SUMMER-19 EXAMINATION

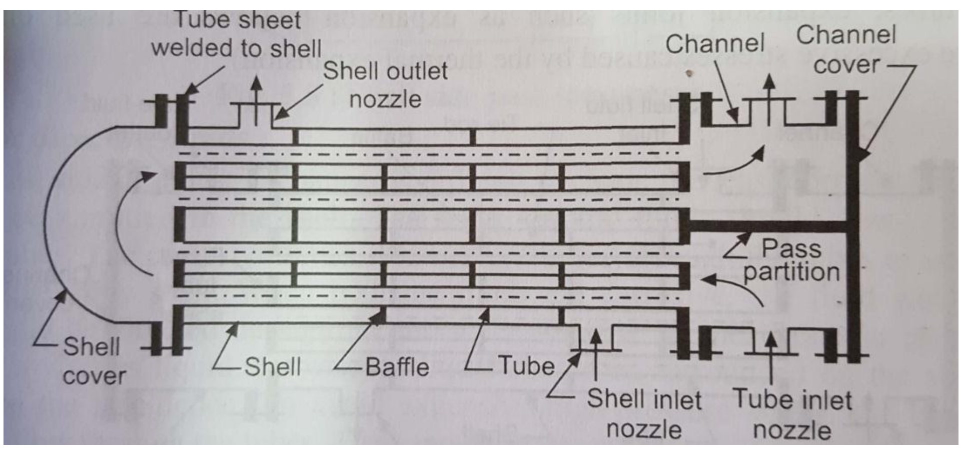
Model Answer

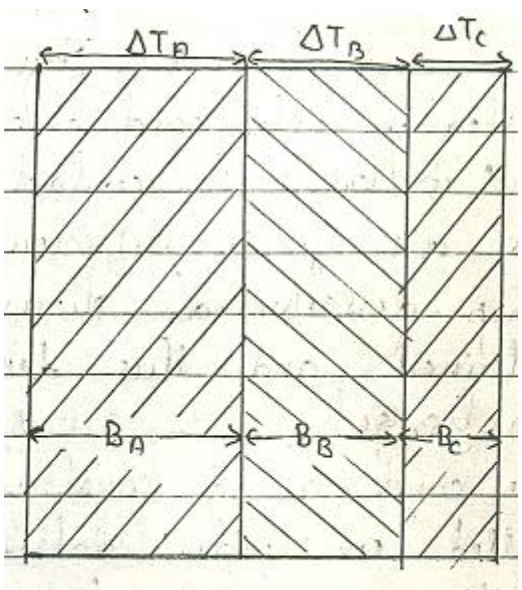
Subject: Heat Transfer Operation   Subject code: 17560

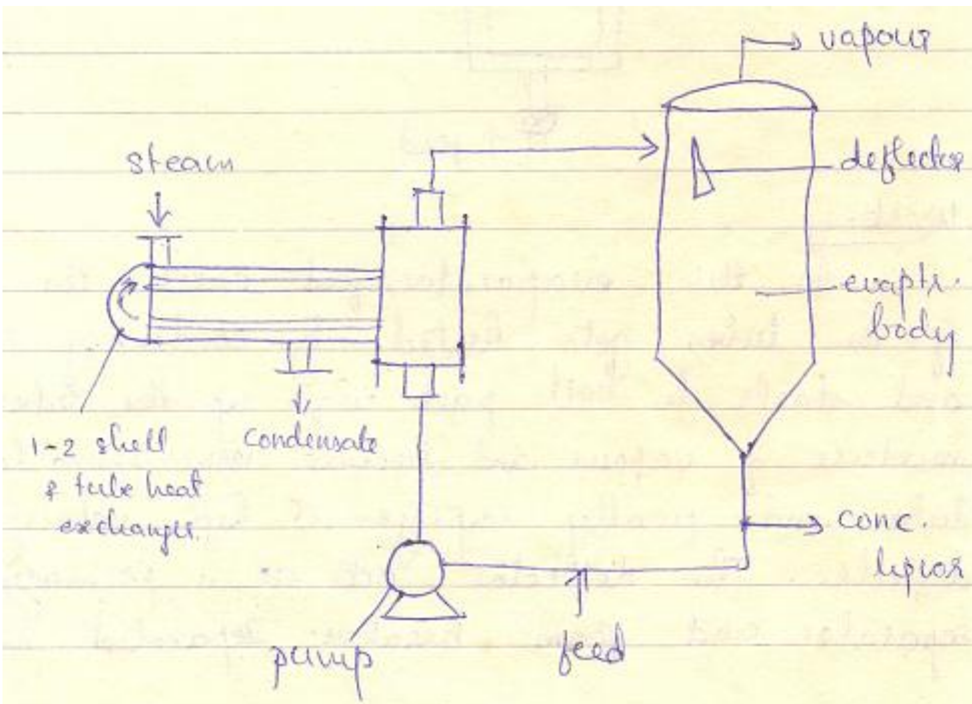
Important Instructions to examiners:

