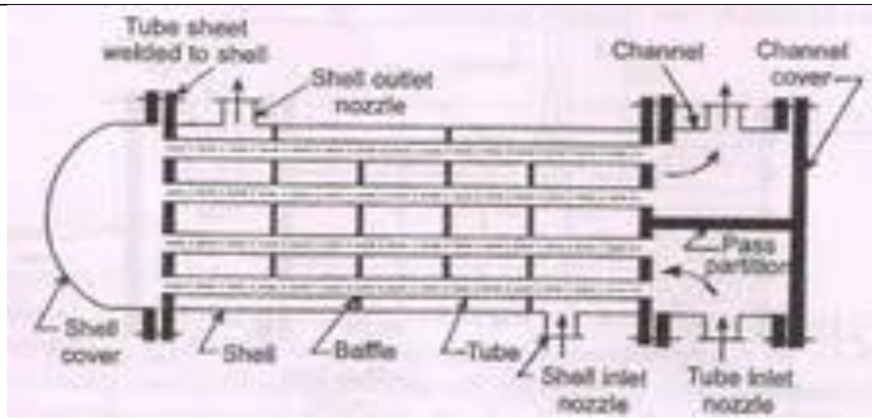
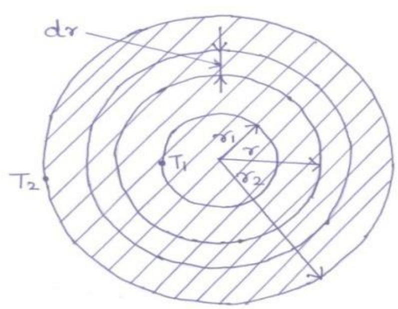
Important Instructions to examiners:

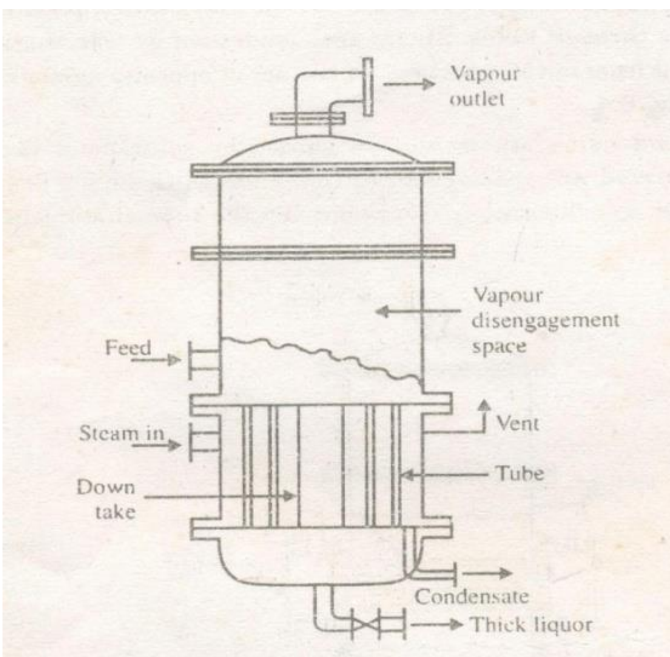
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling 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
1 A	Any three	12
1A-(i)	**Modes of heat transfer are:** **1. Conduction** **2. Convection** **3. Radiation**	1
	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	1
	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 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	1

	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.	1
	Example: Loss of heat from unlagged pipe.	
1A-(ii)	**Film heat transfer coefficient:** Film heat transfer coefficient h is defined as the quantity of heat transferred in unit time through unit area at a temperature difference of 1^0 between the surface and surrounding.	2
	Unit: W/m^2K	2
1A-(iii)	**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.	2
	$W_b \alpha T^4$	
	Or $W_b = \sigma T^4$	2
	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	
1A-(iv)	**1-2 shell and tube heat exchanger:**	4

		
1.B	**Any one**	6
1B-(i)	**Heat transfer through cylinder :** 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 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** 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	1 1

	of this cylindrical element is dr. $Q = - k\, 2\prod L\, (dT / dr)$….(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 $dr / r = - k\, (2\prod L) /Q.dT$…..(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 $r = r_2$, $T = T_2$ $\int_{r2}^{r1} dr /r = -k\, (2\prod L) / Q \int_{T1}^{T2} dT$…..(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)	1 1
	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)	1

