range for products and by-products, character, location, and number of possible customers)
10. Competition (overall production statistics, comparison of various manufacturing processes, product specifications of competitors)
11. Properties of products (chemical and physical properties, specifications,impurities, effects of storage)
12. Sales and sales service (method of selling and distributing, advertising required, technical services required)
13. Shipping restrictions and containers
14. Plant location
15. Patent situation and legal restrictions

Scheme: Feasibility survey definition-1M, Any 10 factors to be considered in a feasibility survery-5M

UNIT – II

4. a)Derive the expression for calculation of total mechanical energy balance to a compressible fluid, assuming ideal gas law holds good. State the assumptions clearly.

$$\frac{dp}{\rho} + VdV + gdZ = 0$$

Integrating the above equation, we get

$$\int \frac{dp}{\rho} + \int VdV + \int gdZ = \text{Constant}$$

or $$\int \frac{dp}{\rho} + \frac{V^2}{2} + gZ = \text{Constant}$$

(A) Bernoulli's Equation for Isothermal Process. For isothermal process, the relation between pressure (p) and density (ρ) is given by equation (12.3) as

$$\frac{p}{\rho} = \text{Constant} = C_1 \text{ (say)} \qquad ...(i)$$

$$\therefore \quad \rho = \frac{p}{C_1}$$

Hence $$\int \frac{dp}{\rho} = \int \frac{dp}{p/C_1} = \int \frac{C_1 dp}{p} = C_1 \int \frac{dp}{p} \qquad (\because C_1 \text{ is constant})$$

$$= C_1 \log_e p = \frac{p}{\rho} \log_e p \qquad \left(\because C_1 = \frac{p}{\rho} \text{ from equation } (i)\right)$$

Substituting the value $\int \frac{dp}{\rho}$ in equation (12.9), we get

$$\frac{p}{\rho} \log_e p + \frac{V^2}{2} + gZ = \text{Constant}$$

Dividing by 'g', $$\frac{p}{\rho g} \log_e p + \frac{V^2}{2g} + Z = \text{Constant.} \qquad ...(12.10)$$

Equation (12.10) is the Bernoulli's equation for compressible flow undergoing isothermal process. For the two points 1 and 2, this equation is written as

$$\frac{p_1}{\rho_1 g} \log_e p_1 + \frac{V_1^2}{2g} + Z_1 = \frac{p_2}{\rho_2 g} \log_e p_2 + \frac{V_2^2}{2g} + Z_2 \qquad ...(12.11)$$

(B) Bernoulli's Equation for Adiabatic Process. For the adiabatic process, the relation between pressure (p) and density (ρ) is given by equation (12.4) as

$$\frac{p}{\rho^k} = \text{Constant} = \text{say } C_2 \qquad ...(ii)$$

$$\therefore \quad \rho^k = \frac{p}{C_2} \quad \text{or} \quad \rho = \left(\frac{p}{C_2}\right)^{1/k}$$

Hence $$\int \frac{dp}{\rho} = \int \frac{dp}{\left(\frac{p}{C_2}\right)^{1/k}} = \int \frac{C_2^{1/k}}{p^{1/k}} dp = C_2^{1/k} \int \frac{1}{p^{1/k}} dp$$

$$= C_2^{1/k} \int p^{-1/k} dp = C_2^{1/k} \frac{p^{\left(-\frac{1}{k}+1\right)}}{\left(-\frac{1}{k}+1\right)}$$

$$= \frac{C_2^{1/k} p^{\left(\frac{k-1}{k}\right)}}{\left(\frac{k-1}{k}\right)} = \left(\frac{k}{k-1}\right) C_2^{1/k} p^{\left(\frac{k-1}{k}\right)}$$

$$= \left(\frac{k}{k-1}\right)\left(\frac{p}{\rho^k}\right)^{1/k} p^{\left(\frac{1-k}{k}\right)} \qquad \left(\because C_2^{1/k} = \frac{p}{\rho^k} \text{ from } (ii)\right)$$

<u>Scheme:</u>Derivation of Bernoulli's equation-2M, applicability for each case of Incompressible fluid-4M

b) A pump is discharging water at the rate of 500 m^3/hr under a pressure of 4kgf/cm^2; The head developed by the pump is to be calculated from the following data:Gauge pressure in the suction pipe =200 mm Hg, Vertical distance between the suction and discharge pressure gauge = 415 cm, Internal diameter of suctionpipe is 350 mm. Internal diameter of Discharge pipe is 300 mm.

