Important Instructions to examiners:

1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling errors should not be given more Importance (Not applicable for subject English and Communication Skills.
4) While assessing figures, examiner may give credit for principal components indicated in the figure. The figures drawn by candidate and model answer may vary. The examiner may give credit for any equivalent figure drawn.
5) Credits may be given step wise for numerical problems. In some cases, the assumed constant values may vary and there may be some difference in the candidate's answers and model answer.
6) In case of some questions credit may be given by judgement on part of examiner of relevant answer based on candidate's understanding.
7) For programming language papers, credit may be given to any other program based on equivalent concept.

Q No	Sub Q.N	Answer	marks
1	a	Any three	12
1a	(i)	**It is necessary to study different modes of heat transfer because:** In process industries there are many operations which involve transfer of energy in the form of heat and also chemical reactions carried on a commercial scale take place with evolution or absorption of heat. It is also necessary to prevent the loss of heat from a hot vessel or a pipe system to ambient air. In all these cases, the major problem is that of transfer of heat at the desired rate. **Modes of heat transfer are:** 1) **Conduction :** If a temperature gradient exist in a continuous substance, heat can flow unaccompanied by any observable motion of mater. Heat flow of this kind is called conduction. In metallic solids thermal conduction results from the motion of unbound electrons. In most liquid and solids which are poor conductors of electricity, thermal conduction results from the transport of momentum of individual molecules. In gases conduction occurs by the random motion of molecules. **Example:** Heat flow in the metal wall of tube 2) **Convection** : When a macroscopic particle of fluid crosses a specific surface, it carries with it a definite quantity of enthalpy. Such a flow of enthalpy is called convection. Since convection is a macroscopic phenomenon, it can occur only when forces act on the particle or stream of fluid and maintain its motion against the force	1 1 1

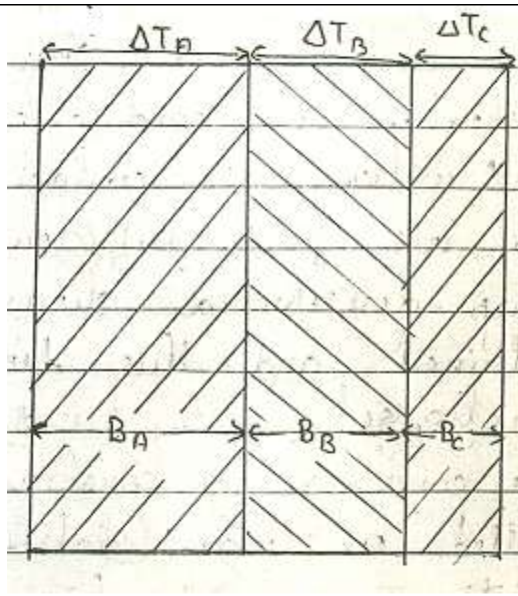
		of friction. There are two types of convection- natural and forced. If the currents are the result of buoyancy forces generated by differences in density and the differences in density are in turn caused by temperature gradient the action is called natural convection. **Example**: heating of water by hot surface **Forced convection** : If the currents are set in motion by the action of a mechanical device such as a pump or agitator, the flow is called forced convection **Example:** heat flow to a fluid pumped through a heated pipe 3) **Radiation**: Radiation is transfer of energy through space by electromagnetic waves. If radiation is passing through empty space, it is not transformed into other forms of energy, nor is it diverted from its path. If matter appears in its path, the radiation will be transmitted, absorbed or reflected. It is only the absorbed energy that appears as heat. Fused quartz transmits all radiation falling on it, a polished opaque surface will reflect all the radiation and a black surface will absorb most of the radiation receiving. **Example**: Loss of heat from unlagged pipe.	1
1a	(ii)	**Kirchhoff's Law :** Consider that the two bodies are kept into a furnace held at constant temperature of T K. Assume that, of the two bodies one is a black body& the other is a non-black body i.e. the body having 'a' value less than one. Both the bodies will eventually attain the temperature of T K & the bodies neither become hotter nor cooler than the furnace. At this condition of thermal equilibrium, each body absorbs and emits thermal radiation at the same rate. The rate of absorption & emission for the black body will be	2