	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
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	3

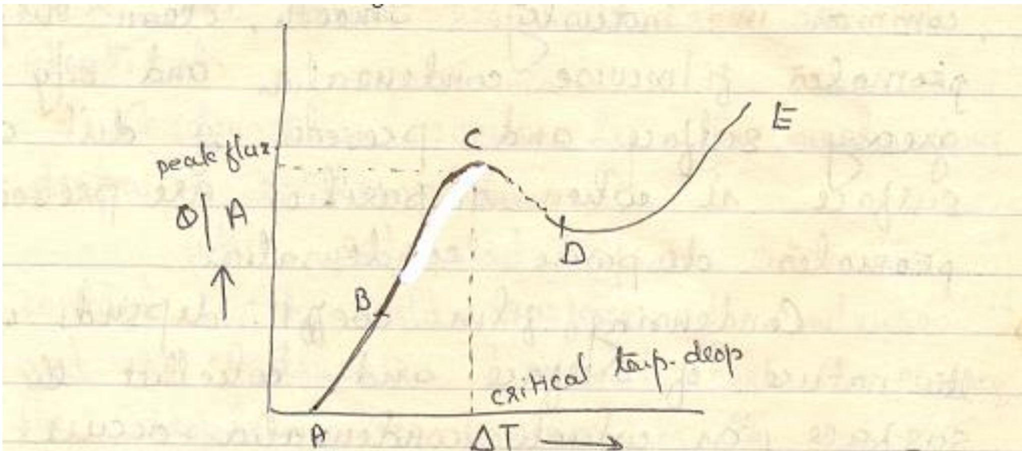
	tubes. Solution to be evaporated is inside the tubes and steam flows outside the tubes in the steam chest. Baffles are incorporated in steam chest to promote uniform distribution of steam. The condensate is withdrawn at a point near lower tube sheet, while non condensable gas is vented to atmosphere 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 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.	3
2	Any four	16
2-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	2 1 1
2-b	Area A= 1 m^2 Thickness B= 0.5 m K = 0.7 W/mK Temperature difference ΔT = 400-310 = 90 K Q= k A ΔT / B = 0.7*1*90 / 0.5	2 1

	= **126 W/m^2**	1
2-c	**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 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. 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 :	2 2

	$I A_3 a_2 = E_2 A_3$ ………….(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-d	**Viscous fluid :** Viscous fluid is passed through shell side **Reason**: because of the presence of baffles in the shell induce turbulence and hence increases heat transfer rate. **High pressure fluid:** High pressure fluid is passed through tube side **Reason**: To avoid expensive high pressure shells (in order to save the cost of expensive material for shell).	1 1 1 1
2-e	**Single pass and multi pass:**	1 mark each for any 4

Single pass	**Multi pass**
Simple in construction	Complex in construction
Flow may be parallel or counter current	Flow is parallel as well as counter 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 through exchanger

3	**Any two**	16
3-a	**Heat transfer in boiling liquids :**	



AB . natural convection $\frac{Q}{A} \propto \Delta T^{1.25}$
BC . nucleate boiling
CD . transition boiling 2
DE . film boiling
D . Leidenfrost point
ΔT . temp. diff. between tube wall & boiling liquid.

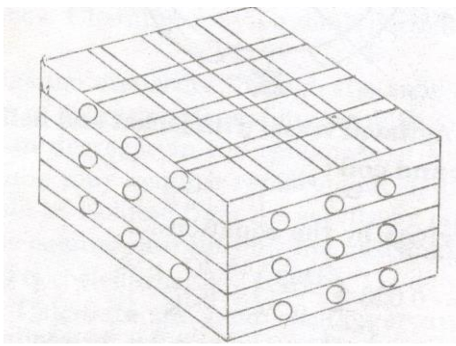
Consider a horizontal tube immersed in a vessel containing boiling liquid. Assume that Q/A, the heat flux and ΔT, the difference between the temperature of the tube wall and that of the boiling liquid , are measure . A plot of Q/A vs ΔT on log coordinates is drawn . This curve can be divided into four 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