Solution:

$$\frac{p_1}{\rho_1 g} + \frac{v_1^2}{2g} + z_1 = \frac{p_2}{\rho_2 g} + \frac{v_2^2}{2g} + z_2$$

p_1=200mmHg(g)=1.305kgf/cm^2=26664.4 Nm^{-2}, p_2=4 kgf/cm^2, ρ=1000 kg/m^3, v_1=0, $A_d=\pi/4d^2$=0.07, v_2=Q/A=500/(3600*0.07)=1.98 m/s, z_2-z_1=415 cm

Total head = pressure head + kinetic head + datum head = 40.6 m

Scheme: Bernoulli's equation-1M, Given data with notations-4M, Answer-1M

(OR)

5 a) Derive constant pressure filtration model.

Astimepassesduringfiltration,either

- thefiltrateflowratediminishesor
- pressuredroprises

Constant-pressurefiltration

- pressure drop is held constant
- flow rate allowed to fall with time

Constant -rate filtration (less common)

- pressure drop is progressively increased

Liquidpassesthrough2resistanceinseries:

- cake resistance (zero at start & increases with time)
- filter medium resistance (impt. during early stages of filtration)

Duringwashing,bothresistancesareconstant,andfiltermediumresistanceisusuallynegligible

General filteration equation: Rate of filtration = driving force/resistance

$$\frac{dV}{dt} = \frac{-\Delta pA}{\mu\left(\frac{\alpha c_s V}{A} + R_m\right)}$$

$$\frac{dt}{dV} = \frac{\mu\alpha_{av}\bar{c}}{\Delta P\, A^2} V + \frac{\mu R_m}{A\Delta P}$$

CONSTANT PRESSURE FILTRATION

Integrating the general filteration equation at constant pressure

$$\frac{t}{V} = \frac{\mu\alpha_{av}\bar{c}}{2\,\Delta P\, A} V + \frac{\mu R_m}{A\Delta P}$$

Where

t-filteration time (s), V- filtration volume (m^3), μ- filtarion vcosity (Pa s), A- filter area (m^2), ΔP- pressure drop over cake and filter medium (Pa), R_m-filter medium resistance (m^{-1}), α_{av}-average specific resistance (m Kg^{-1}), c-average dry cake mass per unit volume filtrate (kg m^{-3})

Scheme: Explanation of constant pressure filtration-1M, Equations-4M

b) The following relation between specific resistance and pressure drop has been determined as: $\alpha = 8.8 \times 10^{10}[1 + 3.36 \times 10^{-4}(\Delta p\ in\ lb/ft^2)^{0.86}]$ **This relation is valid over a pressure range of 0 to 1000 lbf/in^2. A slurry of this material yielding 3 lb of cake solid per cubic filtrate is to be filtered at a constant pressure drop of 70 lbf/in^2 and 70 °F. The resistance of filter medium R_m= 1.2 x10^{10} per ft. Determine square feet of the filter surface area required to give 1400 gal of filtrate in a 1-hr-filtration? $\mu_{filtrate}$ =6.6 x 10^{-4}lb/ft-s.**

Solution:

$\Delta p = 70 \times 144 = 10080 \text{ lbf/ft}^2$

$\alpha = 8.8 \times 10^{10} \left[1 + 3.36 \times 10^{-4} \times (10080)^{0.86}\right]$

$= 1.70 \times 10^{11} \text{ ft/lb}$

$C = 3 \text{ lb/ft}^3, R_m = 1.2 \times 10^{10} \text{ ft}^{-1}$

$V = \frac{1400}{7.48} = 187.2 \text{ ft}^3$

Re-call the expression:

$$q_o = \frac{(\Delta p) g_c}{\mu R_m} = \frac{A \times 10080 \times 32}{6.6 \times 10^{-4} \times 1.2 \times 10^{10}} = \frac{A}{24.42}$$

$$K_c = \frac{\mu c \alpha}{A^2 \Delta P g_c} = \frac{6.6 \times 10^{-4} \times 3 \times 1.7 \times 10^{11}}{A^2 \times 10080 \times 32} = 1038\, A^2$$

$$\frac{t}{V} = \frac{K_c}{2} V + \frac{1}{q_o}$$

Substitute,

$$\Rightarrow 3600 = \frac{10\,38 A^2}{2} \times 187.2^2 + \frac{24.42}{A} \times 187.2$$