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	**Answer any three**	**12**
1a	(i)	**Thermal insulators:** These are substances having low value of thermal conductivities. **Use:** to minimize the rate of heat flow. **Example:** Asbestos, glass wool, cork	1 1 1 mark each for any 2
1a	(ii)	**Fouling factor:** When heat transfer equipment is put into service, after sometime, scale, dirt and other solids deposit on both sides of pipe wall, providing two more resistance to heat transfer. The added resistance must be taken into account in calculation of overall heat transfer coefficient. The additional resistance reduces the original value of overall heat transfer coefficient and required amount of heat is no longer transferred by original heat transfer surface. Hence heat transfer equipment are designed by taking into account the deposition of dirt and scale by introducing a resistance known as fouling factor. **Effect:** It offers additional resistance to heat transfer; reduces the heat transfer coefficient and thus the required amount of heat is no longer transferred by the original heat transfer surface. Hence heat transfer equipment are designed by taking into account the deposition of dirt and scale by introducing a resistance R_d.	2 2
1a	(iii)	**Radiation**: Radiation is transfer of energy through space by electromagnetic waves. If radiation is passing through empty space, it is not	2

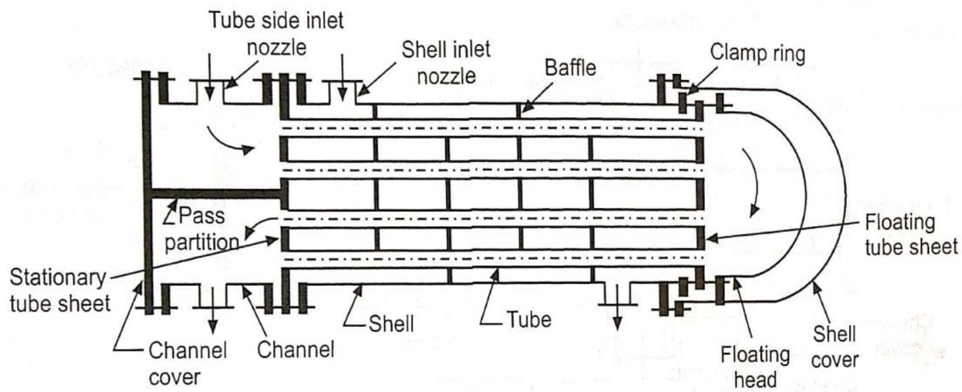
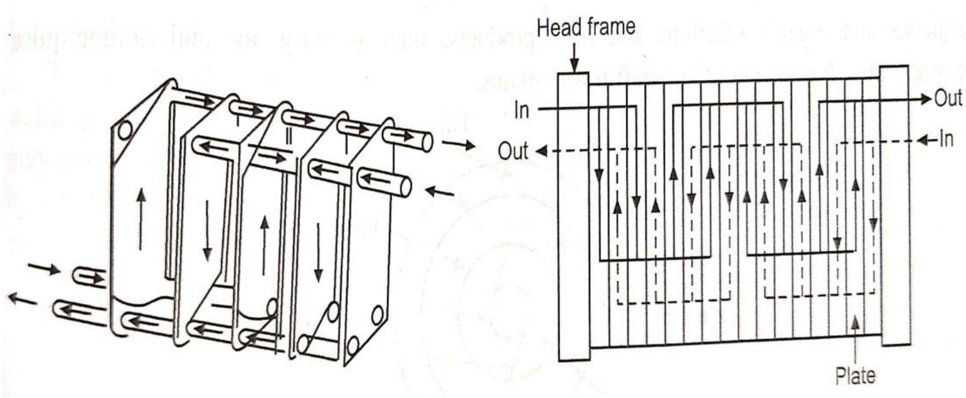
		transformed into other forms of energy, nor is it diverted from its path. If matter appears in its path, the radiation will be transmitted, absorbed or reflected. It is only the absorbed energy that appears as heat. **Example**: Loss of heat from unlagged pipe. **Stefan- Boltzman law:** It states that the total energy emitted (emissive power) per unit area per unit time by a black body is proportional to fourth power of its absolute temperature. $W_b \alpha T^4$ Or $W_b = \sigma T^4$ 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
1a	(iv)	**1-2 shell and tube heat exchanger:**  	4
1	**b**	**Answer any one**	6
1b	(i)	**Heat loss through a composite wall:** From Fourier's law, at steady state,	