1

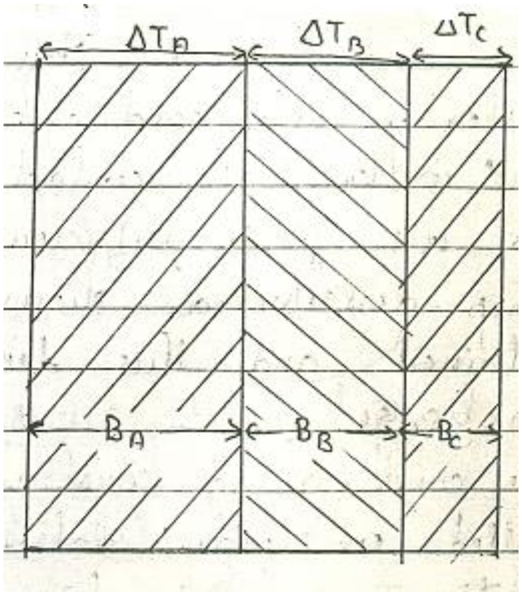
	The segments BC is also straight but slope is greater than AB. The rate of bubble production is large enough for the stream of bubbles moving up through the liquid to increase the velocity of the circulation currents and coefficient of heat transfer becomes greater than that in undisturbed natural convection. This is called **nucleate boiling**.	1
	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
3-b	303 K —Cold fluid→ 328 K ; (t_1) 303 K —Cold fluid→ 328 K (t_2) 383 K —Thermic fluid→ T_2 K ; T_2 ←Thermic fluid— 383 K (T_1) Co-current flow ; Counter current flow	1
	Mass flow rate of water (cold fluid) = Volumetric flow rate × density = 15 × 1000 m_c = 15000 kg/h Mass flow rate of thermic fluid = Volumetric flow rate × density = 21 × 950 m_t = 19950 kg/h	1

	The heat balance over the exchanger is Heat lost by the thermic fluid = Heat gained by the cold fluid $m_t C_{pt} (T_1-T_2) = m_c C_{pc} (t_2-t_1)$ $T_1 = 383$ K, $t_2 = 328$ K, $t_1 = 303$K $19950 \times 2.72 (383 - T_2) = 15000 \times 4.187 \times (328 - 303)$ $\therefore$ $T_2 = 354$ K (81^oC) **LMTD for co current flow,** $\Delta T_1 = T_1 - t_2 = 383 - 303 = 80$ K $\Delta T_2 = T_2 - t_1 = 354 - 328 = 26$ K $\text{LMTD} = \frac{\Delta T1 - \Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} = \frac{80 - 26}{\ln(\frac{80}{26})} = 48K$ **LMTD for counter current flow,** $\Delta T_1 = T_1 - t_2 = 383 - 328 = 55$ K $\Delta T_2 = T_2 - t_1 = 354 - 303 = 51$ K $\text{LMTD} = \frac{\Delta T1 - \Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} = \frac{55 - 51}{\ln(\frac{55}{51})} = 53K$ LMTD for cocurrent flow = **48 K** LMTD for counter current flow = **53 K**	1 1 1 1 1 1
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	2

	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. 	2
	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	2
	Applications of graphite block h.e. i) It is used for very explosive liquid. ii) It can be used for Corrosive Fluid.	2
4 A	Any three	12
4A-(i)	Let we consider 1 meter length of pipe. $Q = \frac{KA\Delta T}{L}$ $\Delta T = 400 - 250 = 150$ $K = 1.2 \frac{Kcal}{hr.m.K}$ $A = 1.8\ m^2$ $L = 40cm = 40/100 = 0.4\ m$	2

