WINTER-14 EXAMINATION

Model Answer

Important Instructions to examiners:

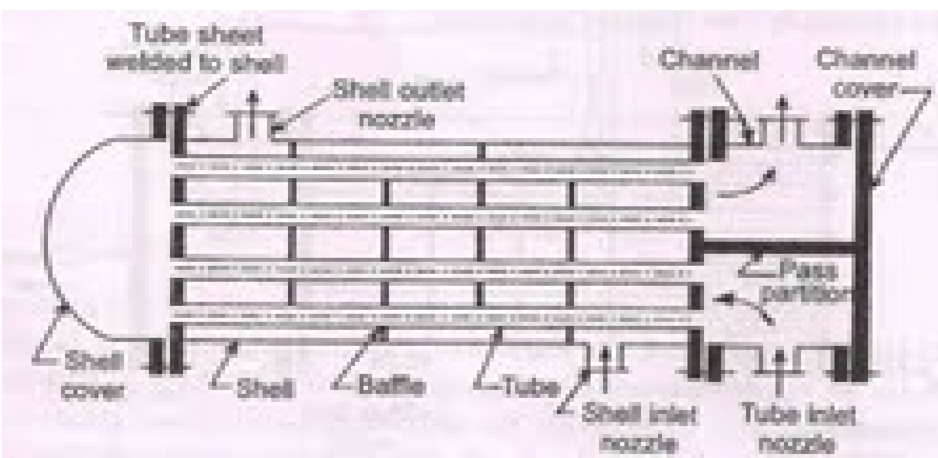
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling 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.

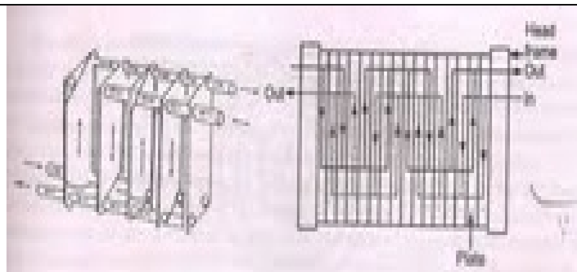
Q No.	Answer	marks	Total marks
1A-a	**Fourier's law of conduction:** It states that the rate of heat flow across an isothermal surface is proportional to the temperature gradient at the surface. $\frac{dQ}{dA} = -k\frac{\partial T}{\partial n}$ Q- rate of heat transfer A- Area perpendicular to heat flow k- Thermal conductivity T- Temperature n- Distance measure normally to the surface.	2 1 1	4
1A-b	**Dimensional Analysis :** It is a method of correlating a number of variables into a single equation expressing and effect. **Physical significance of Dimensional Analysis :** When the value of a physical quantity is influenced by a number of variable, then it is impossible to determine their individual effects by experimental method. In such cases the problem can be made more manageable by adopting the method of dimensional analysis where in the variables are arranged in dimensionless groups which are significantly less than the number of variables. **Prove that N_{re} is dimensionless:** $N_{re} = D\, v\, \rho/\mu$ $= \frac{m.m/sec.Kg/m^3}{Kg/m.sec}$ $= m^3.\ Kg.\ sec/\ m^3.\ Kg.\ sec$	2 2	4

	= no unit		
1A-c	**Stefan-Boltzmann Law** : It states that the total energy emitted (emissive power) by a black body is proportional to fourth power of its absolute temperature. $W_b \propto T^4$ $W_b = \sigma \ T^4$ Where W_b = total energy emitted (emissive power) by a black body σ = Stefan Boltzman constant= $5.67*10^{-8}$ W/m ^{2} K T = absolute temperature	 2 1 1	4
1A-d	**Classification of shell and tube heat exchanger:** 1. Fixed tube heat exchanger 2. Floating head heat exchanger 3. U- tube type heat exchanger 4. Reboiler/ kettle type heat exchanger **Main parts of shell and tube heat exchanger:** 1. Shell 2. Tubes 3. Tube sheet 4. Baffles 5. Channel 6. Channel cover 7. Pass partition 8. Inlets and outlets for shell side and tube side fluid	2 2	4
1B-a	Basis: 1 meter length of pipe Inside radius (r_i) = 80 mm= 0.08m Outside radius (r_o) =180 mm= 0.18m	 2	6