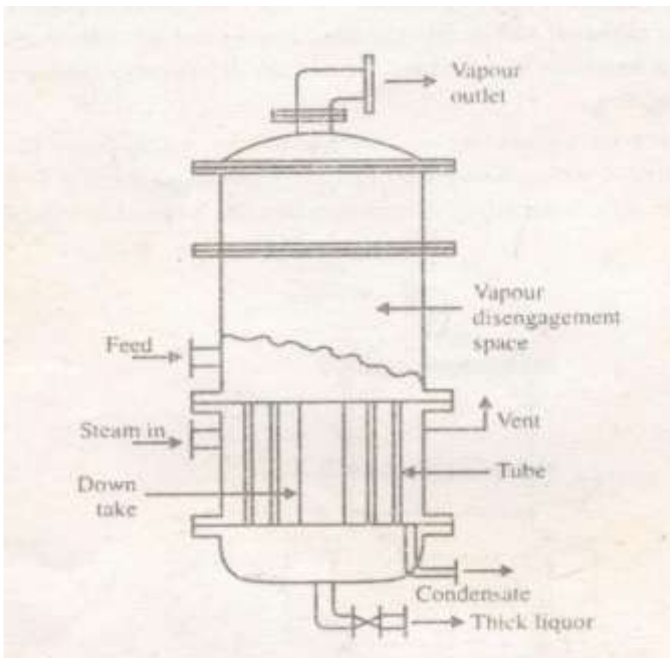
		different from that of the non-black body. Let the area of non-black body be A_1 and A_2 respectively. Let 'I' be the rate at which radiation falling on bodies per unit area and E_1 and E_2 be the emissive powers (emissive power is the total quantity of radiant energy emitted by a body per unit area per unit time)of non-black & black body respectively. At thermal equilibrium, absorption and emission rates are equal, thus, $Ia_1 A_1 = A_1 E_1$ ………………..(1.1) $\therefore\ Ia_1 = E_1$ …………….(1.2) And $Ia_b A_2 = A_2 E_b$ ……………..(1.3) $Ia_b = E_b$ ………….(1.4) From equation (1.1) and (1.4).we get $\frac{E1}{a1} = \frac{Eb}{ab}$ ………….(1.5) Where $a_{1,}a_b$ = absorptivity of non-black & black bodies respectively. If we introduce a second body (non-black) then for the second non-black body, we have : $I A_3 a_2 = E_2 A_3$ ………….(1.6) $\therefore\ Ia_2 = E_2$ …………..(1.7) Where $a_1 = E_2$ are the absorptivity and emissive power of the second non-black body. Combining equations (1.2),(1.4) and(1.7) we get, $\frac{E1}{a1} = \frac{E2}{a2} = \frac{E3}{a3} = E_b$ ………..(1.8)	2
1a	(iii)	**Thermal conductivity:** It is a measure of the ability of the substance to	1

		conduct heat. It is the amount of heat passing through a material of a unit thickness with a unit heat flow area in unit time when a unit temperature difference is maintained across the opposite faces of the material.	
		Unit: W/ (m.K)	1
		Relation between temperature and thermal conductivity:	
		For small temperature ranges, thermal conductivity is taken as constant but for large temperature changes, it varies linearly with temperature and is given by	2
		K= a+bT+cT^2+.. where a,b and c are constants and T is temperature in K	
1a	(iv)	**Single pass and multi pass: (any 4)**	1 mark each

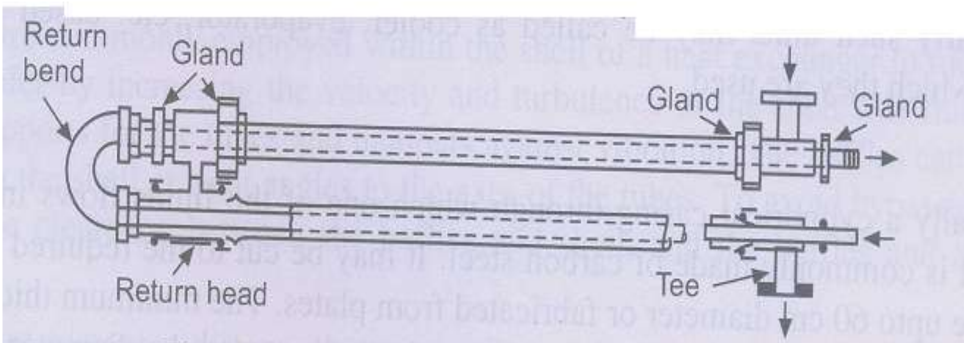
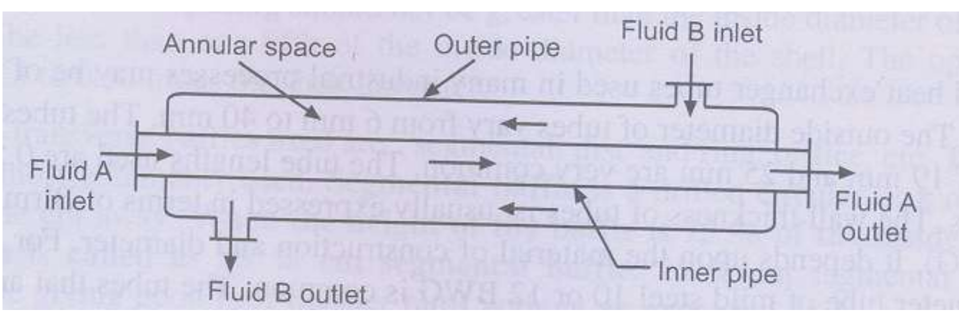
Single pass	Multi pass
Simple in construction	Complex in construction
Flow may be parallel or counter current	Flow is parallel as well as counte current
Inexpensive	Expensive
Heat transfer coefficients are low	Heat transfer coefficients are high
For a given duty, floor space requirement is large	Floor space requirement is low
Frictional losses are low	Frictional losses are high
Heat transfer rates are low	Heat transfer rates are high
Fluid flow once through exchanger	Fluid flow number of times throug exchanger

