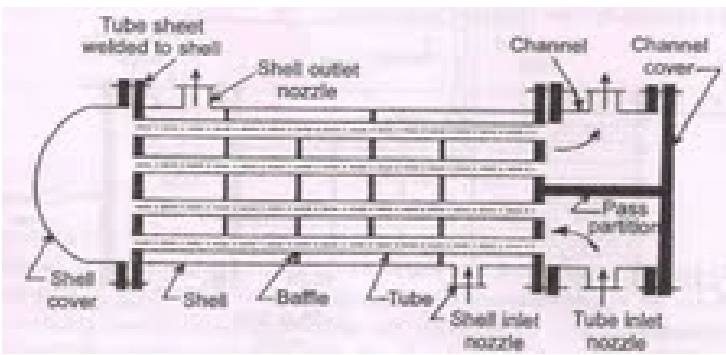
SUMMER-15 EXAMINATION

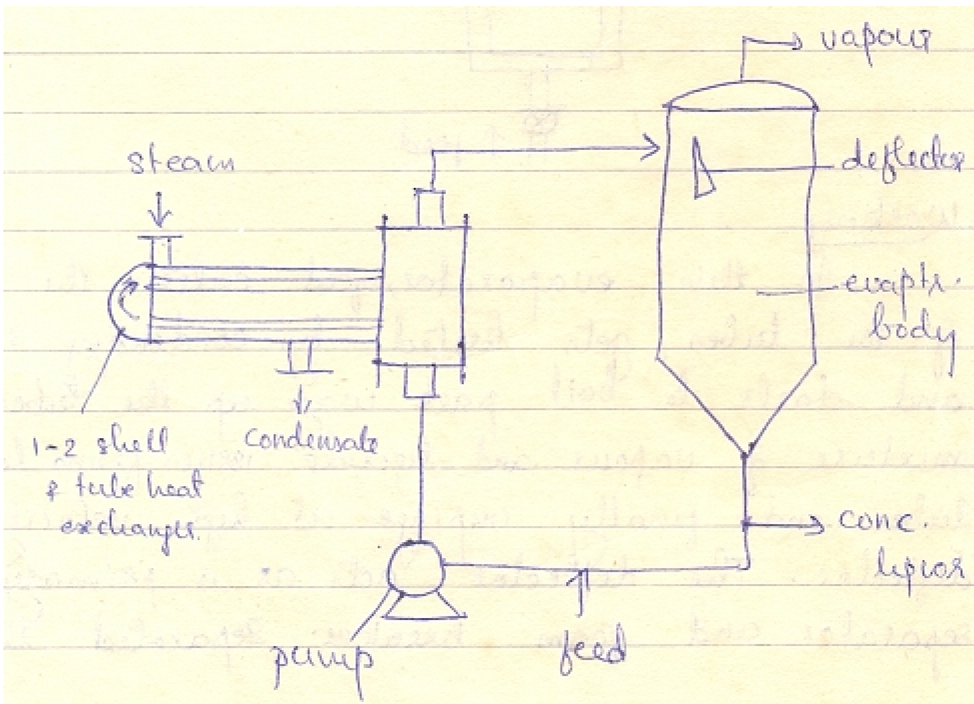
Model Answer

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	**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	4
1A-b	**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 equipments 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.	3 1	4
1A-c	**Radiation:** It is the transport of energy through space by electromagnetic waves. It depends upon the electromagnetic waves as a means for transfer of energy from a source to receiver. **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	2 2	4

	temperature. $W_b \alpha T^4$ Or $W_b = \sigma T^4$ where σ is Stefan Boltzman constant=$5.67*10^{-8}$ (W/m^2K^4)		
1A-d	**1-2 shell and tube heat exchanger:**  	4	4
1B-a	**Heat loss through a composite wall:** 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. ΔT= ΔT1+ ΔT2+ ΔT3 $\Delta T_1= q_1*B_1/ K_1*A$ $\Delta T_2= q_2*B_2/ K_2*A$ $\Delta T_3= q_3*B_3/ K_3*A$ Where A is the area of the wall at right angle to the plane Then $\Delta T= q_1*B_1/ K_1*A + q_2*B_2/ K_2*A + q_3*B_3/ K_3*A$ In steady state conduction, all the heat passes through the first resistance should pass through second and third. So $q_1= q_2= q_3$ $\Delta T= q[B_1/ K_1*A + B_2/ K_2*A + B_3/ K_3*A]$ $= q[R_1+R_2+R_3]$ OR $q= \Delta T/[R_1+R_2+R_3]$	2 2	6

