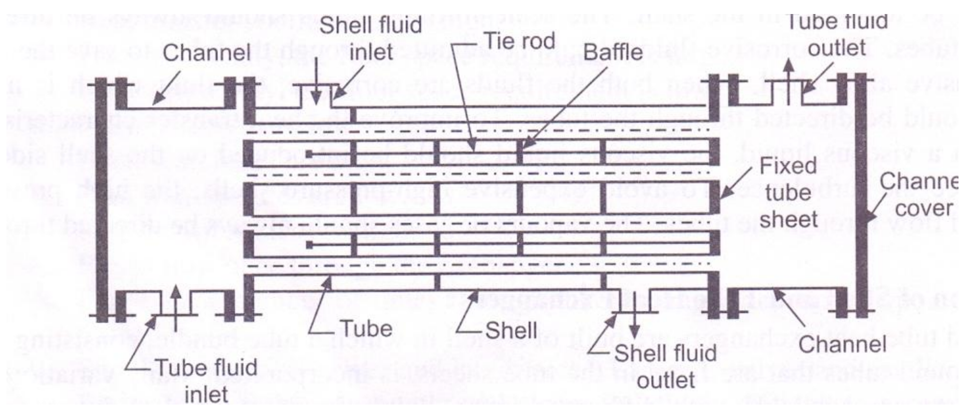
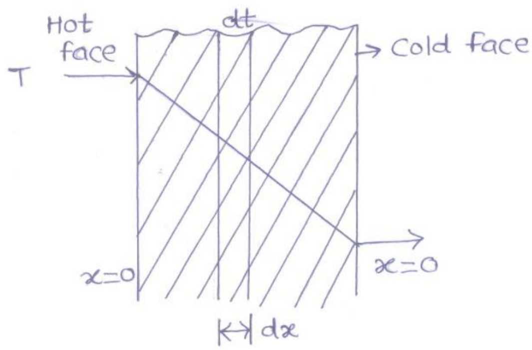
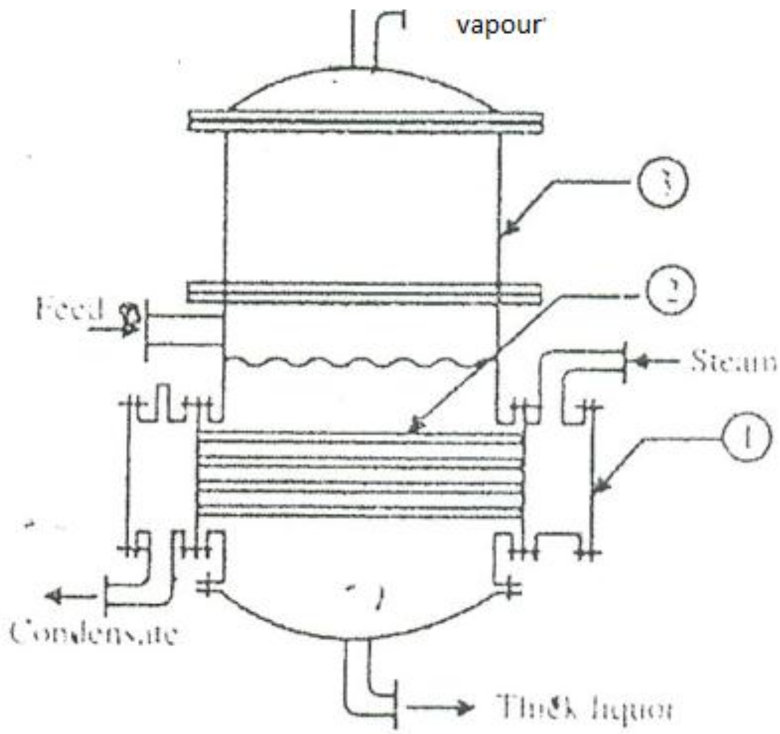
Important Instructions to examiners:

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.