Or

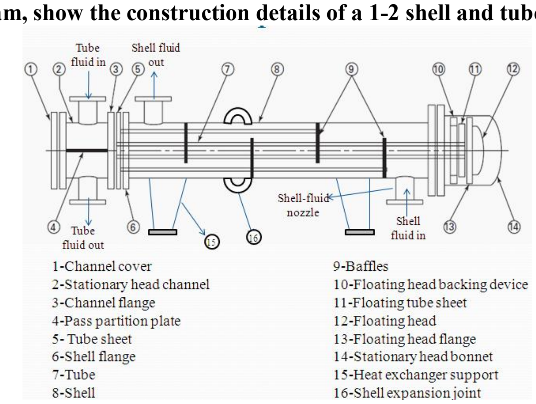
$A^2 - 1.2698A - 5051.7 = 0$

$A = 7107 \text{ ft}^2$

Scheme: Given data with notations-3M, Finding various variables-4M

UNIT – III

6 **a) With a neat diagram, show the construction details of a 1-2 shell and tube heat exchanger.**



Shell: Shell is the container for the shell fluid and the tube bundle is placed inside the shell. Shell diameter should be selected in such a way to give a close fit of the tube bundle. The shell thickness of 3/8 inch for the shell ID of 12-24 inch can be satisfactorily used up to 300 psi of operating pressure.

Tube: Tube OD of ¾ and 1"" are very common to design a compact heat exchanger. The tube length of 6, 8, 12, 16, 20 and 24 ft are preferably used. Longer tube reduces shell diameter at the expense of higher shell pressure drop. Finned tubes are also used when fluid with low heat transfer coefficient flows in the shell side.

Tube sheet: The tubes are fixed with tube sheet that form the barrier between the tube and shell fluids. The tubes can be fixed with the tube sheet using ferrule and a soft metal packing ring. The tube sheet thickness should be greater than the tube outside diameter to make a good seal.

Baffles: Baffles are used to increase the fluid velocity by diverting the flow across the tube bundle to obtain higher transfer co-efficient. The distance between adjacent baffles is called baffle-spacing. The baffle spacing of 0.2 to 1 times of the inside shell diameter is commonly used.

Scheme: Diagram-2M, Explanation of each part-4M

b) Methanol flowing in the inner pipe of a double pipe exchanger is cooled with water flowing in the annulus. The inner pipe ID is 25 mm and OD is 28 mm. The thermal conductivity of steel is 46 $Wm^{-1}K^{-1}$. The individual coefficients are given in the following table. What is the overall coefficient based on

the outside area of the inner pipe? Alcohol coefficient =1020; Water coefficient = 1700; Inside fouling factor = 5680 ; Outside fouling factor = 2840 Wm-^{2} K^{-1}

Solution:

Alcohol coefficient, h_i=1020 Wm-^{2} K^{-1} ; Water coefficient, h_0=1700 Wm-^{2} K^{-1}; Inside fouling factor = 5680 Wm-^{2} K^{-1}; Outside fouling factor = 2840 Wm-^{2} K^{-1}, wall thermal conductivity, k_w=46 Wm^{-1}K^{-1}, d_o=28 mm, d_i=25 mm

$$\frac{1}{U_0} = \frac{1}{h_0} + \frac{1}{h_{0d}} + \frac{d_0 \ln\left(\frac{d_0}{d_i}\right)}{2k_w} + \frac{d_0}{d_i} * \frac{1}{h_{id}} + \frac{d_0}{d_i} * \frac{1}{h_i}$$

U_o= 449.2 Wm-^{2} K^{-1}

Scheme:

Overall heat transfer coefficient-1M, Given data with notations-3M, Answer-2M

(OR)

7 a) Develop the expression for overall heat transfer coefficient.

The heat transfer in fluid 1 is given by:

$$\frac{\dot{Q}}{A} = h_1(T_{w1} - T_1).$$

which is the heat transfer per unit area to the fluid.