	But q= ΔT/R Therefore : $R= R_1+R_2+R_3$ In heat flow through a series of layers the over all resistance is equal to the sum of individual resistances.	2	
1B-b	**Forced circulation evaporator:**  **Application:** used for crystalline products, viscous, salting, scaling and corrosive and foaming solutions.	5 1 mark for any 1	6
2-a	**Thermal conductivity:** It is a measure of the ability of the substance to 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) **Relation between temperature and thermal conductivity:**	2 1	4

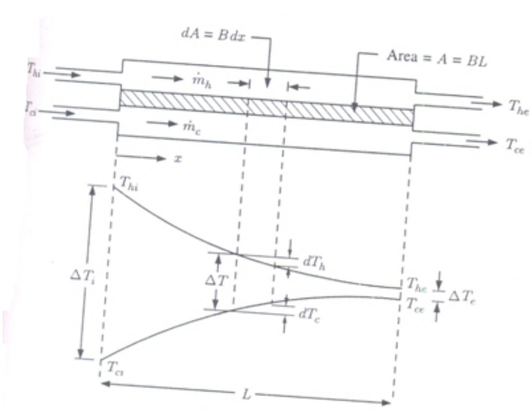
	For small temperature ranges, thermal conductivity is taken as constant but for large temperature changes, it varies linearly with temperature and is given by $K= a+bT+cT^2+..$ where a,b and c are constants and T is temperature in K	1	
2-b	Basis: 1 meter length of pipe Inner radius r_1= 12.5 mm= 0.0125 m Outer radius r_2= 12.5 mm+10 mm= 0.0225 m Ti = 273 + 140 = 413 K T_2 = 273 + 35 = 308 K K= 0.04 W/mK r_{LM}=(r_2-r_1) /ln(r_2/r_1) = 0.0225-0.125/ ln(0.0225/0.0125) = 0.017 Heat loss Q = 2Π r_{LM} Lk(T_1-T_2)/ (r_2-r_1) = 2 Π*0.017 *1*0.04(413-308)/ (0.0225-0.0125) = **44.84 W**	1 1 1 1	4
2-c	**Black body:** It is the substance which absorbs all the radiation falling on it. For a black body, absorptivity α= 1 and transmissivity = reflectivity= 0. **Examples:** lampblack, cosmic background radiation,	2 2	4
2-d	**Application of finned tube heat exchanger:** When the heat transfer coefficient of one of the process fluids is very low as compared to the other, the overall heat transfer coefficient becomes approximately equal to the lower coefficient. This reduces the capacity per unit area of the heat transfer surface and thus make it necessary to provide very large heat transfer area. The heat transfer area of a pipe or or tube is increased by attaching metal pieces called fins. **Used in:** Automobile radiator, air cooled steam condensers for turbine and engine works, economiser	2 1 mark each for any2	4

2-e	**Use of baffle:** 1. To increase the rate of heat transfer by increasing the velocity and turbulence of the shell side fluid. 2. Structural support for the tubes and dampers against vibration.	1 mark each	4

Square pitch	Triangular pitch
Permits external cleaning of the tubes	Difficult to clean
Causes low pressure drop on the shell side fluid	Causes more pressure drop
Less no. of tubes can be accommodated than with triangular pitch	Larger no. of tubes can be accommodated in a given shell diameter
Creates comparatively less turbulence	Creates large turbulence in the shell side fluid
Can be used for dirty fluids also	Used for clean fluid