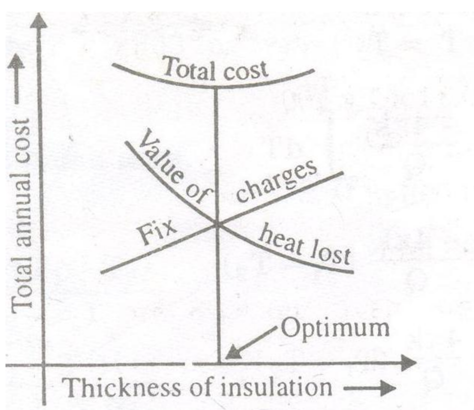
Q No.	Answer	marks
1 A	Any three	12
1A-(i)	**Fourier's law of conduction:** It states that the rate of heat flow across an isothermal surface is proportional to the temperature gradient at the surface. $\frac{dQ}{dA} = -k\frac{\partial T}{\partial n}$ Q- rate of heat transfer A- Area perpendicular to heat flow k- Thermal conductivity T- Temperature	2 2
1A-(ii)	1) **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 **Example:** heat flow to a fluid pumped through a heated pipe	1 1 1 1

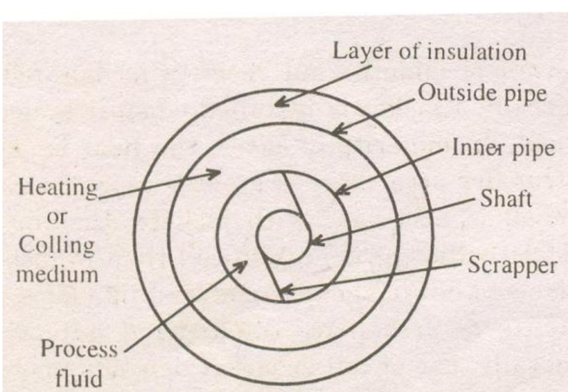
1A-(iii)	**Absorptivity (α) :** It is the fraction of radiation falling on a body which is absorbed. **Reflectivity(ρ)** : It is the fraction of radiation falling on a body which is reflected. **Transmissivity(τ):** It is the fraction of radiation falling on a body which is transmitted. **$\alpha + \rho + \tau = 1$**	1 1 1 1
1A-(iv)	**Fixed tube sheet heat exchanger:**  	4
1.B	**Any one**	6
1B-(i)	**Heat transfer through a slab of uniform thickness :** 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.	2 2

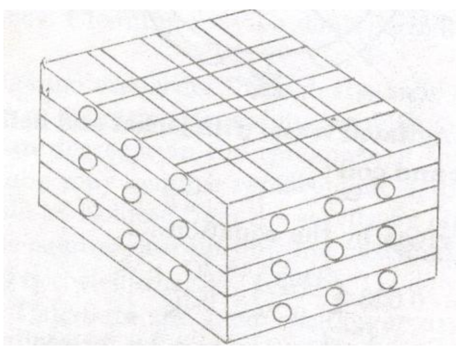
	 At Steady State, there can be neither accumulation nor depletion of heat within a plane wall &Q is constant along heat flow. The ordinary use of Fourier's Law requires that the differential eqn is integrated over entire path from x = 0,x = x. $\therefore Q = -K\,AdT/dx$ $Q\,dx = -\,K\,A\,dT$ OR $Q\ {}_0\int^x dx = -K\,A\ {}_{T1}\int^{T2}.dt$ $Q.x = -\,K\,A\,(T_2 - T_1)$ OR $Q = K\,A\,(T_2 - T_1)\,/\,x$	2
1B-(ii)	**Horizontal tube evaporator**: Construction: It consists of a vertical cylindrical shell incorporating a horizontal square tube bundle at the lowest portion of the shell. Channels are provided on either ends of the tube bundle for introduction of steam and withdrawal of condensate. A vapour outlet is provided on the top cover and a thick liquor outlet is provided at the bottom. Feed point is located at a convenient point. In this evaporator, steam is inside the tube and the liquor to be concentrated	2

	surrounds the tubes. Steam which is admitted through one of the steam chest and flows through the tubes. Working: Heat given out by condensing steam will be gained by the solution in the evaporator and the solution boils. Vapours formed are removed from top, while the thick liquor is removed from the bottom.  1 – Steam chest 2 – Tube 3 – Evaporator	2 2
2	Any four	16
2-a	**Modes of heat transfer are:** **1. Conduction** **2. Convection** **3. Radiation**	1