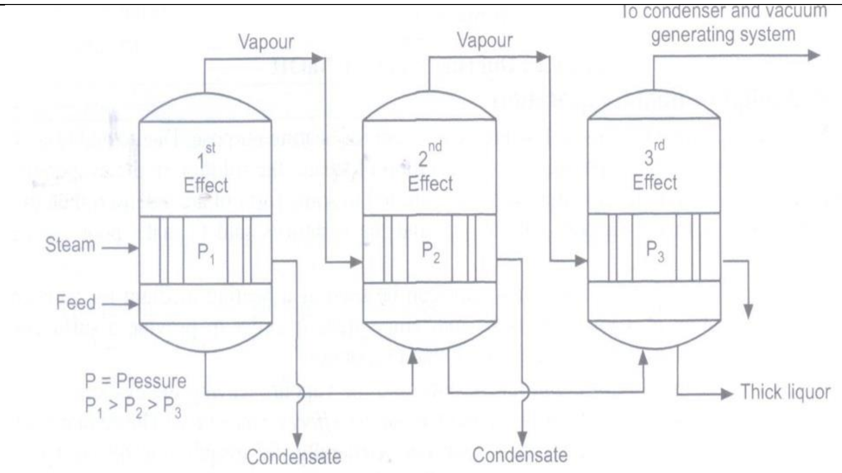
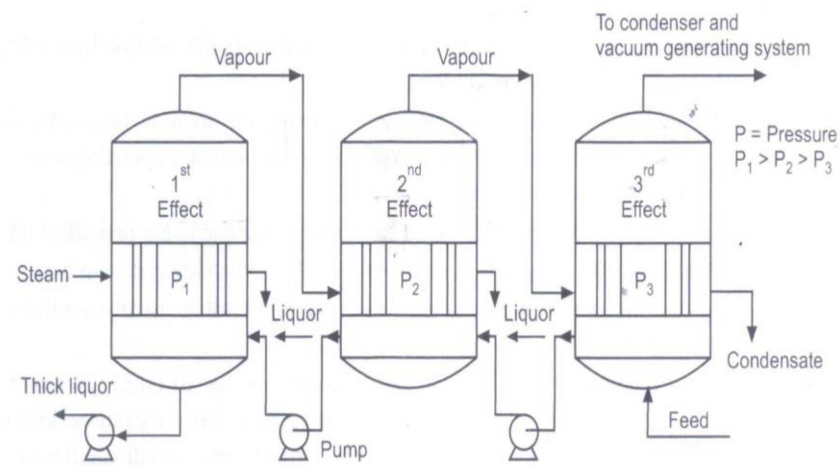
	$Q = \frac{1.2 \times 1.8 \times 150}{0.4}$	1
	$= 810 \ \frac{Kcal}{hr.}$	1
4A-(ii)	The **capacity** of an evaporator is defined as the number of kilogram of water evaporated per hour. The **economy** of an evaporator is defined as the number of kilogram of water evaporated per kilogram of steam fed to the evaporator. Most of the evaporators use low pressure steam for heating purpose .Due to addition of heat of solution in evaporator by condensation of steam, the solution in the evaporator will boil. If vapours leaving the evaporator are fed to some form of condenser then heat associated with vapour will be lost and system is said to make poor use of steam. The vapour coming out evaporator can be used as heating media for another evaporator which will be operating at lower pressure than the pressure in the evaporator from which vapours are issuing so as to provide sufficient temperature gradient for heat transfer in that evaporator. When single evaporator is put into service and vapours leaving the evaporator are condensed and discarded the method is known as single effect evaporation **Methods of increasing the economy of an evaporator:** 1. Using multiple effect evaporator 2. Vapour recompression **A. 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.	1 1 2

	B. Methods of increasing economy by vapour recompression methods are: **1.** Mechanical recompression **2.** Thermal recompression	
4A-(iii)	Rate of heat transfer by radiation Assume length of pipe = 1 m e= 0.9 σ = 5.67*10-8 w/(m^2.k^4) T_1 = 395 K T_2 = 293 K Do = 70mm = 0.07m Outside surface area per 1 meter length of pipe is A = π Do L = π×0.07×1 = 0.2198 m^2 The net radiation rate per 1 m length of pipe is Qr = eσA (T1^4- T2^4) = 0.9 × 5.67 × 10-8×0.2198 (395^4 – 293^4) **= 190.384 w/m**	 1 1 2
4A-(iv)	**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
4 B	**Any one**	6