1	b	**Any one**	6
1b	(i)	**Heat loss through a composite wall:**	

			2
		Consider a flat wall constructed of a series of layers of thickness x1, x2, x3 respectively. Let the thermal conductivities of layers be K_1, K_2, K_3 . Let ΔT1, ΔT2, ΔT3 be the temperature drop across the layers. Let ΔT be the total temperature drop across the entire wall.	1
		$\Delta T = \Delta T_A + \Delta T_B + \Delta T_C$	1
		$\Delta T_A = q_1 * B_A / K_1 * A \quad \Delta T_B = q_2 * B_B / K_2 * A \quad \Delta T_C = q_3 * B_C / K_3 * A$ Where A is the area of the wall at right angle to the plane Then $\Delta T = q_1 * B_A / K_1 * A + q_2 * B_B / K_2 * A + q_3 * B_C / K_3 * A$ In steady state conduction, all the heat passes through the first resistance should pass through second and third. So $q_1 = q_2 = q_3$	1
		$\Delta T = q[B_A / K_1 * A + B_B / K_2 * A + B_C / K_3 * A]$ $= q[R_1 + R_2 + R_3]$ OR $q = \Delta T / [R_1 + R_2 + R_3]$ But $q = \Delta T / R$ Therefore : $R = R_1 + R_2 + R_3$	1

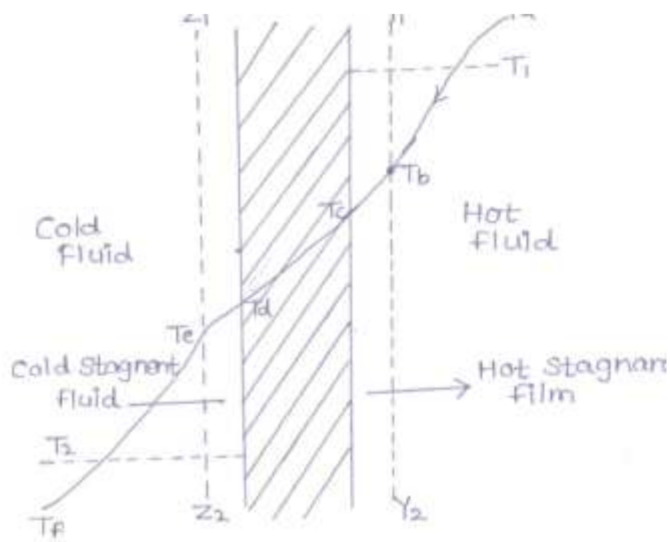
		In heat flow through a series of layers the overall resistance is equal to the sum of individual resistances.	
1b	(ii)	**Calendria type(Short tube) evaporator:**  **Construction:** It consists of vertical cylindrical shell incorporating short vertical tube bundle with horizontal tube sheet. Vapour inlet is provided at top cover while thick liquor discharge is provided at bottom. Downtake is provided at centre of tube bundle for circulating cooler liquid back to the bottom of the tubes. Solution to be evaporated is inside the tubes and steam flows outside the tubes in the steam chest. Baffles are incorporated in steam chest to promote uniform distribution of steam. The condensate is withdrawn at a point near lower tube sheet, while non condensable gas is vented to atmosphere from point near top tube sheet. **Working:** Thin liquor is introduced to the tube side and steam into steam chest . The liquor covers top of tubes. Heat transfer to boiling liquid inside	1 3 2

		the tubes take place from condensing steam on outside of tubes. Vapours formed will rise through the tubes, come to the liquid surface from which they are disengaged into the vapour space and removed from the vapour outlet. Thick liquor is removed from the bottom of the evaporator.	
2		Any four	16
2	a	**Sensible heat:** Sensible heat the amount of heat required to change the temperature of a substance. $Q = mCp\Delta T$ where m - mass flow rate Cp - specific heat ΔT - Change in temperature **Latent heat:** It is the amount of heat required to change the phase of a substance at constant temperature. $Q = m\lambda$ Where m- mass flow rate λ – latent heat of vaporization/ condensation	1 1 1 1
2	b	Area $A = 1\ m^2$ Thickness $B = 0.5$ m $K = 0.7$ W/mK Temperature difference $\Delta T = 400-310 = 90$ K $Q = k\ A\ \Delta T / B$ $= 0.7*1*90 / 0.5$ $= \mathbf{126\ W/m^2}$	 2 1 1
2	c	The heat transfer area of the tube and pipe is increased substantially by attaching the metal pieces. The metal pieces employed to extend or increased the heat transfer surface are known as fins. Types of extended	

		surfaces are:	
		1) **Longitudinal fins:** In longitudinal fins, long metal strips or channel are attached to the outside of the pipe and the direction of flow is parallel to the axis of the tube.	1
		Used in: Double pipe heat exchangers in situations involving gases and viscous liquids.	1
		2) **Transverse fins:** In transverse fins, the metal pieces are attached to the pipe or tube by grooving at right angles to the axis of pipe or tube.	1
		Used in: Automobile radiator, air cooled steam condensers for turbine and engine works, economiser	1
2	d	**Double pipe heat exchanger:**  **OR** 	4
2	e	**Absorptivity (α):**	1