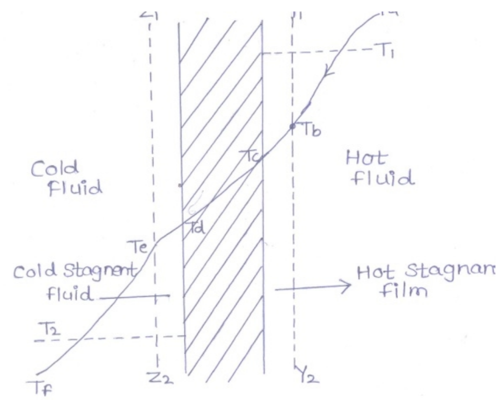
	Thermal conductivity(k)= 0.08 W/mK Inside temperature = 392.8 K Outside temperature = 313 K $r_L = r_o - r_i / \ln(r_o/r_i) = 0.1233$ $Q = k\ 2\ \pi\ r_L.L(T_1-T_2) / (r_o-r_i)$ $= 0.08*2*\pi* 0.1233* 1(392.8-313)/(0.18-0.08)$ = **49.44 W/m**	 1 2 1	
1B-b	**Methods of increasing the economy of an evaporator:** 1. Using multiple effect evaporator 2. Vapour recompression **Multiple effect evaporation:** 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. Increasing the number of effects between steam supply and condenser increases the amount of evaporation per kg of steam fed to the first effect and also the operating cost will be less, but capital cost, maintenance and repair charges increases with increase in number of effects. **Methods of feeding multiple effect evaporation system:** 1. Forward feed arrangement: In this, the liquid feed flows in the same direction as the vapour flows. Fresh feed and steam are fed to the first effect. For effectively utilizing temperature potentials, this arrangement is preferable. 2. Backward feed arrangement: In this arrangement, the feed solution and vapour flow in opposite direction. Fresh feed is admitted to the first effect and steam to the last effect. If the liquid is very viscous, then we adopt backward feed arrangement.	2 1 3	6

	3. Mixed feed arrangement: In this feed arrangement, steam is admitted to the first effect. Feed solution is admitted to an intermediate effect and flows to the first effect from where it is fed to last effect for final concentration. This is adopted for best overall performance.		
2a	**Thermal conductivity:** It is a characteristic property of the material through which heat is flowing and is a function of temperature. Thermal conductivity of a substance is a measure of the ability of the substance to conduct heat. It is the quantity 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. Thermal conductivity is independent of temperature gradient and it slightly depends on temperature. For small temperature ranges it is considered constant and for large temperature ranges K depends on temperature.	3	4
	Unit: Unit of thermal conductivity in SI is W/mK	1	
2-b	Basis: 1 m^2 area of wall		4
	Resistance offered by sil-o-cel brick = B_1/k_1A		
	R_1 = 0.045/0.138*1 = 0.326 K/W	1	
	Resistance offered by common brick = B_2/k_2A		
	R_1 = 0.09/1.38*1 = 0.0652 K/W	1	
	Total resistance R = R_1+R_2	1	
	= 0.326+ .0652 = **0.391 K/W**	1	
2-c	**Show that at thermal equilibrium, the ratio of emissivity to absorptivity is same for all bodies**		4
	Kirchoff's law states that at temperature equilibrium, the ratio of the total	1	

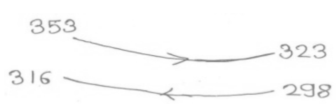
	emissive power of any body to the absorptivity of that body depends only upon the temperature of the body. Take any two bodies in temperature equilibrium with common surroundings. By Kirchoff's law $W_1/\alpha_1 = W_2/\alpha_2$ If the first body is a black body, then $\alpha_1=1$ i.e. $W_1 = W_b = W_2/\alpha_2$ or $\alpha_2= W_2/W_b$ But $W_2/W_b = \varepsilon_2$ (emissivity) Or $\boldsymbol{\alpha_2= \varepsilon_2}$	 1 1 1	
2-d	**1-2 floated head shell and tube heat exchanger** 	4	4
2-e	**Plate and frame heat exchanger:**		4