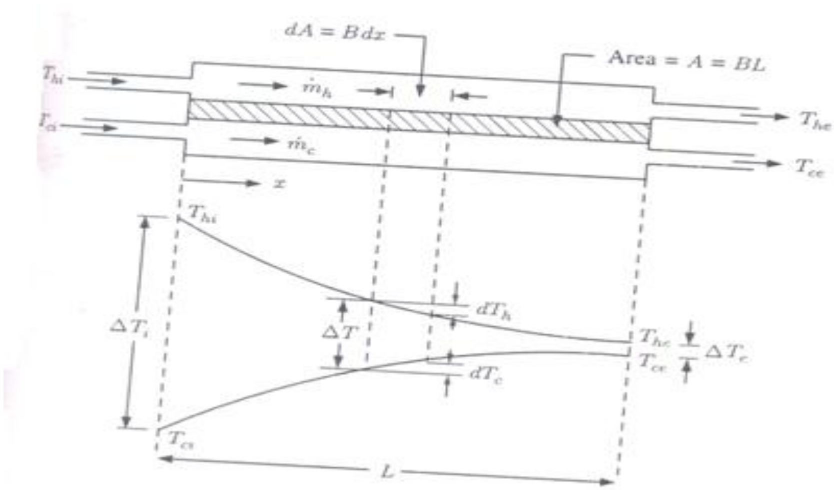
		$Q = kA\,\Delta T / B$	
		Q- rate of heat transfer	1
		A- Area perpendicular to heat flow	
		k- Thermal conductivity	
		ΔT - Temperature drop	
		B – thickness of layer	
		Heat loss through a composite wall:	
			1 1
		Consider a flat wall constructed of a series of layers of thickness x1, x2, x3 respectively. Let the thermal conductivities of layers be K_1, K_2, K_3 . Let $\Delta T1$, $\Delta T2$, $\Delta T3$ be the temperature drop across the layers. Let ΔT be the total temperature drop across the entire wall.	1
		$\Delta T= \Delta T_A+ \Delta T_B+ \Delta T_C$	
		$\Delta T_A= q_1*x_1/ K_1*A$ $\Delta T_B= q_2*x_2/ K_2*A$ $\Delta T_C= q_3*x_3/ K_3*A$	
		Where A is the area of the wall at right angle to the plane	1
		Then $\Delta T= q_1*x_1/ K_1*A + q_2*x_2/ K_2*A + q_3*x_3/ K_3*A$	
		In steady state conduction, all the heat passes through the first resistance	

		should pass through second and third. So $q_1 = q_2 = q_3$ $\Delta T = q[x_1/K_1*A + x_2/K_2*A + x_3/K_3*A]$ $= q[R_1+R_2+R_3]$ OR $q = \Delta T/[R_1+R_2+R_3]$ But $q = \Delta T/R$ Therefore : $R = R_1+R_2+R_3$ In heat flow through a series of layers the overall resistance is equal to the sum of individual resistances.	1
1b	(ii)	**Forced circulation evaporator:**  **Applications of forced circulation in Evaporator(any 1)** 1. For handling high viscous solutions 2. For handling solutions having Scale forming tendencies	5 1