		It is defined as the fraction of radiation falling on a body which is getting absorbed.	
		Reflectivity (ρ) :	
		It is defined as the fraction of radiation falling on a body which is getting reflected.	1
		Transmissivity (τ) :	
		It is defined as the fraction of radiation falling on a body which is getting transmitted.	1
		$(\alpha)+(\rho)+(\tau) = 1$	
		Material for which $(\alpha)+(\rho) = 1$ is called an **opaque material**	1
3		**Any two**	16
3	a	At steady state : Heat gained by cold water = Heat removed from hot water	
		Q = mc Cpc (t2-t1) = mhCph (T1-T2)	1
		mc = mass flow rate of cold water = 8000 kg/s	
		mh = mass flow rate of hot water = 10000 kg/s	
		Cpc = 4.187 kJ/kg k	
		Cph =2.095 kJ/kg k	
		t2 =?, t1=298 k ,T1 = 353 K, T2 =323 K	
		Q= 8000 x 4.18 x (t2-298)	
		Q= heat gained by cold fluid = Heat lost by hot fluid	2
		8000 x 4.18 x (t2-298) = 10000 X 2.095 (353 – 323)	
		t2 = 316.8 K	1
		Δ T1=353-316.8 =36.2K, ΔT2= 323-298 = 25 k	
		Δ Tlm= (36.2-25)/ln(36.2/25) = 30.26 K	2
		A= Q/ (U Δ Tlm) = 628500 X 10^3/ 3600 (300 x 30.26) =19023 m^2	2
		HEAT TRANSFER AREA REQUIRED = 19.23 m^2	

3	b	$1/U = 1/h_o + 1/h_i + 1/k/x$ Where U= overall heat transfer coefficient h_o= 1750 w/m^{2}k hi=5800 w/m^{2}k x=(15-10) mm = 5mm=0.005m k=46.52 w/ m^{2}k 1/U=1/1750 + 1/5800 + 1/46.52/0.005 U= **1175 w/ m^{2}k**	2 2 2 2
3	c	**Relation between individual and overall heat transfer coefficients:** Consider a hot fluid flowing through a circular pipe & a cold fluid flowing on the outside of the pipe. Heat is flowing from the bulk of hot fluid to the bulk of cold fluid through a metal wall of pipe. (i) When heat is flowing from bulk of hot fluid to the metal wall , although heat transfer in bulk fluid takes by convection current ,there is a very small layer of fluid near the pipe in which heat transfer takes place by conduction. This is because flow in this layer is laminar & there is no mixing of molecules. This layer is known as viscous sublayer. This thin film of fluid flowing in Laminar flow is of great importance in determining the rate of heat transfer. The Thermal conductivity of fluid is very low so that resistance offered by this film is very large through the film is thin. (ii) When heat across metal wall resistance is comparatively low. (iii) When heat transfer takes place from metal to the bulk of fluid there exists a thin film of cold fluid which has a high resistance. (iv) Heat then flows from this thin film to bulk of cold fluid by convection. The process of heat transfer from bulk of hot fluid to bulk of cold fluid is represented by fig.	1

			1
		Y1, y2 represents thin film on hot side in which liquid is flowing in Laminar flow. Ta – Tb –Tc is temperature drop from bulk of hot fluid to metal wall on hot side. T1 = is Avarage temperature on hot side Z1 Z2 represents thin film on cold side in which liquid is flowing in Laminar flow. Td –Te – Tf is temperature drop from metal wall to the bulk of cold fluid. T2 is average temperature on cold side. The rate of heat tranfer on hot side liquid is given by $Q = Ki\ Ai\ (Ta - Tc)/X1$ ……..(i) The effective thickness x1 depends on nature of flow , nature of surface and is generally not known. Therefore an indirect method of calculating heat transfer rate is by use of inside heat transfer coefficient represented by hi. Rate equation is usually written as	1

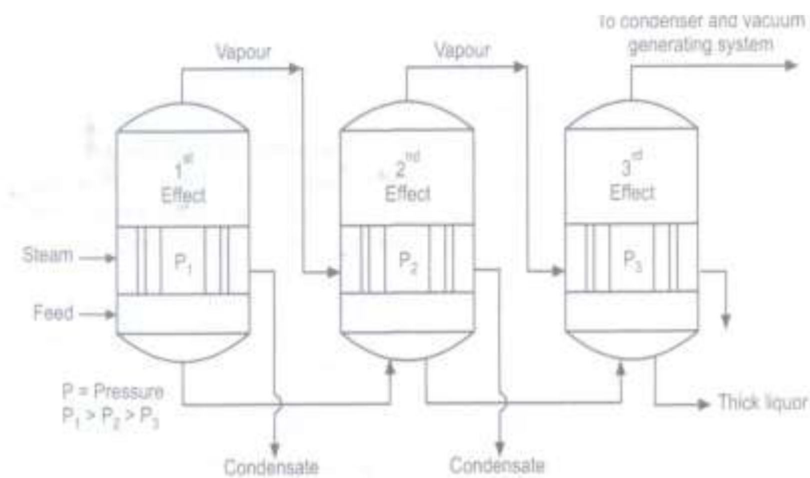
		$Q = hi\ Ai\ (Ta - Tc)$ ……..(ii)	
		Comparing equation (i) & (ii),	1
		$hi = K1/x1$	
		Resistance for heat tranfer is given as	
		$R = X/K_A = 1/K/x(A) = 1/hiAi$	
		$\therefore$Resistance offered by film on hot side= 1/hiAo	
		= Resistance of metal wall = L/KmAm	
		= Resistance of thin film on cold fluid =1/hoAo	1
		So effectively heat tranfer is across this there is $Q_1 + Q_2 + Q_3$ films.	
		At Steady State,	
		$Q_1 = Q_2 = Q_3 = Q = \text{Constant}$	
		$\therefore Q = \Delta t/R_1+R_2+R_3$	
		$\therefore Q = T_1 - T_2/[(1/hiAi)+(Lm/R\ Am)+(1/hoAo)]$ …….(i)	
		We multiply N & D by Ai=area of heat transfer on hot side,we get	
		$Q = (T_1-T_2)Ai/[(1/hiAi)+(Lm/Km.Am)+(1/ho.Ao)]\ Ai$	
		$=(T_1-T_2)Ai[(1/hi)+(Lm/Km.Ai/Am)+(1/ho.Ai/Ao)]$	1
		Since pipes are circular,	
		$A = 2\prod rl$	
		$=(T_1-T_2)Ai[(1/hi)+(Lm/Km.2\prod r_i\ L/2\prod r_m\ L)+(1/ho.2\prod r_i/2\prod r_o)]$	1
		$=(T_1-T_2)Ai[(1/hi)+(Lm/Km.\ r_i/r_m)+(1/ho..\ r_i/r_o)]$	
		We assume a new parameter,	
		U_i = Overall heat transfer coefficient on inside liquid.	1
		$\therefore 1/Ui = 1/hi + Lm/.ri/rm + 1/ho\ ri/ro$ ……(i)	
4 a		Any three	12
4a	(i)	**Solution :**	
		e= 0.8 $\sigma = 5.67*10^{-8}\ w/(m^2.k^4)$	1