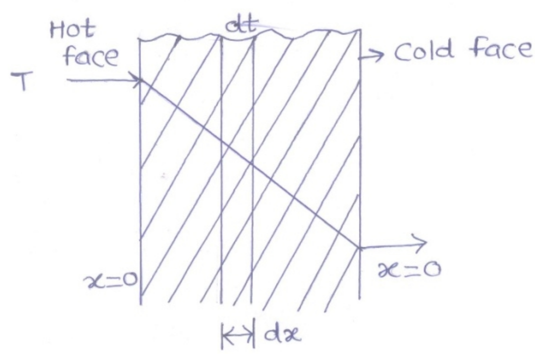
		2	
	Construction: It consists of a series of rectangular, parallel plates held firmly together between head frames. The plates have corner ports and are sealed by gaskets around the ports and along the plate edges. The plates are having corrugated faces. These plates serve as heat transfer surfaces and are of stainless steel.. It is provided with inlet and outlet nozzles for fluids at ends.	1	
	Working: The hot fluid passes between alternate pairs of plates, transferring heat to cold fluid in the adjacent spaces. The plates can be readily separated for cleaning and heat transfer area can be increased by simply adding more plates.	1	
3-a	Sider Tate Equation is, $hiDi/K = 0.023\,(Nre)^{0.8}(Pr)^{1/3}(\mu/\mu w)^{0.14}$ ……..(i)	2	8
	Where, $(\mu/\mu w)$ = Sider Tate Correction Factor Nre = 15745 NP = 36 hi = inside heat transfer coefficient $W/m^2.K$ Di = inside diameter of pipe =20 m = 0.02 m K = 0.25 W/m.K $\mu = 550 \times 10^{-6}$ Pa.s $\mu w = 900 \times 10^{-6}$ Pa.s	2	

	Substitute this values in equation (ii) $hi(0.02)/0.25 = 0.023\ (15745)^{0.8}\ (36)^{1/3}\ (550 \times 10^{-6} / 900 \times 10^{-6})^{0.14}$. ∵ hi (0.02)/(0.05) = 0.023 xx2278.84 x 3.3 x 0.933 ∴ hi (0.02/0.25) = 161.37 ∴ hi = 2017 $W/m^2.K$ ∴ Inside heat transfer coefficient = **2017 W/m^2.K**	2 2	
3-b	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	2	8

	 	2	
	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 $Q = hi\ Ai\ (Ta - Tc)$ ……..(ii)	1	

	Comparing equation (i) & (ii), $hi = K1/x1$ 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 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 $Q = (T_1-T_2)Ai/[(1/hiAi)+(Lm/Km.Am)+(1/ho.Ao)]\ Ai$ $=(T_1-T_2)Ai[(1/hi)+(Lm/Km.Ai/Am)+(1/ho.Ai/Ao)]$ Since pipes are circular, $A = 2\prod rl$ $=(T_1-T_2)Ai[(1/hi)+(Lm/Km.2\prod r_i L/2\prod r_m L)+(1/ho.2\prod r_i /2\prod r_o)]$ $=(T_1-T_2)Ai[(1/hi)+(Lm/Km.\ r_i/ r_m)+(1/ho.\ .\ r_i/ r_o)]$ We assume a new parameter, U_i = Overall heat transfer coefficient on inside liquid. $\therefore 1/Ui = 1/hi + Lm/Km.ri/rm + 1/ho\ ri/ro$ ……(i)	1 2	