1 mark each for any2

3-a	**To derive Q=UA ΔT_{lm}**		8



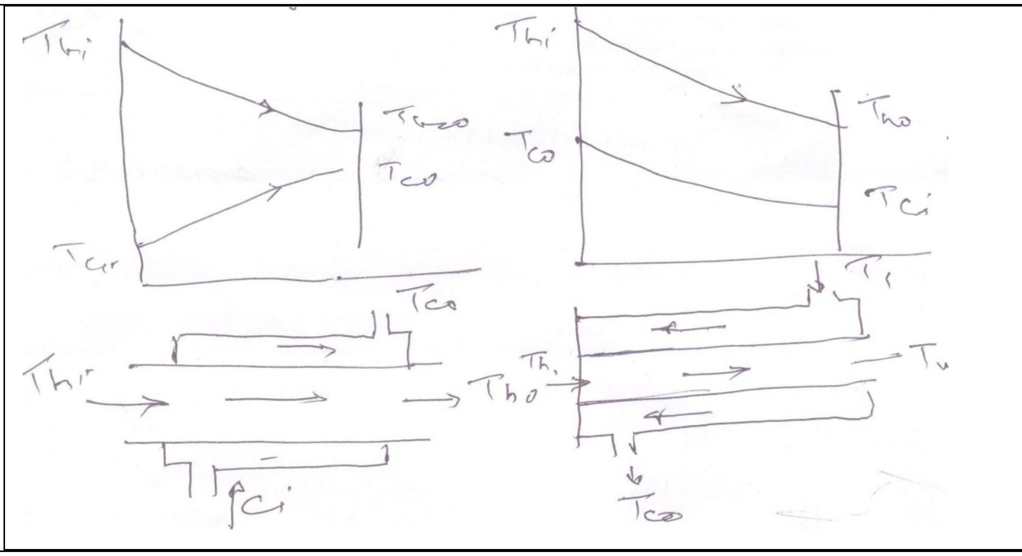
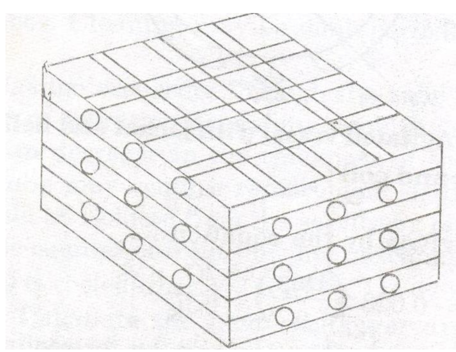
1

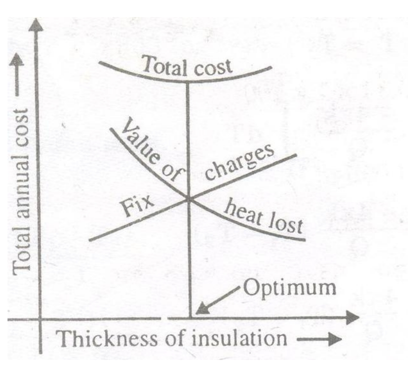
Consider an elementary area dA(=B.dx). The rate of heat transfer across it is

	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) On differentiating d(ΔT) =dTh- dTc -------------------------------------(5) substituting for dq, dTh and dTc from equations (1), (2) and (3) into equation (5) , we obtain d(ΔT)/ ΔT= - (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 (ΔTe/ ΔTi) = - (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 $q = m_h Cp_h (T_{hi} - T_{he})$ -----------------------------(7) $= mc\ Cpc\ (T_{ce} - T_{ci})$ --------------------------(8)	1 1 1 1 1	

	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 ΔTlm** Where $\Delta Tlm= (\Delta Ti-\ \Delta Te)/\ \ln(\Delta Ti/\ \Delta Te)$	1 1	
3-b	**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.	2 marks each for any 4	8

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	**Graphite block heat exchanger:** Graphite heat exchangers are well suited for handling corrosive fluids. Graphite is inert towards most corrosive fluids and has very high thermal conductivity. Graphite being soft, these exchangers are made in cubic or cylindrical blocks. In cubic exchangers, parallel holes are drilled in a solid cube such that parallel holes of a particular row are at right angles to the holes of the row above & below. Headers bolted to the opposite sides of the vertical faces of the cube provide the flow of process fluid through the block. The headers located on the remaining vertical faces direct the service fluid through the exchanger in a cross flow. 	4	8