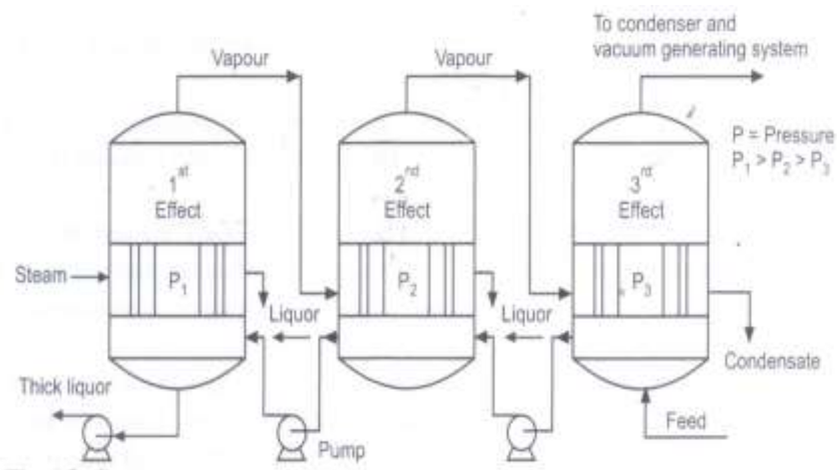
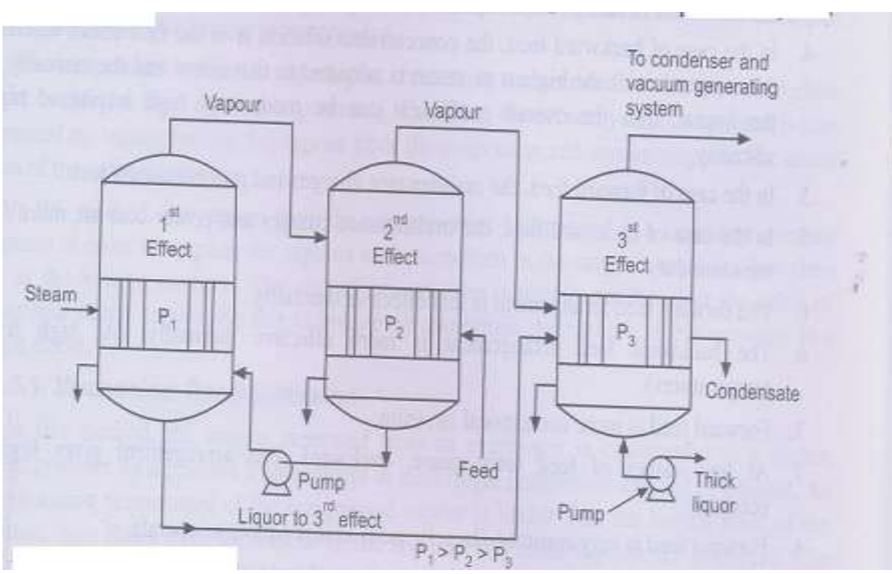
		$T_1 = 377$ K $T_2 = 283$K The heat loss by radiation is $Qr/A = e\sigma (T_1^4 - T_2^4)$ $= 0.9 * 5.67 * 10^{-8} * (377^4 - 283^4)$ **= 703.5 w/m²**	1 2
4a	(ii)	**Heat transfer equipment (any 4)** 1. Cooler: To cool process fluid by means of water or atmospheric air. 2. Condenser: To condense a vapour or mixture of vapours. 3. Chiller: To cool a process fluid to a temperature below that can be obtained by using water as a cooling media 4. Heater: Which imparts sensible heat to process fluid. 5. Vaporiser: Which vaporizes part of liquid. 6. Reboiler: Employed to meet latent heat requirement at the bottom of distillation column. 7. Evaporator: To concentrate a solution by evaporating water.	1 mark each
4a	(iii)	**Capacity** of an evaporator is defined as the number of kilogram of water evaporated per hour. **Economy** of an evaporator is defined as the number of kilogram of water evaporated per kilogram of steam fed to the evaporator.	2 2
4a	(iv)	**Factors on which rate of heat transfer depends are:** 1. Area perpendicular to heat flow 2. Thermal conductivity of the material 3. Temperature gradient 4. Distance normal to the surface The relationship is given by Fourier's law. **Fourier's law of conduction:**	2