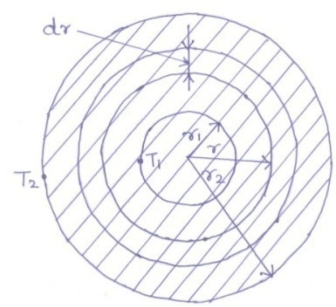
3-c	Heat lost by hot fluid =Heat gained by water		8
	Heat lost by hot fluid = mh x cp_h (Thi –Tho)		
	= 10,000 x 2095 x 30 J		
	= 10,000 x 2095 x30 J	1	
	Heat gained by cold fluid = mc xcp_c (Tco –Tci)		
	= 8000 x 4180 (Tco-298)	1	
	∴(Tco -298) = 10,000 x 2095 x30/8000 x 4180		
	=10/8 x15.3		
	= 18.79		
	∴Tco =18.79 +298	1	
	= 316.79 K		
	We assume counter current flow		
			
	$\therefore \Delta T_1 = 353-316.79$		
	$= 36.21$		
	$\therefore \Delta T_2 = 323-298 = 25$		
	$\therefore$ LMTD = $\Delta T_1 - \Delta T_2 / \ln(\Delta T_1 / \Delta T_2)$		
	= 36.21 -25 / ln(36.21 / 25)	2	
	= 30.29 K		
	∴ We know that,		
	$Q = U A \Delta T$		
	Q = mh Cpo $(T_1 - T_2)$		

	= 10000/3600 x 2095 (353 – 323) = 174583.33 W $U = 300\ W / (m^2.K)$ $A = Q / (U\ \Delta Tlm)$ = 174583.33 / 300 x 30.29 **= 19.21 m^2**	1 1 1	
4A-a	Consider that a wall is made of material of thermal conductivity K & is of uniform thickness (x) & constant cross sectional area (A) .Assume K is independent of temperature & heat losses to atmosphere is negligible . Hot face is at a temperature T_1 & cold face is at a temperature T_2. The direction of heat flow is perpendicular to the wall & T varies in direction of X-axis.  At Steady State, there can be neither accumulation nor depletion of heat within a plane wall &Q is constant along heat flow. The ordinary use of Fourier's Law requires that the differential eqn is integrated over entire path from x = 0,x = x. $\therefore Q = -K\ AdT/dx$ $Q\ dx = -\ K\ A\ dT$ OR	1 1 1	4

	$Q \int_0^x dx = -K A \int_{T1}^{T2} .dt$ $Q.x = - K A (T_2 – T_1)$ OR $Q = K A (T_2 – T_1) / x$	1	
4A-b	Basis :-10000 kg/hr of feed. Amount of solid = 10000 x 0.05 = 500 kg ∴ Amount of H_2O =9500 kg Concentration of solid in final solution = 0.25 Let 'x' is weight of final solution ∴ Solid balance ∴ 0.25 x = 500 ∴ x = 500 / 0.25 = 2000 kg ∴ H_2O Evaporated = 10000 – 2000 = 8000 kg /hr ∴ Capacity of Evaporator = **8000 kg /hr**	1 1 1 1	4
4A-c	Outside area of pipe =∏DL Assume L = 1m Do = 50mm = 0.05m Outside area per length of pipe =∏ x 0.05 x 1 $= 0.157 m^2 /m$ ΔT = 415 -290 = 125 K hc = 1.18 (ΔT /Do) $= 1.18 (125 /0.05)^{0.25}$ $= 8.34 W / m^2 .K$	 1	4

	Heat loss per unit length of pipe by convection = hc.A.$(T_1 – T_2)$ = 8.34 x 0.157 (415 -290) = 163.7 W /m Heat loss per unit length of pipe by radiation = e σ A$(T_1^4 - T_2^4)$ = 0.9* 5.67*10^{-8} (415^4-290^4) = 181 W/m Total heat loss = 163.7+181 = **344.7 W/m**	 1 1 1	
4A-d	(i) Main maintenance of a heat exchanger is cleaning of tubes as the surface of the tubes is heat transfer surface cleaning of tubes & required from both inside & outside. (ii) Cleaning of tubes from inside is done by mechanical or chemical means. (iii) It can be done by brushing (a round brush is used) or by acid cleaning. (iv) For mechanical cleaning, heat exchanger should be opened. (v) Replacement of gasket is essential to avoid leakage when opened for cleaning. (vi) In case of acid cleaning dil. HCL is circulated for predetermined time & then alkali is flushed for neutralization of residual acid. Finally heat exchanger is flushed with fresh water. (vii) There are chances of leakage occuring through tube sheet which may be rectified by welding. Corrosion of tubes may require replacement or filling by welding. A Tube which leaks at a certain point should be isolated from surface by plugging both ends of the tube.	1 mark each for any four points	4
4B-a	Consider the thick walled hollow cylinder as shown in fig.(a).The inside radius of cylinder is r_1 and the outside radius is r_2 and length of cylinder is L. Assume that thermal conductivity of the material of which cylinder is made be k. Let the temperature of the inside surface be T_1 and that of the outside surface	1	6