The heat transfer in fluid 2 is similarly given by

$$\frac{\dot{Q}}{A} = h_2(T_2 - T_{w2}).$$

Across the wall, we have

$$\frac{\dot{Q}}{A} = \frac{k}{L}(T_{w2} - T_{w1}).$$

The quantity Q/A is the same in all of these expressions. Putting them all together to write the known overall temperature drop yields a relation between heat transfer and overall temperature drop, T_2-T_1:

$$T_2 - T_1 = (T_2 - T_{w2}) + (T_{w2} - T_{w1}) + (T_{w1} - T_1) = \frac{\dot{Q}}{A}\left[\frac{1}{h_1} + \frac{L}{k} + \frac{1}{h_2}\right].$$

We can define a thermal resistance, R, as before, such that

$$\dot{Q} = \frac{(T_2 - T_1)}{R},$$

where R is given by

$$R = \frac{1}{h_1 A} + \frac{L}{Ak} + \frac{1}{h_2 A}.$$

The overall coefficient is the reciprocal of the overall resistance to heat transfer, which is the sum of several individual resistances along with individual dirt factors.

$$\frac{1}{U_0} = \frac{1}{h_0} + \frac{1}{h_{0d}} + \frac{d_0 \ln\left(\frac{d_0}{d_i}\right)}{2k_w} + \frac{d_0}{d_i} * \frac{1}{h_{id}} + \frac{d_0}{d_i} * \frac{1}{h_i}$$

Scheme: Derivation-3M, final expression -1M

b) A chemical plant produces 300 metric tonnes of H_2SO_4 per day. It is cooled from 60°C to 40°C by 500 metric tonnes of H_2O per day which has an initial temperature of 15°C. A counter flow cooler consisting of concentric pipes 12.5 mm thick is to be used. The inner pipe through which the acid flows is 7.5 cm bore and the outer one is 12.5 cm bore. The outside dia. of the pipe is 10cm. k (of pipe) =40. Calculate the length of the pipe required.

Properties (@ the mean temperature):	Acid	Water
Density (kg/m^3)	1800	998.2
C_p-> (kcal/kg °C)	0.35	1.0
k ->(kcal/hrm°C)	0.26	0.575
μ->(kg/m.hr)	40.3	3.96

Solution:

$M_{h.}$=300*10^3 kg/day; $M_{c.}$=500*10^3 kg/day; T_1=hot fluid inlet temperature=60°C, T_2=hot fluid outlet temperature=40°C,t_1= cold fluid inlet temperature=15°C,

Heat Balance: Q= $M_{h.}$ $C_{p,h}(T_{h1}-T_{h2})$ = $M_{c.}$ $C_{p,c}(T_{c1}-T_{c2})$ =U A ΔT_{lm}

t_2 = cold fluid outlet temperature=90°C.

ΔT_{lm}= log mean temperature difference:

$$\Delta T_{lm} = \frac{(T_1 - t_2) - (T_2 - t_1)}{\ln\frac{(T_1-t_2)}{(T_2-t_1)}} = 34.97$$

Mass flow rate of Petroleum fraction required= 4164 kg/hr

Area required for heat transfer=13 m^2

A=$\pi d_o L$=41.4m

Scheme: Calculating mean temp diff-2M, Heat Balance Eq-2M, Area req-2M, Length-2M

UNIT – IV

8a) What is meant by minimum and actual reflux ratio?

Minimum reflux ratio: As the reflux ratio is reduced, the distance between the operating line and the equilibrium curve becomes smaller. The minimum reflux ratio R_m is the limiting reflux where the operating line either touches the equilibrium curve or intersects the equilibrium curve at the q-line. The minimum reflux ratio will require an infinite number of trays to attain the specified separation of x_D and x_B.

The*Optimum Reflux Ratio*(R_0) is that at which the total cost of the distillation is a minimum, taking into account the capital cost of the column (which depends on the number of theoretical plates) and running cost, which depends on the reflux ratio. Note that the capital costs of the reboiler and condenser also depend on the reflux ratio. Thus, usually for very low energy costs R_0/R_{min}= 1.3, and for high energy cost R_0/R_{min}= 1.1 (it is best not to use R_0/R_{min}< 1.1 to allow for possible errors in the V.L.E data).