		It states that the rate of heat flow across an isothermal surface is proportional to the temperature gradient at the surface. $\frac{dQ}{dA} = - k\frac{\partial T}{\partial n}$ Q- rate of heat transfer A- Area perpendicular to heat flow k- Thermal conductivity T- Temperature	2
4 b		**Any one**	6
4b	(i)	Consider the hollow sphere of inside radius r_1 and the outside radius r_2. Assume that thermal conductivity of the material of which sphere is made be k (constant). Let the temperature of the inside surface be T_1 and that of the outside surface be T_2 . Assume that $T_1 > T_2$,therefore the heat flows from the inside of sphere to outside . It is desired to calculate the rate of heat flow for this case. Consider a spherical element at any radius r , where r is between r_1 and r_2 . The rate if heat flow according to Fourier's Law is goven by, $$Q = - k (4\prod r^2) (dT / dr)….(i)$$ Rearranging the eqn (i) ,we get $$dr / r^2 = - k (4\prod) /Q.dT…..(ii)$$ Only variables in eqn (ii) are r and T (assuming k to be constant). Integrate the eqn (ii) between the limits When $r = r_1,\quad T = T_1$	1 1

		When $r = r_2$, $T = T_2$	
		$$\int_{r1}^{r2} dr/r2 = -k(4\prod)/Q \int_{T1}^{T2} dT \ldots\ldots(iii)$$	1
		$$[-1/r]_{r1}^{r2} = -k(4\prod)/Q\,(T_2 - T_1)\ldots\ldots(iv)$$	
		$$[1/r_1 - 1/r_2] = k(4\prod)/Q\,(T_1 - T_2)\ldots\ldots(v)$$	
		Rate of heat flow through sphere is :	1
		$$\therefore Q = k(4\prod)(T_1 - T_2)/[1/r_1 - 1/r_2] \quad vi)$$	
		It can be put into more convinient form by expressing the rate of heat flow as :	
		$$Q = k(4\prod)(T_1 - T_2)\{(r_1.r_2)/[r_2 - r_1]\} \quad \ldots\ldots(vii)$$	
		Where r_m is the logarithmic mean radius & is given by	
		$$r_m = \sqrt{(r_1.r_2)}$$	1
		$$r_m^2 = r_1.r_2$$	
		$$A_m = 4\prod r_m^2\ldots.(ix)$$	
		A_m is called as logarithmic mean area.	
		Equation (viii) becomes	
		$$\mathbf{Q = k\ A_m\,(T_1 - T_2)/(r_2 - r_1)\ldots.(x)}$$	1
		$$Q = (T_1 - T_2)/[(r_2 - r_1)/k\ A_m] = \Delta T/R$$	
		Where $R = (r_2 - r_1)/k\ A_m$	
4b	(ii)	**Advantages of short tube evaporator :** i) Relatively inexpensive ii) As scaling occurs inside the tubes , it can be easily removed by mechanical or chemical means. iii) Provides moderately good heat transfer at a reasonable cost.	1 mark each for any 3

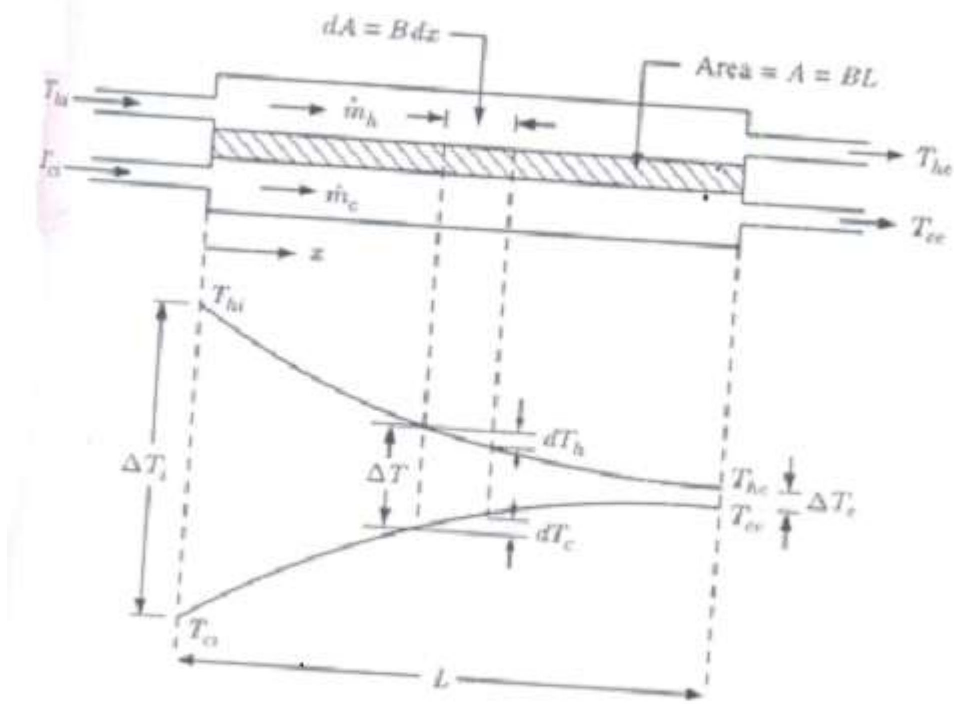
		iv) Can be put into more rigorous services than horizontal tube evaporator. **Disadvantages of short tube evaporator :** i) Floor space required is large ii) Amount of liquid hold up in the evaporator is large iii) Since there is no circulation, these units are not suitable for viscous liquid.	1 mark each
5		Any two	16
5	a	**Multiple effect evaporation:** This is used to increase the economy of an evaporator**.** In this system, evaporators are arranged in series so that the vapour produced in first effect is fed to the steam chest of second effect as heating medium in which boiling takes place at low pressure and temperature and so on. The different feed arrangements are **1.Forward feed arrangement:** In this arrangement, the liquid feed flows in the same direction as the vapour flows. Fresh feed enters the first effect and steam is also fed to the steam chest of first effect. The vapours produced in first effect are fed to steam chest of second effect as heating media and concentrated liquor from first effect is fed to the next effect in series. The pressure in the second effect is less than in the first effect and so on.	2 3 marks each for any two