be T_2 . Assume that $T_1 < T_2$,therefore the heat flows from the inside of cylinder to outside . It is desired to calculate the rate of heat flow for this case.



(a)Heat flow through thick walled cylinder

1

Consider a very thin cylinder (cylindrical element) , concentric with the main cylinder , of radius r , where r is between r_1 and r_2 . The thickness of wall of this cylindrical element is dr.

$$Q = - k\, 2\prod L\, (dT / dr) \ldots.(i)$$

Equation (i) is similar to eqn (a) . Here area perpendicular to heat flow is $2\prod rL$ and dx of eqn (a) is equal to dr.

Rearranging the eqn (i) ,we get

$$dr / r = - k\, (2\prod L) / Q.dT \ldots..(ii)$$

Only variables in eqn (ii) are r and T (assuming k to be constant).

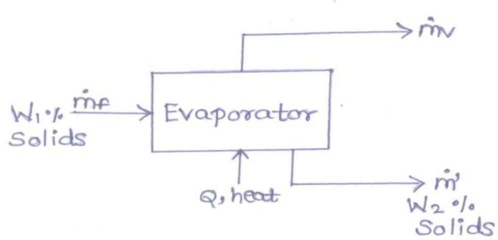
Integrate the eqn (ii) between the limits

When $r = r_1$, $T = T_1$

When $r = r_2$, $T = T_2$

$$\int_{r_2}^{r_1} dr / r = -k\, (2\prod L) / Q \int_{T_1}^{T_2} dT \ldots..(iii)$$

	$\ln\ r_2 - r_1 = -k\,(2\prod L)\,(T_1 - T_2)$…..(iv) $\ln(r_2 / r_1) = k\,(2\prod L)\,(T_1 - T_2) / Q$……(v) Rate of heat flow through thick walled cylinder : $\therefore Q = k\,(2\prod L)\,(T_1 - T_2) / \ln(r_2 / r_1)$….(vi) Equation (a) can be used to calculate the flow of heat through a thick walled cylinder. It can be put into more convinient form by expressing the rate of heat flow as : $Q = k\,(2\prod r_m L)\,(T_1 - T_2) / (r_2 - r_1)$……(vii) Where r_m is the logarithmic mean radius & is given by $r_m = (r_2 - r_1) / \ln(r_2 / r_1)$ $= (r_2 - r_1) / 2.303 \log(r_2 / r_1)$……(viii) $A_m = 2\prod r_m L$….(ix) A_m is called as logarithmic mean area. Equation (viii) becomes $Q = k\ A_m\,(T_1 - T_2) / (r_2 - r_1)$….(x) $Q = (T_1 - T_2) / [(r_2 - r_1)/k\ A_m] = \Delta T / R$ Where $R = (r_2 - r_1)/k\ A_m$	1 1 1	
4B-b	Consider that the evaporator is fed with m_f kg/h of weak solution containing w_1 % solute & thick liquor is withdrawn at m' kg/h containing w_2 % solids by weight. Let m_v be the kg/h of water evaporated. Then :		6



1

Overall material balance :

$$m_f = m_v + m \ldots (i)$$

Material balance of solute :

Solute in feed = Solute in thick liquor

1

$$W_1 \times m_f/100 = w_2\, m' / 100$$

$$W_1 \times m_f = w_2\, m' \ldots (ii)$$

1

Knowing three out of five quantities ,we can find the values of other two with the help of above two equations.