2		**Answer any four**	**16**
2	a	**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. **Unit:** Unit of thermal conductivity in SI is W/mK or J/(s.m.K)	3 1
2	b	Let area A= 1 m^2 x_1= 4mm = 4*10^{-3} m k_1 = 0.138 w/mK A=1 m^2 x_2= 90mm = 90*10^{-3} m k_2 = 1.38 w/mK A=1 m^2 Thermal resistance o sil-o-cel brick R_1= x_1/k_1 A R_1 = 4*10^{-3} /0.138x1 **= 0.0289 k/w** Similarly Thermal resistance of common brick brick R_2 = x_2/k_2 A R_2 = 90*10^{-3} / 1.38x1 = **0.0652 k/w** R = R_1 + R_2 = **0.029** + **0.0652 =0.0942 k/w**	 1 1 1 1
2	c	**To show that at thermal equilibrium the ratio of total emissive power to its absorptivity is same for all bodies** 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.	 1

		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 different from that of he 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.	1
		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 :	1
		$I A_3 a_2 = E_2 A_3$ …………(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.	1

		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	d	**1-2 floated head shell and tube heat exchanger**  	4
2	e	**Plate and frame heat exchanger:**  **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	2 1

		stainless steel.. It is provided with inlet and outlet nozzles for fluids at ends. **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		**Answer any two**	16
3	a	**To derive Q=UA ΔT_{lm}**  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, dq= -mh Cph dTh-------------------(2) = mc Cpc dTc ----------------------(3) Now ΔT = Th- Tc -----------------(4)	1 1

		On differentiating	
		$d(\Delta T) = dTh - dTc$ -------------------------------------(5)	1
		substituting for dq, dTh and dTc from equations (1), (2) and (3) into equation (5) , we obtain	
		$d(\Delta T)/\Delta T = -(1/(mh\ Cph) + 1/(mc\ Cpc))\ U\ B\ dx$	1
		$\int_{\Delta Ti}^{\Delta Te} d(\Delta T)/\Delta T = -(1/(mh\ Cph) + 1/(mc\ Cpc))\ U\ B \int_0^L dx$	
		$\ln(\Delta Te/\Delta Ti) = -(1/(mh\ Cph) + 1/(mc\ Cpc))\ U\ A$ ---------------------------(6)	
		where $\Delta Te = T_{he} - T_{ce}$	1
		$\Delta Ti = T_{hi} - T_{ci}$	
		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)	1
		$= mc\ Cpc\ (T_{ce} - T_{ci})$ --------------------------(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)	1
		Equation (9) is the performance equation for a parallel-flow heat exchanger.	

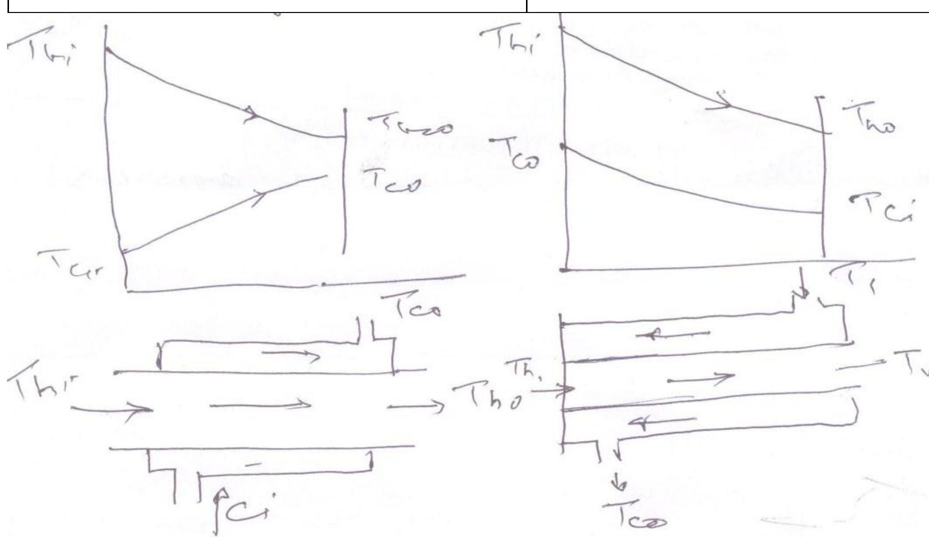
Q= U A ΔTlm — 1

Where ΔTlm= (ΔTi- ΔTe)/ ln (ΔTi/ ΔTe)

3 b **Differentiate Co current and Counter current Flow arrangement in Heat Transfer:** — 2 mark each

Co current and counter current flow:

Co current flow	**Counter current flow**
i) Both hot fluid & cold fluid enter at same end & come out from other end	i) Both hot fluid & cold fluid enter at different ends & come out from Different ends.
ii) Both fluid flow in the same direction.	ii) Both fluid flow in opposite direction.
iii) LMTD is low	iii)) LMTD is more.