		 2.**Backward feed arrangement**: In this arrangement, the feed solution and vapour flow in opposite direction. The fresh feed is admitted to the last effect and pumped through other effects. The steam is fed to the steam chest of first effect. The vapours produced in first effect are fed to steam chest of second effect as heating media. Concentrated liquor is obtained from first effect. The pressure in the second effect is less than in the first effect and so on. This arrangement is used for viscous liquid.	

		 3.**Mixed feed arrangement:** In this feed arrangement, The steam is fed to the steam chest of first effect. The vapours produced in first effect are fed to steam chest of second effect as heating media and so on. Feed solution is admitted to an intermediate effect and flows to the first effect from where it is fed to the last effect for final concentration. 	
5	b	Heat lost by hot fluid	

		$Q_h = m_h\ Cp_h\ (T_{hi}-T_{ho})$	2
		$= 5000 * 2.72*(423-363) = 816000$ kJ/h	
		Heat gained by cold fluid	
		$Q_c = m_c\ Cp_c\ (T_{co}-T_{ci})$	2
		$= 15000*4.187*(Tco – 303)$	
		$Q_h = Q_c$	2
		$816000 = 15000*4.2*(Tco – 303)$	
		Outlet temperature of water = **316 K**	2
5	c	Area = $\pi d^2/4$	
		$= 3.14 x 10^{-4}\ m^2$	1
		Velocity = Volumetric flow rate/ area	
		$= 300x10^{-6}/ 3.14x10^{-4}$	
		$= 0.955$ m/s	1
		$N_{Re} = Du\rho/ \mu$	1
		D =20 mm = 0.02 m, u =0.955m/s	
		$\mu = 0.8$ kg/m.s	
		$\rho = 1100\ kg/m^3$	
		$N_{Re} = 0.02x0.955x1100/0.8 = 26.26$	1
		$N_{Pr} = Cp\ \mu/k = 1.26 \times 10^3 x\ 0.8/0.384 = 2625$	1
		The equation to find out heat transfer coefficient for turbulent flow	
		$N_{NU} = 1.86[\ N_{Re} x\ N_{Pr}\ x\ D/L]^{1/3}\ (\ \mu/\ \mu_w)^{0.14}$	1
		$=1.86[26.26)(2625)0.02/5]^{1/3}\ [0.8/1.0]^{0.14}$	
		$= 11.71$	1
		Nu= hD/k	
		h=11.71x0.384/0.02	
		h=**225 W/m^2.k**	1
6		Any two	16

6	a	Basis: 5000 kg/hr feed is fed to the evaporator.	
		Material balance of solids:	1
		Solids in feed= solids in the thick liquor	
		0.05x5000=0.2 x m’	
		m’=1250kg/h.	1
		overall Material balance:	
		kg/h feed= kg/h water evaporated + kg/h thick liquor	
		water evaporated(m_v)=5000-1250=3750kg/h	1
		Energy balance is	
		$m_s \lambda_s = m*c_{pf} *(T-T_f) + m_v \lambda_v$	1
		m_s 2185 = 5000*4.187*(378-298) + 3750 *2259	
		steam fed(m_s)= 4643.5 kg/h	1
		steam economy= kg/h water evaporated/kg/h steam consumed	
		= 3750/4643.5=**0.808**	1
		Q= U*A*****ΔT	
		4643.5*2185*1000/ 3600 = 2350 * A*(399-378)	1
		A = **57.1 m²**	1
6	b	**To derive ΔTlm= (ΔTi- ΔTe)/ ln (ΔTi/ ΔTe)**	



2

Consider an elementary area dA(=B.dx). The rate of heat transfer across it is given by

dq= U (Th-Tc) B dx -------------(1)

Since there are no losses to the surroundings, the heat transfer rate is also equal to the rate of change of enthalpy on either side. Therefore, 1

dq= -mh Cph dTh-------------------(2) 1

= mc Cpc dTc ----------------------(3)

Now ΔT = Th- Tc -----------------(4)