	Advantages of it over Shell & Tube Heat Exchanger : i)Rate of Heat transfer is very High. ii) It can be used for handling corrosive liquids **Applications of graphite block h.e.** i) It is used for very explosive liquid. ii) ii) It can be used for Corrosive Fluid.	2 2	
4A-a	**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.  **Optimum Thickness Of Insulation**	2 2	4

4A-b **Kirchhoff's Law :** 4

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. 1

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,

$$I a_1 A_1 = A_1 E_1 \qquad \text{.....................(1.1)}$$

$$\therefore \; I a_1 = E_1 \qquad \text{................(1.2)}$$

And

$$I a_b A_2 = A_2 E_b \qquad \text{.................(1.3)}$$

$$I a_b = E_b \qquad \text{.............(1.4)}$$

From equation (1.1) and (1.4).we get 1

$$\frac{E1}{a1} = \frac{Eb}{ab} \qquad \text{.............(1.5)}$$

Where $a_{1,}a_b$ = absorptivity of non-black & black bodies respectively.

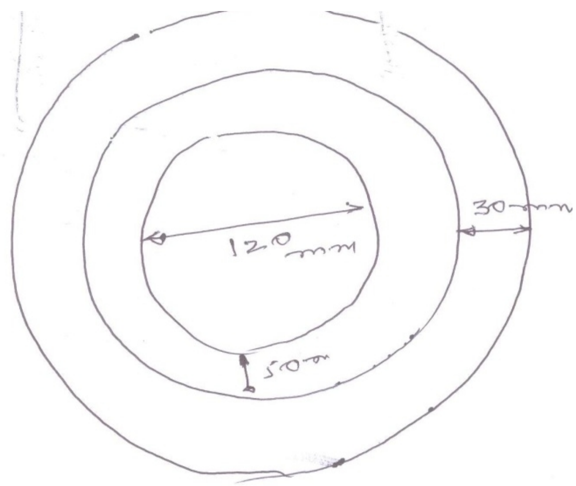
If we introduce a second body (non-black) then for the second non-black body,we have :

$$I\, A_3\, a_2 = E_2\, A_3 \qquad \text{.............(1.6)}$$

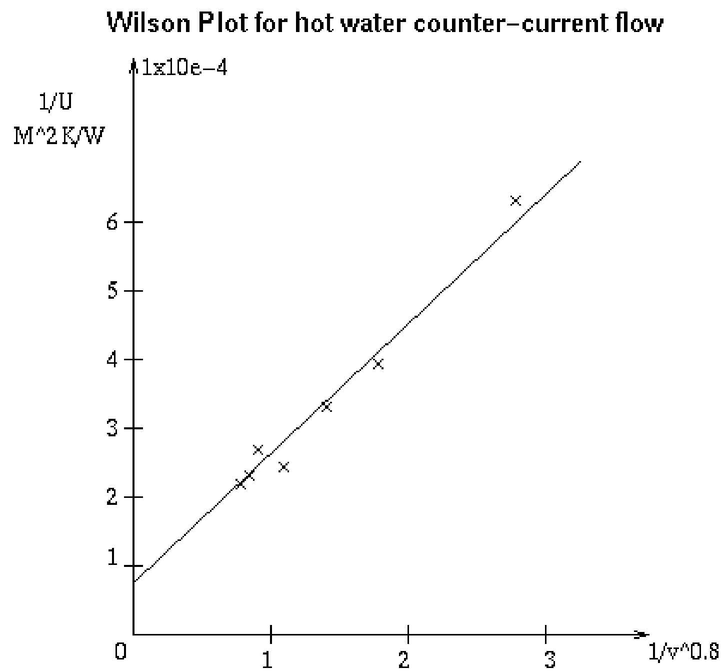
	∴ $Ia_2 = E_2$ ………….(1.7) Where $a_1 = E_2$ are the absorptivity and emissive power of the second non-black body. Combining equations (1.2),(1.4) and(1.7) we get, $\frac{E1}{a1} = \frac{E2}{a2} = \frac{E3}{a3} = E_b$ ………..(1.8)	1	
4A-c	**Parts of Shell & Tube heat Exchanger :** **i**)Shell – to transfer the hot liquid ii) Tube – to hold the liquid to be heated iii) Baffles – To increase turbulence on shell side iv) Tube Sheet – to hold the tubes	1 mark each	4
4A-d	**Basis :** 10,000 kg/hr of solution. Amount of NaOH in Solution = 10,000 x 0.1 = 1000 kg ∴ 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 ∴ H_2Oevaporated =10,000 – 2000	1 1 1	4