Let Tf , T and Ts be the temperatures , of feed entering the evaporator , solutions in the evaporators and condensing steam respectively.

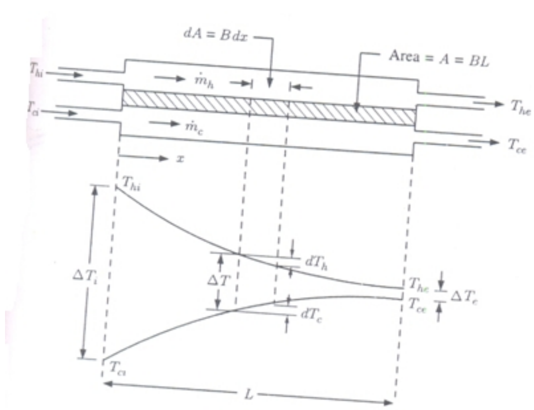
Let 'λs' be the latent heat of condensation of steam at saturation temperature and assume that only latent heat of condensation is used. Then, rate of heat transfer through heating surface from steam is :

$$Q_s = m_s \lambda_s \ldots (iii)$$

Where m_s is mass flowrate of steam to the evaporator in kg/h.

Heat transfer rate on steam side = Heat transfer rate on liquor side.

Enthalpy balance can be written in terms of specific heats & temperatures of solutions , in case of solutions having negligible heats of dilution. 1

	Heat transfer to solution in evaporator by condensing steam (in absece of heat losses) is utilised to heat the feed solution from Tf to T and for vaporisation of water from solution. $Qs = Q$ $= m_f\, Cpf\, (T - T_f) + (m_f - m')\, \lambda_v$.......(vii) $m_s \,.\, \lambda_s = mf\, Cpf\, (T - T_f) + (m_f - m')\, \lambda_v$.....(viii) where Cp_f = specific heat of feed solution λ_v = latent heat of evaporation from thick liquor For negligible boiling point rise $\lambda v = \lambda$ Where λ =latent heat of vaporisation of water at pressure in the Vapour space & can be read from steam tables. Above equation (viii) becomes : $m_s\, \lambda_s = m_f\, Cp_f\, (T - T_f) + (m_f - m')\, \lambda$......(ix) $m_s\, \lambda_s = m_f\, Cp_f\, (T - T_f) + m_v\, \lambda$.....(x)	1 1 1	
5-a	**To derive Q=UA ΔT_{lm}** 		8

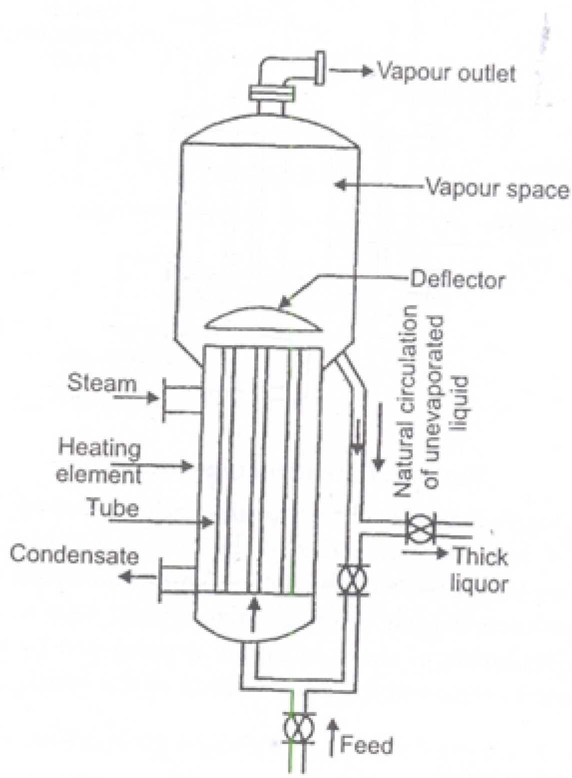
	Consider an elementary area dA(=B.dx). The rate of heat transfer across it is given by	2	
	$dq = U (Th-Tc) B\,dx$ -------------(1)		
	Since there are no losses to the surroundings, the heat transfer rate is also equal to the rate of change of enthalpy on either side. Therefore,	1	
	$dq = -mh\,Cph\,dTh$-------------------(2)		
	$= mc\,Cpc\,dTc$ ----------------------(3)		
	Now $\Delta T = Th - Tc$ -----------------(4)		
	On differentiating	1	
	$d(\Delta T) = dTh - dTc$ -----------------------------------(5)		
	substituting for dq, dTh and dTc from equations (1), (2) and (3) into equation (5) , we obtain	1	
	$d(\Delta T)/\Delta T = -\left(1/(mh\,Cph) + 1/(mc\,Cpc)\right) U\,B\,dx$		
	$\int_{\Delta Ti}^{\Delta Te} d(\Delta T)/\Delta T = -\left(1/(mh\,Cph) + 1/(mc\,Cpc)\right) U\,B \int_0^L dx$	1	
	$\ln(\Delta Te/\Delta Ti) = -\left(1/(mh\,Cph) + 1/(mc\,Cpc)\right) U\,A$ ------------------------------(6)		
	where $\Delta Te = T_{he} - T_{ce}$		
	$\Delta Ti = T_{hi} - T_{ci}$	1	
	Now if q is the total rate of heat transfer in the heat exchanger, then		
	$q = m_h Cp_h (T_{hi} - T_{he})$ -----------------------------(7)		