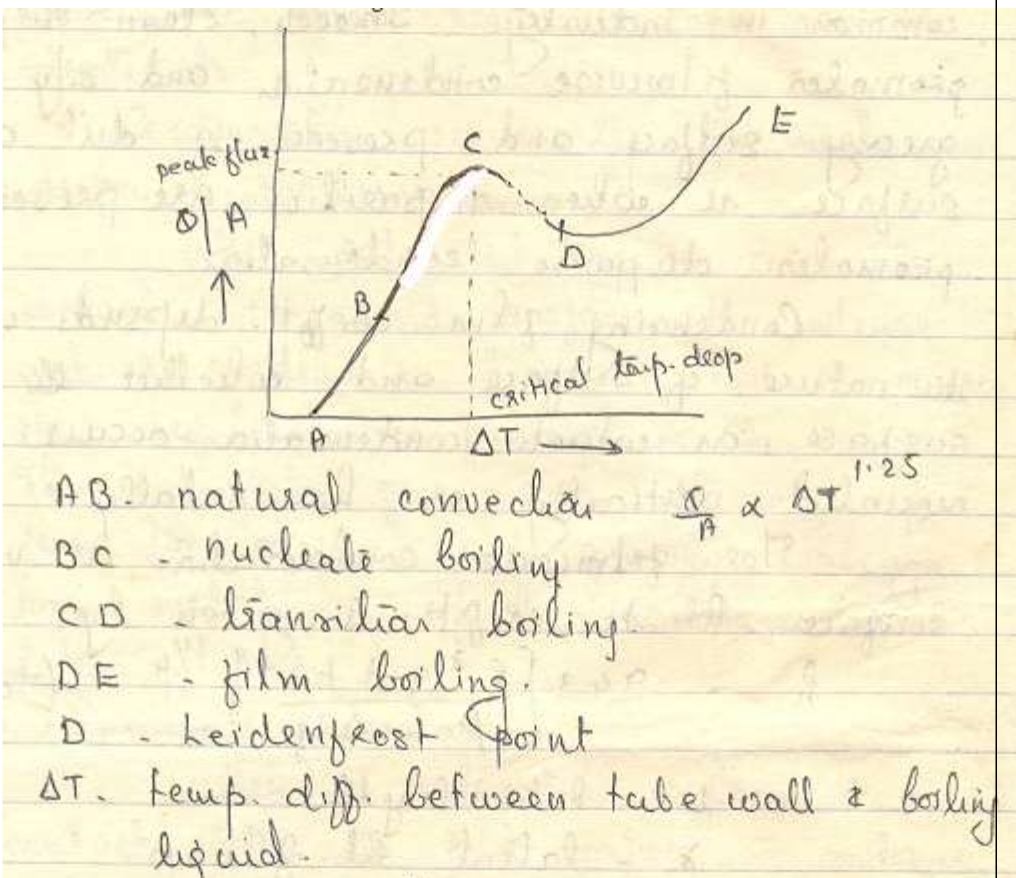
On differentiating

d(ΔT) =dTh- dTc -------------------------------------(5) 1

substituting for dq, dTh and dTc from equations (1), (2) and (3) into

		equation (5) , we obtain $d(\Delta T)/ \Delta T= - (1/(mh\ Cph) + 1/(mc\ Cpc))\ U\ B\ dx$ $\int_{\Delta Ti}^{\Delta Te} d(\Delta T)/ \Delta T = - (1/(mh\ Cph) + 1/(mc\ Cpc))\ U\ B\int_0^L dx$ $\ln (\Delta Te/ \Delta Ti) = - (1/(mh\ Cph) + 1/(mc\ Cpc))\ U\ A$ ------------------------------ (6) where $\Delta Te = T_{he}-T_{ce}$ $\Delta Ti= T_{hi} - T_{ci}$ Now if q is the total rate of heat transfer in the heat exchanger, then $q = m_hCp_h (T_{hi}-T_{he})$ -----------------------------(7) $= mc\ Cpc (T_{ce}- T_{ci})$ --------------------------(8) Substituting equations (7) and (8) into equation (6), $\ln (\Delta Te/ \Delta Ti) = -1/q[(T_{hi}-T_{he}) + (T_{ce}- T_{ci})]U\ A$ $q= U\ A (\Delta Ti- \Delta Te)/ \ln (\Delta Ti/ \Delta Te)$ -----------------------------(9) Equation (9) is the performance equation for a parallel-flow heat exchanger. $Q= U\ A\ \Delta Tlm$ Where $\Delta Tlm= (\Delta Ti- \Delta Te)/ \ln (\Delta Ti/ \Delta Te)$	1 1 1

6 c **Heat transfer in boiling liquids :**



2

Consider a horizontal tube immersed in a vessel containing boiling liquid. Assume that Q/A, the heat flux and ΔT, the difference between the temperature of the tube wall and that of the boiling liquid , are measure . A plot of Q/A vs ΔT on log coordinates is drawn . This curve can be divided into four segments. At low temperature drops, the line AB is straight and has slope of 1.25.Here heat transfer is by **natural convection**. Bubbles formed on the surface of the heater, are released from it , raise the surface and are disengaged in to the vapour space.

2

The segments BC is also straight but slope is greater than AB. The rate of

		bubble production is large enough for the stream of bubbles moving up through the liquid to increase the velocity of the circulation currents and coefficient of heat transfer becomes greater than that in undisturbed natural convection. This is called **nucleate boiling**.	2
		In the segments CD the flux decreases as the temperature drop raises and reaches a minimum at point D. As the temperature drop is raised , more and more bubbles are present that they tend to coalesce on the heating surface to formed and layer of insulating vapour. This type is called **transition boiling.**	1
		In DE the flux again increases with ΔT and at large temperature drop surpasses the previous maximum reached. The hot surface becomes covered with a film of vapour through with heat is transferred by conduction and by radiation .This is known as **film boiling**.	1