	= 9000-1000 = 8000 $$\therefore \text{Capacityof Evaporation} = 8000\frac{kg}{hr}$$	1	
4B-a	(see table below)	1.5 marks each for any 4	6

Forward feed	**Backward feed**
Flow of solution to be concentrated is parallel to steam flow.	Flow of solution to be concentrated is in opposite direction to steam flow.
Does not need pump for moving the solution from effect to effect.	Need pump for moving the solution 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 the first effect where temperature is highest and viscosity is lowest , Thus high overall coefficient.
Maintenance charges and power cost are low	Maintenance charges and power cost 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

	temperature higher economy.		
4B-b	 $Q = \frac{2\prod L(T1-T2)}{\frac{\ln(r2-r1)}{K}+\ln(\frac{r3/r2}{K2})}$ $T_1 = 2351^0$ c, $T_2 = 38^0$ c $r_1 = \frac{120}{2}$ = 60 mm = 0.06 m r_2 = 60 + 50 = 110 mm r_3 = 110 + 30 = 140 mm = 0.140 m K_1 = 0.062 w/m.k K_2 = 0.872 w/m.k	1 1	6

	Assume, L = 1m $$Q = \frac{2\prod(235-38)}{\frac{\ln\left(\frac{0.11}{0.06}\right)}{0.062}+\ln\left(\frac{\left(\frac{0.140}{0.11}\right)}{0.872}\right)}$$ **= 123.162 W/m** Let T be the temperature between two layers of Insulation. $\therefore Q = (T_1 - T)/R_1$ $123.16 = (508-T_0) / 1.56$ **T = 315.93 K**	1 1 1 1	
5-a	**Wilson Plot:** The Wilson plot method was developed by Wilson in 1915 to evaluate the convection coefficients in shell and tube condensers for the case of a vapour condensing outside by means of a cool liquid flow inside. It is based on the separation of the overall thermal resistance into the inside convective thermal resistance and the remaining thermal resistances participating in the heat transfer process.	2	8



2

Data points:

1/V^0.8	1/U (x10e-4)
0.84	2.15
0.86	2.22
0.99	2.78
1.38	3.37
1.14	2.44
1.77	3.94
2.85	6.37

1/U=1/h1+c 2

Where c is a constant.

For turbulent flow we can write Nnu α $NRe^{0.8}$

hi α $v^{0.8}$

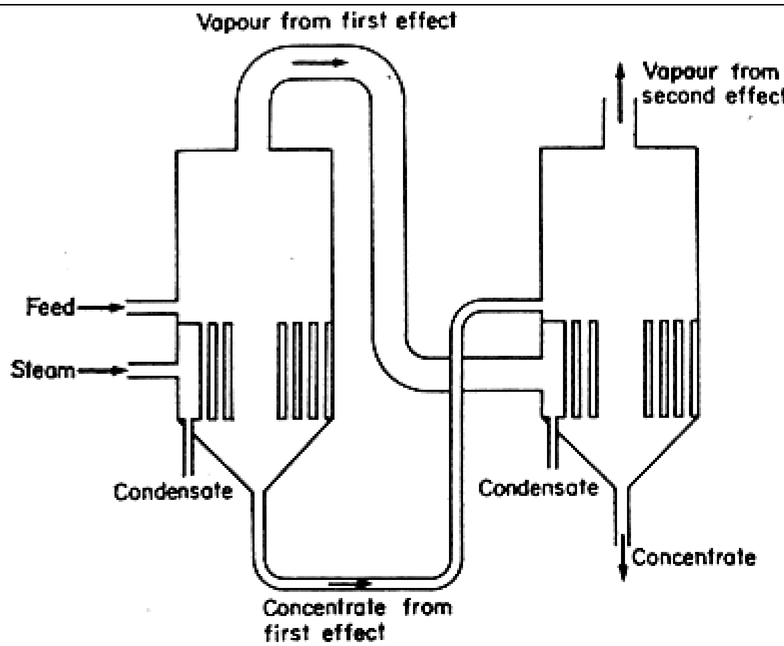
hi= a . $v^{0.8}$

therefore 1/U=1/ a . $v^{0.8}$ +C

where u is the linear velocity of the cold fluid. A plot of 1/U vs 1/ $v^{0.8}$ results in