	$= m_c C_{pc} (T_{ce} - T_{ci})$ --------------------------(8) Substituting equations (7) and (8) into equation (6), $\ln (\Delta T_e / \Delta T_i) = -1/q[(T_{hi} - T_{he}) + (T_{ce} - T_{ci})]U A$ $q = U A (\Delta T_i - \Delta T_e) / \ln (\Delta T_i / \Delta T_e)$ -----------------------------(9) Equation (9) is the performance equation for a parallel-flow heat exchanger. $Q = U A \Delta T_{lm}$ Where $\Delta T_{lm} = (\Delta T_i - \Delta T_e) / \ln (\Delta T_i / \Delta T_e)$	1 1 1	
5-b	Basis :5000kg/hr of feed to evaporator. Let m', m_v be the flow rate of product and water vapour. Material balance of solute: 0.01 x 5000=0.02 x m' m'= 2500 kg/hr overall material balance: Feed=water evaporated + thick liquor Water evaporated= 5000-2500= 2500kg/hr. Assuming no heat loss, the heat balance is: $m_f H_f + m_s \lambda_s = m' H' + m_v H_v$ (1) mf= 5000kg/h m'=2500kg/h mv=2500kg/h Hf, H', Hv are enthalpies of feed,thick liquor and water vapour respectively.	1 1 1	8

	Hf=125.79 kJ/kg		
	H'= 419.04kJ/kg		
	Hv=2676.1kJ/kg		
	λs= latent heat of condensation of steam	1	
	= enthalpy of saturated steam- enthalpy of saturated water		
	=2691.5-461.30 = 2230.2kJ/kg.		
	Thus putting the values in eqn. (1) we get		
	5000X 125.79 + ms (2230.2) = 2500x419.04 + 2500x2676.1	1	
	ms= 3187.56 kg/h		
	steam consumption = steam flow rate = 3187.56 kg/h	1	
	steam economy = 2500/3187.56 = 0.784		
	rate of heat transfer = msλs= 3187.56 x2230.2 = 71088963kJ/h	1	
	= 71088963 x 1000/3600 = 1974693.4J/s (i.e. W)		
	ΔT= Ts-T=383-373=10k		
		1	
	Q=UA ΔT		
	U= Q/A ΔT = 1974693.4/69 X10 = 2862W/m^2 .k		
	Overall heat transfer coefficient = 2862W/m^2 .k		