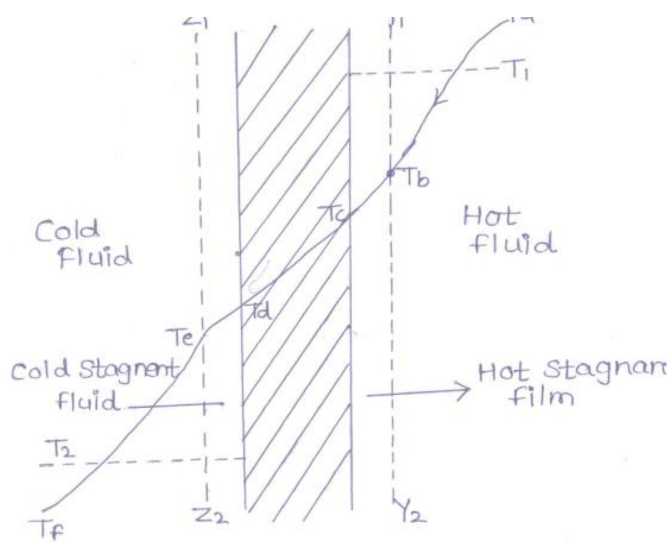
	2) **Conduction :** If a temperature gradient exist in a continuous substance, heat can flow unaccompanied by any observable motion of mater. Heat flow of this kind is called conduction. In metallic solids thermal conduction results from the motion of unbound electrons. In most liquid and solids which 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
	3) **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 **Example:** heat flow to a fluid pumped through a heated pipe	1
	4) **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.	1

	Fused quartz transmits all radiation falling on it, a polished opaque surface will reflect all the radiation and a black surface will absorb most of the radiation receiving. **Example**: Loss of heat from unlagged pipe.	
2-b	**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
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. It neither reflects nor transmits but absorbs all the radiation incidents on it. So it is treated as an ideal radiation receiver. It is not necessary that	4

	the surface of the body be black in colour. The black body radiates maximum possible amount of energy at a given temperature and though perfectly black bodies do not exist in nature, some materials approach it. E.g. lamp black is the nearest to a black body. It absorbs 96% of visible light.	
2-d	**Scrapped surface heat exchanger** is basically a double pipe heat exchanger with fairly large central tube, 100 to 300 mm in diameter, jacketed with steam or cooling liquid. The scrapping mechanism-rotating shaft provided with one or more longitudinal scrapping blades is incorporated in the inner pipe to scrape the inside surface. The process fluid (viscous liquid) flows at low velocity through inside pipe and cooling or heating medium flows through the annular space created between two concentric pipes. The rotating scrapper continuously **scraps** the surface thus preventing localized heating and facilitating rapid heat transfer. Liquid-solid suspensions, viscous aqueous and organic solutions and food products, such as margarine and orange juice concentrates are often heated or cooled in such type of exchanger. It is also widely used in paraffin wax plants. 	2 2

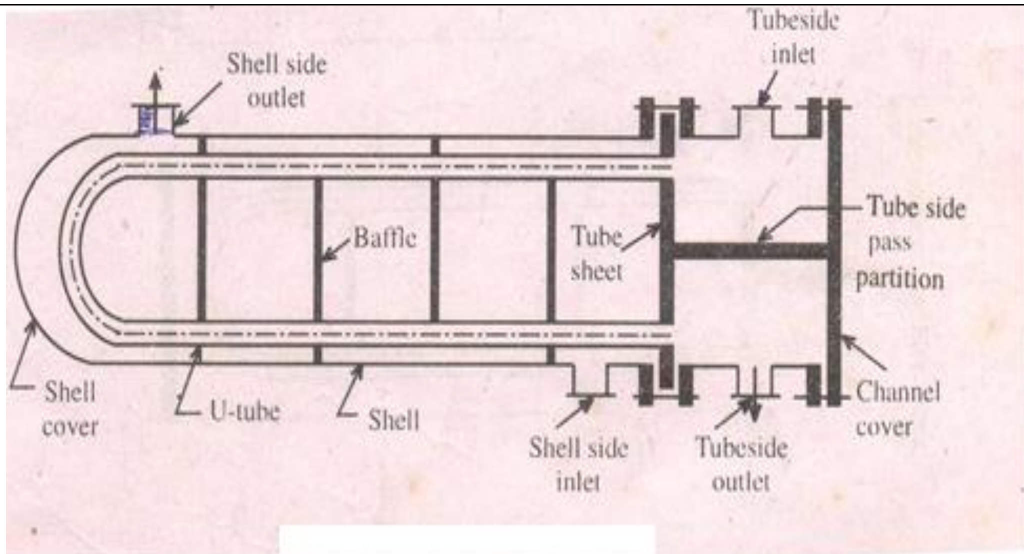
2-e	**Graphite block heat exchanger:** Graphite heat exchangers are well suited for handling corrosive fluids. Graphite is inert towards most corrosive fluids and has very high thermal conductivity. Graphite being soft, these exchangers are made in cubic or cylindrical blocks. In cubic exchangers, parallel 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. 	2 2
3	**Any two**	16
3-a	Inside Diameter = Di = 26 mm = 0.026 m Outside Diameter = Do = 35 mm = 0.035 m Xw =35 – 26 /2 = 4.5 mm = 0.0045 m Dw = log mean diameter $= \frac{Do-Di}{ln\,(\frac{Do}{Di})}$ $= \frac{0.035-0.026}{\ln(\frac{0.035}{0.026})}$	1 1