4B-(i)	**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. $\Delta T= \Delta T_A+ \Delta T_B+ \Delta T_C$ $\Delta T_A= q_1*B_A/ K_1*A$ $\Delta T_B= q_2*B_B/ K_2*A$ $\Delta T_C= q_3*B_C/ K_3*A$ 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 $q_1= q_2= q_3$ $\Delta T= q[B_A/ K_1*A + B_B/ K_2*A + B_C/ K_3*A]$ $= q[R_1+R_2+R_3]$ OR $q= \Delta T/[R_1+R_2+R_3]$ But $q= \Delta T/R$	1 1 1 1 1

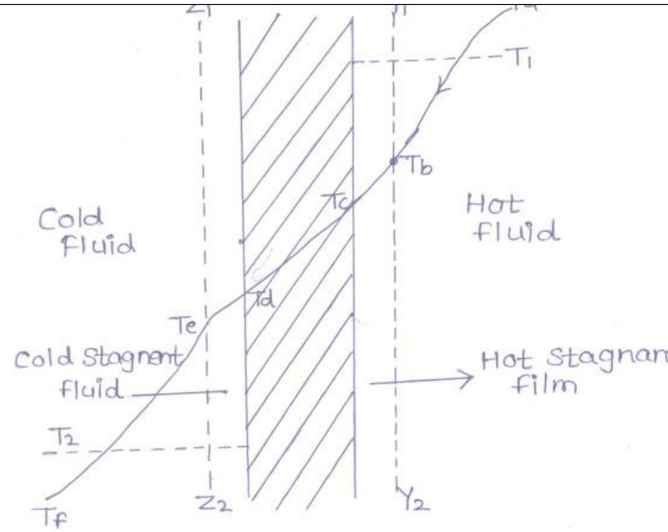
	Therefore : $R = R_1 + R_2 + R_3$ In heat flow through a series of layers the overall resistance is equal to the sum of individual resistances.	1
4B-(ii)	**Forward feed and backward feed arrangements (any 4)**	1.5 marks each

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.

	 **Forward feed arrangement**  **Backward feed arrangement**	
5	Any two	16
5-a	$1/U = 1/h_o + 1/h_i + 1/k/x$	1
	Where U= overall heat transfer coefficient	
	h_o= 1750 w/m^{2}k	1
	hi=5800 w/m^{2}k	1
	x=(15-10) mm = 5mm=0.005m	1

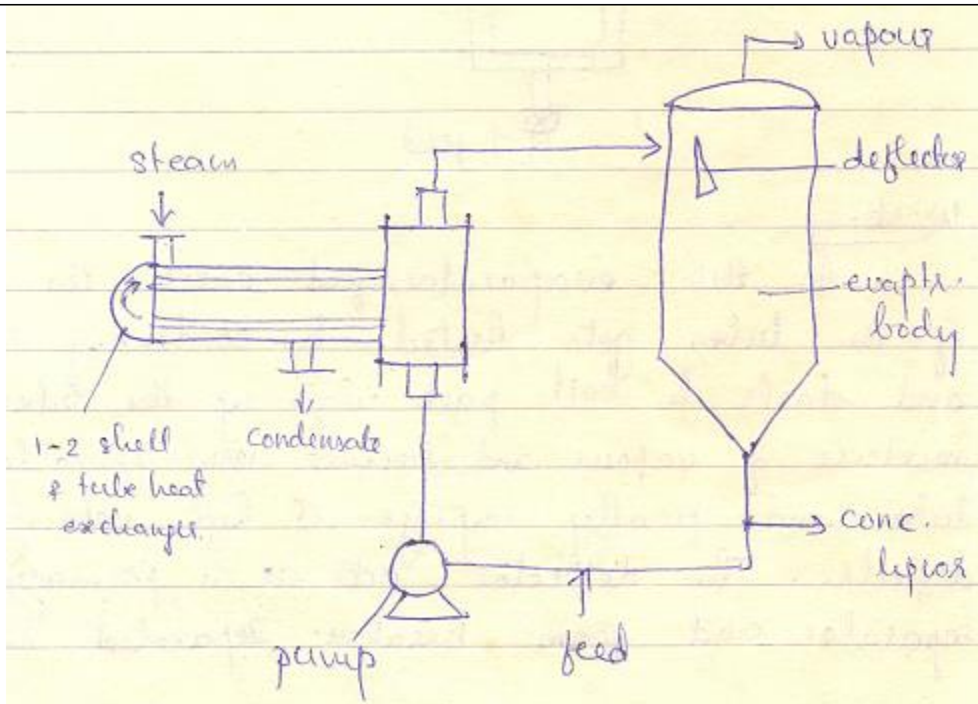
	k=46.52 w/ m^2k	
	1/U=1/1750 + 1/5800 + 1/46.52/0.005	2
	U= **1175 w/ m^2k**	2
5-b	Basis: 30000 kg/hr feed is fed to the evaporator.	
	Material balance of solids:	
	Solids in feed= solids in the thick liquor	
	0.05x30000=0.30 x m’	
	m’=5000kg/h.	2
	overall Material balance:	
	kg/h feed= kg/h water evaporated + kg/h thick liquor	
	water evaporated= mv=30000-5000=25000kg/h	1
	Enthalpy balance is	
	$m_s \lambda_s = m_f Cp_f (T-T_f) + m_v \lambda_v$	1
	m_s *2185 = 30000*4.1(380-298) + 25000 * 2257	1
	steam fed= 30439.8 kg/h	1
	steam economy= kg/h water evaporated/kg/h steam consumed	1
	= 30440/25000 = **0.82**	1
5-c	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*4.2*(Tco – 303)	
	$Q_h = Q_c$	1
	816000 = 15000*4.2*(Tco – 303)	1
	Outlet temperature of water = **316 K**	2
6	Any two	16