Scheme: Definition of each-2M

b)A mixture of water and ethyl alcohol containing 0.25 mole fraction of ethanol is continuously distilled in a plate fractionating columns to give a product of 0.75 mole fraction of alcohol and a waste of 0.04 mole fraction of alcohol. Determine the number of theoretical and actual plates required, if the feed is liquid at its bubble point and a reflux ratio of 2 is used. The efficiency of the plate is 75%.

Equilibrium data:

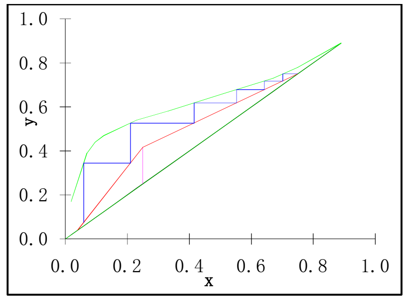
%X:	1.9	7	9.6	12.4	23	33	51	67	75	89
% Y:	17	39	44	47	54	58	66	73	78	89

Solution:

x_F=0.25, x_D=0.75, x_B=0.04, η=0.75

Intercept on y-axis of rectifying section operating line: 0.667

Number of equilibrium stages including reboiler =6, Number of actual plates=8



Scheme: Writing x_F, x_D, x_B, η -2M, McCabe Thiele Diagram-4M, Finding theoretical and actual stages -4M

(OR)

9 a) Compare and contrast plate and packed columns.6M

Selection of column type: Plate or Packed

- In a plate tower, the liquid and gas are contacted in stage-wise manner on the trays.
- Packed towers (columns) are used asthe continuous contacting devices.

Some typical criterions for the selection of column type

1. *Gas pressure drop*. Packed towers will ordinarily require a smaller pressure drop. This is especially important for vacuum distillation.

2. *Liquid holdup*. Packed towers will provide a substantially smaller liquid holdup. This is important where liquid deterioration occurs with high temperatures and short holding times are essential. It is also important in obtaining sharp separations in batch distillation.

3. *Liquid/gas ratio*. Very low values of this ratio is best handled in tray tower & high values are best handled in packed towers.

4. *Liquid cooling*. Cooling coils are more readily built into tray towers; and liquid can more readily be removed from trays, to be passed through coolers and returned, than from packed towers.

5. *Side streams*. These are more readily removed from tray towers.

6. *Foaming systems*. Packed towers operate with less bubbling of gas through the liquid and are the more suitable. Packed column is the preferred choice than a plate column to handle toxic and flammable liquids due to lower liquid holdup to keep the unit as small as possible for the sake of safety.

7. *Corrosion*. Packed towers for difficult corrosion problems are likely to be less costly.

8. *Solids present*. Neither type of tower is very satisfactory. Agitated vessels and venturi scrubbers are used. Plate columns are normally suitable for fouling liquids or laden with solids. They are easier to clean and could handle substantial temperature variation during operation.

9. *Cleaning*. Frequent cleaning is easier with tray rowers.

10. *Large temperature fluctuations*. Fragile packings (ceramic, graphite) tend to be crushed. Trays or metal packings are satisfactory.

11. *Floor loading*. Plastic packed towers are lighter in weight than tray towers, which in turn are lighter than ceramic or metal packed towers. In any event, floor loadings should be designed for accidental complete filling of the lower with liquid.

12. *Cost*. If there is no overriding consideration, cost is the major factor to be taken into account.

Scheme: Comparison-6M

b) It is desired to absorb 90% of the Acetone in a gas containing 1 mole % Acetone in air in a counter current stage tower. The total inlet gas flow to the tower is 30 kg mole/hr, and the total inlet pure water flow to be used to absorb Acetone is 90 kg mole/hr. The equilibrium relation is *Y* = 2.53 *X*, where '*Y*' and '*X*' are mole fractions of Acetone in gas and liquid phases respectively. Determine the number of theoretical plates required. Assume dilute solution concept.

Solution: m=2.53, L_0 = 90 kg mole/hr, G= V_{N+1} =30 kg mole/hr, A = $L_0/(mV_{N+1})$ = 90/(2.53×30) = 1.186, X_0 =0, Y_{n+1}=0.01, Y_1=0.00101

$$N_{OG} = \frac{\ln\left[\frac{y_{n+1}-mx_0}{y_1-mx_0}\left(1-\frac{1}{A}\right)+\frac{1}{A}\right]}{\ln A}$$

N=5.16

Scheme: Data with corresponding notations-4M, NTU equation-2M