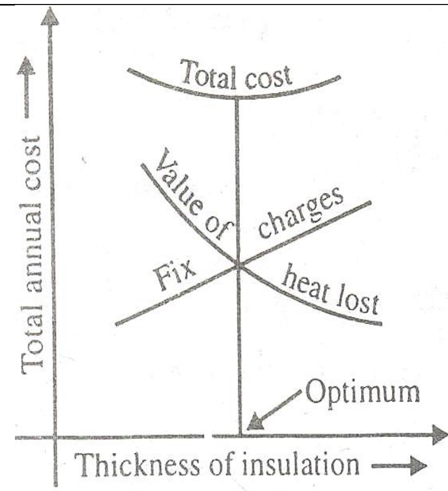


3 c **FIND U? hi=12, ho=11600 W/m^2 K**

ID=25mm, OD=29mm

K=34.9 W/mK

		$1/U = 1/h_o + 1/h_i + 1/k/x$ Where U= overall heat transfer coefficient h_o= 11600 W / m^2 K hi=12 W / m^2 K x=(29-25)/2 mm = 2mm=0.002m k=34.9 W/m^2 K 1/U=1/12 + 1/11600 + 0.002/34.9 U= **1/0.08347** = 11.979 W/m^2 K	2 2 2 2
4 a		**Answer any three**	**12**
4a	(i)	**Optimum thickness of insulation and its determination process:.** **Optimum thickness of insulation:** The optimum thickness of an insulation is obtained by purely economic approach. The greater the thickness, the lower the heat loss & the greater the initial cost of insulation & the greater the annual fixed charges. It is obtained by purely economic approach. Increasing the thickness of an insulation reduces the loss of heat & thus gives saving in operating costs but at the same time cost of insulation will increase with thickness. The optimum thickness of an insulation is the one at which the total annual cost (the sum values of heat lost and annual fixed charges) of the insulation is minimum.	2

		 **Optimum Thickness Of Insulation**	2
4a	(ii)	**State & prove Kirchoff's law of radiation:** **Kirchoff's law**: It states that at equilibrium temperature, the ratio of total emissive power of any body to absorptivity depends only upon the temperature of the body. Thus when any body is at equilibrium temperature with its surrounding, its emissivity and absorptivity are equal. 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 different from that of he non-black body. Let the area of non-black body be A_1 and A_2 respectively. Let 'I' be the	1 1

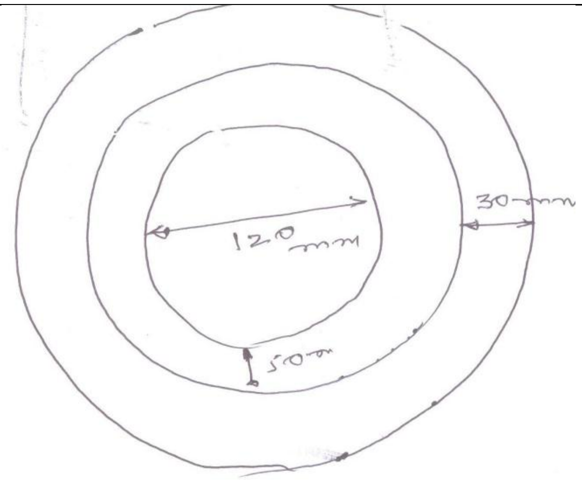
		rate at which radiation falling on bodies per unit area and E_1 and E_2 be the emissive powers (emissive power is the total quantity of radiant energy emitted by a body per unit area per unit time)of non-black & black body respectively. At thermal equilibrium, absorption and emission rates are equal, 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)	1 1
4a	(iii)	**Parts of shell and tube heat exchanger and their function: (any 4)** **i)** Shell – to transfer the hot liquid	1 mark each