5-c	Mass flow rate of isobutene= 27t/h = 7.5 kg/s λ for isobutene= 286 kJ/kg **Heat load** = Q $=m_1 \lambda$ = 7.5x 286 = 2145 kJ/s = 2145 kW =**2145 X 10^3 W** $Q= m_2 Cp_2 (t_2-t_1)$ 2145 = m_2 x 4.187x(315-300) m_2 = 34.15 kg/s Mass flow rate of cooling water= 34.15 kg/s	1 2 1 2 2	8
6-a	The change from liquid to vapour state is known as vapourisation and that from vapour to liquid is known as condensation. In either case, the latent heats involved are identical. In the condensation of a pure vapour, it is necessary to remove the latent heat of vapourisation. Condensation is a convection process that involves a change of phase from vapour to liquid and it occurs whenever a saturated vapour comes into contact of a cold surface, for example In surface condenser, heat transfer from the vapour to the surface takes place and the vapour gets condensed on the surface. The process of condensation which is the reverse of boiling,occurs by two distinct mechanism and that too at very different rates of heat transfer, The two distinct mechanism are 1) Dropwise condensation 2) Filmwise condensation **Dropwise condensation**: When a saturated vapour comes into contact with a cold surface, it condenses and if condensate does not wet the surface, the droplets are formed on the surface.. The droplets grow and ultimately fall from or fall down under the influence of gravity leaving behind the bare	2 2	8

	metal surface on which further condensation takes place.The condensation occurring by this mechanism is known as dropwise condensation. **Filmwise condensation**: When a saturated vapour comes into contact with the cold surface, it condenses and if condensate wets the surface it formes a continuous film of condensate through which heat mass be transferred. The additional vapour is then required to condense into the liquid film rather than directly on the surface. The condensate ultimately flows down the surface under the influence of gravity. In Filmwise condensation, the film covering the acts as a resistance to heat transfer while in dropwise condensation a large portion of a surface is directly exposed to the vapour. Because of this the rate of heat transfer and heat transfer coefficient in dropwise condensation is larger than filmwise condensation.	2 2	
6-b	$N_{Re} = Du\rho/\mu$ D = 20 mm=0.02 m, u=3 m/s $\mu = 485\times10^{-6}$ Pa.s or $(N.s)/m^2 = 485\times 10^{-6}$ Kg/(m.s) $\rho = 984.1$ Kg/m^3 at arithmetic mean bulk temperature $N_{Re =}$ 0.02 x 3x 984.1/ 485x 10^{-6} =121744 Npr = Cp μ/k = k= 0.657 W/(m.K) Cp= 4187J/kg.k Npr = 4187 x 485x 10^{-6}/ 0.657 = 3.09 The Dittus –Boelter equation for cooling is $N_{Nu} = 0.023 (N_{Re})^{0.8} (Npr)^{0.3}$ $hD/k = 0.023 (N_{Re})^{0.8} (Npr)^{0.3}$ $h = 0.023 (N_{Re})^{0.8} (Npr)^{0.3} \times k/D$	1 2 1 1 1 1	8

	$h = 0.023\ (121744)^{0.8}\ (3.09)^{0.3} \times 0.657/0.02$ $h = 12398.6\ W/m^2\ K$	1	
6-c	**Long tube vertical evaporator**  	2	8
	Construction: A long tube evaporator consist of a long tubular heating element incorporating tubes 25mm to 50mm in diameter and 4to 8 m in length. The tubular heating element projects into a vapour space for removing entrained liquid from the vapour. The upper tubesheet of tubular exchanger is free and a vapour deflector is incorporated in the vapour space just above it. A return pipe connecting the vapour space to the bottom of the exchanger is provided for natural circulation of a unvapourised liquid. It is provided with inlet connection for feed, steam and outlet connections for vapour, thick	3	

	liquor ,condensate etc. **Working:** In this evaporator feed enters the bottom of the tubes,gates heated by the condensing steam, starts to boil part way up the tubes and the mixture of vap. and liquid comes out from the top of the tubes and finally impinges at high velocity on a deflector. The deflector acts both as a primary separator and foam breaker. The separated liquid enters the bottom of the exchanger and parts of this liquid is taken out as a product. This type of evaporator is widely used for handling of foamy, frothy liquids. It is typically used for the production of condensed milk and concentrating black liquor in the pulp and paper industry.	3	