	a straight line with the slope equal to 1/a and intercept equal to Xw/K +1/h0. The values of h0 is obtained from the intercept and a represents the value of film coefficient hi for a unit velocity of cold fluid.	2	
5-b	mass flow rate= 1kg/s density of water(ρ)=980kg/m^3 volumetric flow rate(Q)= 1/980 m^3/s= 1.02x10^{-3} m^3/s velocity(u)= Q/A =1.02x10^{-3}x4/3.14(0.025x0.025)=0.519 x4m/s= 2.078m/s NRe= Duρ/μ= 15894.38x4= 63577.52 Flow is turbulent. Thus We have to use Dittus Bolter equation. Npr= 5.32(Cp μ/K) NNu= 0.023$(NRe)^{0.8x}$$(Npr)^{0.3}$ hid/k= 264.32 **i) hi=6661.08 w/m^2k** overall heat transfer coefficient(U)= I/U= 1/h0+1/hi =2.167x10^{-4} **ii) U= 4612.7 W/m^2k** **T1(393k)----→T2(393k)** **t2(358k)←------t1(298k)** ΔT1= T1-t2=(393-358)=35K ΔT2=t1-T2 = (393-298)=95k ΔTlm= (95-35)/ln(95/35)=60**k** iii) Q=UA ΔTlm	 1 1 2 2	8

	Q=m.cp. ΔT=251220 W 251220= **4612.7 x 3.14x0.025xLx60** **L=11.56m**	2	
5-c	Two methods for increasing the economy of evaporation 1) Use of Multiple effect evaporators 2) Vapour recompression Multiple effect evaporators: An evaporator is essentially a heat exchanger in which a liquid is boiled to give a vapour, so that it is also, simultaneously, a low pressure steam generator. It may be possible to make use of this, to treat an evaporator as a low pressure boiler, and to make use of the steam thus produced for further heating in another following evaporator called another effect. Consider two evaporators connected so that the vapour line from one is connected to the steam chest of the other as shown in **Fig**, making up a two effect evaporator.	2 3	8

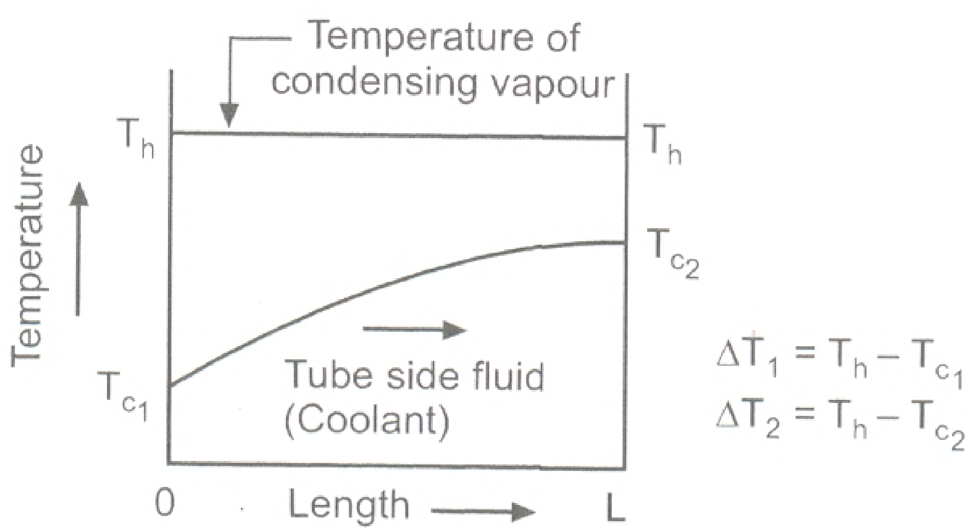
	 **Feeding of Multiple Effect Evaporators** In a two effect evaporator, the temperature in the steam chest is higher in the first than in the second effect. In order that the steam provided by the evaporation in the first effect will boil off liquid in the second effect, the boiling temperature in the second effect must be lower and so that effect must be under lower pressure. Consequently, the pressure in the second effect must be reduced below that in the first. In some cases, the first effect may be at a pressure above atmospheric; or the first effect may be at atmospheric pressure and the second and subsequent effects have therefore to be under increasingly lower pressures. Often many of the later effects are under vacuum. Under these conditions, the liquid feed progress is simplest if it passes from effect one to effect two, to	3	