	= 0.0303 m K for steel = 50 w/(m.k) Overall heat transfer coefficient based on the outside area of inner pipe (Uo) is given by : $$\frac{1}{U}=\frac{1}{ho}+\frac{1}{hi}\cdot\frac{Do}{Di}+\frac{xw.Do}{k.Dw}+Rdo+Rdi(\frac{Do}{Di})$$ Above eqn. is inclusive of dirt factors. $$\frac{1}{Uo}=\frac{1}{500}+\frac{0.035}{0.026}\cdot\frac{1}{250}+\frac{0.0045}{50}\cdot\frac{0.035}{0.0303}.+1.7\times10^{-3}+0.86\times10^{-3}(\frac{0.035}{0.026})$$ Uo (inclusive of dirt factors) = **96.65 w/($m^2.k$)** Uo excluding dirt factors : $$\frac{1}{Uo}=\frac{1}{ho}+\frac{1}{hi}\cdot\frac{Do}{Di}+\frac{xw.Do}{k.Dw}$$ $$\frac{1}{Uo}=\frac{1}{500}+\frac{1}{250}\cdot\frac{0.035}{0.026}+\frac{0.0045}{50}\left(\frac{0.035}{0.0303}\right)$$ Uo = 133.56 W/($m^2.k$) Uo (exclusive of dirt factors) = **133.56 W/$m^2.k$**	1 1 1 1 1 1
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	2

	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.  Y1, y2 represents thin film on hot side in which liquid is flowing in Laminar flow.	2

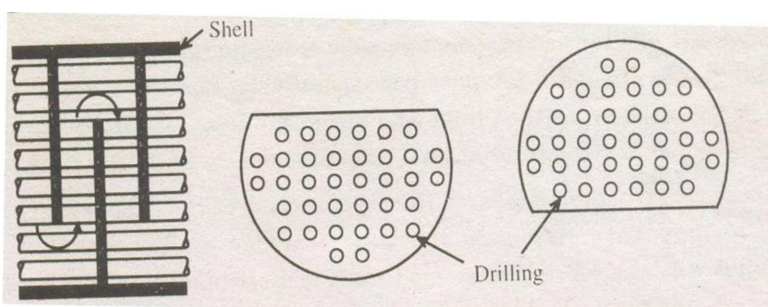
	Ta – Tb –Tc is temperature drop from bulk of hot fluid to metal wall on hot side. T1 = is Avarage temperature on hot side Z1 Z2 represents thin film on cold side in which liquid is flowing in Laminar flow. Td –Te – Tf is temperature drop from metal wall to the bulk of cold fluid. T2 is average temperature 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) 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.	1
	At Steady State,	

	$Q_1 = Q_2 = Q_3 = Q = Constant$ $\therefore Q = \Delta t / R_1 + R_2 + R_3$ $\therefore Q = T_1 - T_2 / [(1/hiAi) + (Lm/R\ Am) + (1/hoAo)]$ …….(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)	2
3-c	**U tube heat exchanger:**	4