		ii) Tube – to hold the liquid to be heated **iii)** Baffles – To increase turbulence on shell side **iv)** Tube Sheet – to hold the tubes **v)** Tie rods – to hold the baffles in place **vi)** Pass partition – divides the tubes equally into two sections **vii)** Channel – to provide inlet and outlet connections for the tube side fluid	
4a	(iv)	**Basis :** 10,000 kg/hr of solution. Amount of NaOH in Solution = 10,000 x 0.1 = 1000 kg	 1
		∴ Amount of H_2O = 9000 kg Find concentration of solution = 50 % Let 'x' is amount of find solution $\therefore 0.5 = \frac{1000}{x}$ $\therefore x = \frac{1000}{0.5}$ = 2000 kg	 1
		∴ H_2O evaporated =10,000 – 2000 = 9000-1000 = 8000	 1
		$\therefore \textbf{Capacity of Evaporation} = \mathbf{8000\,\frac{kg}{hr}}$	1
4 b		**Answer any one**	**6**

4b	(i)	**Compare forward feed and backward feed arrangement: (any4)**	1.5 mark each

Forward feed	Backward feed
Flow of solution to be concentrated is parallel to steam flow.	Flow of solution to be concentrated i in opposite direction to steam flow.
Does not need pump for moving the solution from effect to effect.	Need pump for moving the solutio from effect to effect.
As all heating of cold feed solution is done in first effect , less vapour is produced , so lower economy.	Solution is heated in each effect result in better economy.
The most concentrated liquor is in the last effect where temperature is lowest and viscosity is highest , leads to reduction in capacity.	The most concentrated liquor is in th first effect where temperature i highest and viscosity is lowest , Thu high overall coefficient.
Maintenance charges and power cost are low	Maintenance charges and power co are more.
Most common as it is simple to operate	Not very common as it need pump.
More economical in steam.	At low values of feed temperatur higher economy.

4b	(ii)	**120mm OD, 1^{st} layer 50mm, K_1=0.062W/mK, 2^{nd} layer 30mm,K_2=0.872 W/mK, OT=235 C, lag=38C, T of JOINT ?**	



2

$$Q = \frac{2\prod L(T1-T2)}{\frac{\ln (r2-r1)}{K}+\ln(\frac{r3/r2}{K2})}$$

$T_1 = 235^0$ C, $T_2 = 38^0$ C

$$r_1 = \frac{120}{2} = 60 \text{ mm} = 0.06 \text{ m}$$

1

$$r_2 = 60 + 50 = 110 \text{ mm}$$

$$r_3 = 110 + 30 = 140 \text{ mm} = 0.140 \text{ m}$$

$K_1 = 0.062$ w/m.k

$K_2 = 0.872$ w/m.k

Assume, L = 1m

$$Q = \frac{2\prod (235-38)}{\frac{\ln (\frac{0.11}{0.06})}{0.062}+\ln(\frac{(\frac{0.140}{0.11}}{0.872})}$$

1

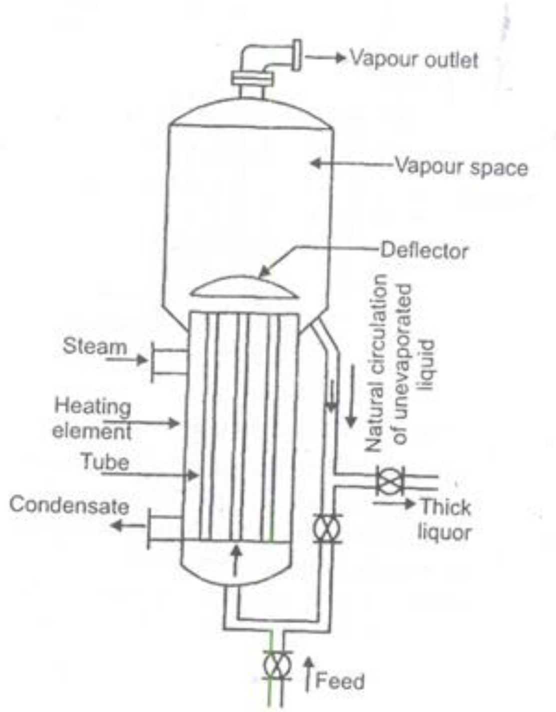
		= 123.162 W/m	
		Let T be the temperature between two layers of Insulation.	1
		$\therefore Q = (T_1 - T)/R_1$	
		$123.16 = (508 - T_0) / 1.56$	1
		T = 315.93 K	
5		**Answer any two**	**16**
5	a	Heat lost by hot fluid	
		$Q_h = m_h\ Cp_h\ (T_{hi} - T_{ho})$	2
		= 5000 * 2.72*(423-363) = 816000 kJ/h	
		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	b	**LMTD for co current flow,**	
		$\Delta T_1 = T_{hi} - T_{ci} = 423 - 311 = 112$ K	2
		$\Delta T_2 = T_{ho} - T_{co} = 367 - 339 = 28$ K	
		$\text{LMTD} = \frac{\Delta T1 - \Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} = \frac{112 - 28}{\ln(\frac{112}{28})} = 60.6\text{K}$	2
		LMTD for counter current flow,	
		$\Delta T_1 = T_{hi} - T_{co} = 423 - 339 = 84$ K	2
		$\Delta T_2 = T_{ho} - T_{ci} = 367 - 311 = 56$ K	