<table>
<tr><td></td><td>effect three, and so on, as in these circumstances the feed will flow without pumping. This is called forward feed. It means that the most concentrated liquids will occur in the last effect. Alternatively, feed may pass in the reverse direction, starting in the last effect and proceeding to the first, but in this case the liquid has to be pumped from one effect to the next against the pressure drops. This is called backward feed and because the concentrated viscous liquids can be handled at the highest temperatures in the first effects it usually offers larger evaporation capacity than forward feed systems, but it may be disadvantageous from the viewpoint of product quality.

Description of vapour recompression should also carry same mark distribution.</td><td></td><td></td></tr>
<tr><td>6-a</td><td>Drop wise and film wise condensation
<table>
<tr><th>Drop-wise condensation</th><th>Film-wise condensation</th></tr>
<tr><td>1. 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.</td><td>1. 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</td></tr>
<tr><td>2. Heat transfer coefficient are very high in case of drop-wise condensation since the</td><td>2. Heat transfer coefficients are relatively very low in case of film-wise condensation since</td></tr>
</table></td><td>4</td><td>8</td></tr>
</table>

	heat does not have to flow through film by conduction	the heat does have to flow through film by conduction		
	3. Oily or greasy surfaces seem to tend towards drop-wise condensation	3. Smooth, clean surfaces seem to tend towards film-wise condensation		
	4. Drop-wise condensation is very difficult to achieve	4. Film-wise condensation is easily obtainable		

Temperature- length curve for a condenser



4

6-b	Mass flow rate of hot water =25kg/s. Cp=4.187 kJ/kg.k The rate of heat given Q1= m. Cp.(T1-T2)= 25x4.187x(328-298)=3140.2kJ/s=3140.2×10^3 W	1	8

	Heat is given by hot water available at 90^{0}C (363k) Rate of heat loss by hot water Q2= m.Cp.(t2-t1)=30x4.187x(363-t1) As per energy balance Q1=Q2 30x4.187x(363-t2)= 3140.2 (363-t2)= 20 t2=363-20=338k	2	
	i) For counter current flow (298k)T1----------→T2(328k) (338k) t2 ←-------t1 (363k) ΔT1= t2-T1=(343-298)=40K ΔT2=t1-T2 = (363-328)=35k ΔTlm= (40-35)/ln(40/35) =**37.44k**	1	
	ii) For Co current flow ΔT1= t1-T1=(363-298)=65K ΔT2=t2-T2 = (338-328)=10k ΔTlm= (65-10)/ln(65/10)= **29.38K** Thus counter current is suitable arrangement as in this case the ΔTlm is larger.	1	
	The rate of heat transfer is given by	2	

	Q= U A ΔTlm 3140.2x10^3= 1500xAx 37.44 **A= 55.91m^2**	1	
6-c	Basis: 30000 kg/hr feed is fed to the evaporator. Material balance of solids: Solids in feed= solids in the thick liquor 0.10x30000=0.05xm' m'=6000kg/h. overall Material balance: kg/h feed= kg/h water evaporated + kg/h thick liquor water evaporated= mv=30000-6000=24000kg/h enthalpy balance over evapoprator(assuming no heat loss) Q=ms λs= mf.Cpf.(T-Tf)+ mv λ msx2202=30000x4x(323-293)+24000x2383 ms=27599kg/h. steam consumption= 27599kg/h steam economy= kg/h water evaporated/kg/h steam consumed = 24000/27599.5 =**0.87** Heat load= Q= ms λs= 27599.5x2202=16881694 w ΔT=Ts-T= 393-323=70K A =Q/U ΔT= 16881694/3000x70= **83.16 m^2**	 1 1 2 2 1 1	8