6-a	**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.	2

		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),	
	$hi = K1/x1$	1
	Resistance for heat tranfer is given as	
	$R = X/K_A = 1/K/x(A) = 1/hiAi$	
	∴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,	
	$Q_1 = Q_2 = Q_3 = Q = Constant$	1
	$\therefore Q = \Delta t/R_1+R_2+R_3$	
	$\therefore Q = T_1 - T_2/[(1/hiAi)+(Lm/R\ Am)+(1/hoAo)]$ …….(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,	1
	$A = 2\prod rl$	
	$=(T_1-T_2)Ai[(1/hi)+(Lm/Km.2\prod r_i\ L/2\prod r_m\ L)+(1/ho.2\prod r_i/2\prod r_o)]$	
	$=(T_1-T_2)Ai[(1/hi)+(Lm/Km.\ r_i/r_m)+(1/ho..\ r_i/r_o)]$	
	We assume a new parameter,	

	U_i = Overall heat transfer coefficient on inside liquid. ∴ 1/Ui =1/hi + Lm/.ri/rm +1/ho ri/ro ……(i)	1
6-b	**Dimensionless groups** 1. **Reynold s number** N_{Re} = Duρ/μ D- diameter of pipe u- velocity of flow ρ – density of fluid μ - viscosity of fluid 2. **Nusselt Number** N_{NU}= hd/k h – fim heat transfer coefficient d - diameter of pipe k – thermal conductivity of fluid 3. **Prandtl Number** N_{PR} -C_p μ/k C_p – specific heat of fluid μ - viscosity of fluid k – thermal conductivity 4. **Grashoff Number** N_{GR} =$D^3\rho^2(g\beta)\Delta T / \mu^2$ D- diameter of pipe ρ – density of fluid g- acceleration due to gravity β – coefficient of thermal expansion ΔT – temperature difference μ - viscosity of fluid	1 1 1 1 1 1 1 1
6-c	**Forced circulation evaporator:**	

		3
	Construction: It consists of circulating pump, separating space, evaporator body with vapour outlet at top, deflector plate, outlet for discharge of thick liquor and external heating surface- horizontal shell and tube heat exchanger.	2
	Working: Centrifugal pump forces the liquid through tubes at high velocity and is heated as it passes through tubes due to heat transfer from condensing steam on shell side. Boiling does not take place in tubes as they are under sufficient static head which raises the boiling point above that in separating space. Solution becomes superheated and flashes into a mixture of vapour and liquid just before entering the separator due to reduction in static head when it flows from exchanger to separator. The two phase mixture impinges on a deflector plate in separating space and vapours are removed from top and liquid is returned to centrifugal	3

	pump. Part of the solution leaving separating space is withdrawn as the concentrated liquor and make up feed is continuously introduced at pump inlet.	