		$LMTD = \frac{\Delta T1 - \Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} = \frac{84-56}{\ln(\frac{84}{56})} = 69.06K$ LMTD for cocurrent flow = **60.6 K** LMTD for counter current flow = **69.06 K** **Since LMTD for counter current is more, the fluid must be directed in counter current fashion.**	1 1
5	c	Basis: 2000 kg/hr feed is fed to the evaporator. Material balance of solids: Solids in feed= solids in the thick liquor 0.05x2000=0.2 x m' m'=500kg/h. overall Material balance: kg/h feed= kg/h water evaporated + kg/h thick liquor water evaporated(m_v)=2000-500=1500kg/h Energy balance is $m_s \lambda_s = m*c_{pf} *(T-T_f) + m_v \lambda_v$ m_s 2185 = 2000*4 *(380-298) + 1500 *2257 steam fed(m_s)= 1849.66 kg/h steam economy= kg/h water evaporated/kg/h steam consumed = 1500/1849.66=**0.811** Heat load Q= $m_s \lambda_s$ Q = 1849.66 * 2185 kJ Q = **4041507.1*1000 / 3600** **= 1122641 W**	 1 1 1 1 2 1 1
6		**Answer any two**	**16**
6	a	**Dropwise and filmwise condensation:**	2 marks each for

Points	Dropwise condensation	Filmwise

				condensation	any 4 points
		mechanism	In case of drop-wise condensation the condensate (condensed liquid) does not wet the surface and collects to grow for a while and then fall from the surface, leaving bare metal surface for further condensation.	In case of film-wise condensation the condensed liquid wets the surface and forms a continuous film of condensate through which heat transfer takes place. This condensate flows down due to action of gravity	
		Heat transfer coefficient	Heat transfer coefficient are very high in case of drop-wise condensation since the heat does not have to flow through film by conduction	Heat transfer coefficients are relatively very low in case of film-wise condensation since the heat does have to flow through film by conduction	
		Surface type	Oily or greasy surfaces seem to tend towards drop-wise condensation	Smooth, clean surfaces seem to tend towards film-wise condensation	
		Stability	Drop-wise condensation is very difficult to achieve and unstable	Film-wise condensation is easily obtainable and stable	
		equations	If the students write equations for	If the students write	

		film coefficients on vertical and horizontal surfaces marks should be given | equations for film coefficients on vertical and horizontal surfaces marks should be given	
6	b	$N_{Re} = Du\rho/\mu$	1
		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	
		$N_{Re} = 0.02 \text{ x } 3\text{x } 984.1/ 485\text{x } 10^{-6} = 121744$	1
		Npr = Cp μ/k =	1
		k= 0.657 W/(m.K)	
		Cp= 4187J/kg.k	
		$Npr = 4187 \text{ x } 485\text{x } 10^{-6}/ 0.657 = 3.09$	1
		The Dittus –Boelter equation for cooling is	
		$N_{Nu} = 0.023 (N_{Re})^{0.8} (Npr)^{0.3}$	1
		$hD/k = 0.023 (N_{Re})^{0.8} (Npr)^{0.3}$	
		$h = 0.023 (N_{Re})^{0.8} (Npr)^{0.3} \text{ x } k/D$	1
		$h = 0.023 (121744)^{0.8} (3.09)^{0.3} X\ 0.657/0.02$	1
		h = 12398.6 W/m^2 K	1
6	c	**Long tube vertical evaporator:**	



2

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 tube sheet 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 un vapourised liquid. It is provided with inlet connection for feed, steam and outlet connections for vapour, thick liquor, condensate etc. 3

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