		2
	Construction: The U-tube heat exchanger consist of U-shaped tubes ,both the ends of which are fixed to a single stationary tube sheet .At one end of shell the channel is provided with pass partition and is used for entry and exit of tube sheet fluid .At opposite end of the shell ,there is cover which is integral with it.The shell is provided with two nozzels for entry and exit of shell side fluid . the tube sheet is clamped between shell flange and channel flange. The entire tube bundle can be removed from the shell from channel end .The differntial thermal expansion between shell and tubes is absorbed by U – bends which can be expand or contract freely without affecting other tubes. **Working**: In this exchanger, the tube side fluid enters through channel, it flows first to one arm of U shaped tubes,it comes at other end , travels down through bend , flows through the other arm of U shaped tubes and ultimately leaves the exchanger through outlet provided on channel. During its passage through exchanger it exchanges the heat with shell side fluid. The tube bundle can be removed for cleaning of the tubes from outside. The inside of the tube can be cleaned only by chemical means.	2

4 A	Any three	12
4A-(i)	**Solution:** Thermal conductivity = 0.6 W/(m.K) Temperature of inside wall = 289 k Temperature of outside wall = 279 k L = 0.3 m Area = 7 × 6 = 42 m Q = $\frac{kA\Delta T}{L}$ = $\frac{0.6\times42\times10}{0.3}$ = 840 w	2 1 1
4A-(ii)	The **economy** of an evaporator is defined as the number of kilogram of water evaporated per kilogram of stem 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 1 1

	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. **B. Methods of increasing economy by vapour recompression methods are:** **1.** Mechanical recompression **2.** Thermal recompression	1
4A-(iii)	Solution: $Q = \frac{\sigma . A1(T1^4 - T2^4)}{\frac{1}{e1} + \frac{A1}{A2}(\frac{1}{e2} - 1)}$ σ = 5.67×10^{-8} W/$m^2.k^4$ e_1 = 0.79 , e_2 = 0.93 T_1 = 500 k T_2 = 300k $A_1 = \pi \times \frac{70}{1000} \times 3$ = 0.659 m2 A_2 = 4(0.3× 3) = 3.6 m2	1 1 1

	$Q = \frac{5.67\times10^{-8}\times0.659\times(500^4-300^4)}{\frac{1}{0.79}+\frac{0.659}{3.6}(\frac{1}{0.93}-1)}$ = 1588.5 W	1
4A-(iv)	**Baffles:** Baffles are commonly used on shell side to increase rate of heat transfer by increasing the turbulence of shell side liquid. They also support the tubes against vibration. The baffles cause the fluid to flow through the shell at right angles to the axis of tube. Clearance between baffles & shell should be minimum to avoid by passing of fluid. Common types of baffles are segmental baffle. Segmental baffle is drilled circular disc of sheet metal with one side cut away when the height of baffle is 75% of inside dia of the shell it is called as 25% cut segmental baffle. 	4
4 B	**Any one**	6
4B-(i)	**Vapour Recompression:** Thermal energy in the vapour evolved from a boiling solution can be utilised to vaporize more water if at all there is a temperature drop for heat transfer in desired direction. The compressed vapour having higher condensing temperature is then fed to the steam chest of the evaporator from which it came.so economy of evaporator is also increased by recompressing the vapour from evaporator and condensing it	2

	in the steam chest of the same evaporator. In this method ,the vapour from the evaporator are compressed to a saturation pressure of steam to upgrade the vapours to the condition of original steam to permit their use as heating media. The cost of supplying the required amount of compression usually smaller than the value of latent heat in vapour. By this we can obtain multiple effect economy in single effect. **Methods of increasing economy by vapour recompression methods are:** **1.** Mechanical recompression **2.** Thermal recompression **Vapor-recompression evaporation** is the evaporation method by which a blower, compressor or jet ejector is used to compress, and thus, increase the pressure of the vapor produced. Since the pressure increase of the vapor also generates an increase in the condensation temperature, the same vapor can serve as the heating medium for its "mother" liquid or solution being concentrated, from which the vapor was generated to begin with. If no compression was provided, the vapor would be at the same temperature as the boiling liquid/solution, and no heat transfer could take place. If compression is performed by a mechanically driven compressor or blower, this evaporation process is usually referred to as **MVR** (**Mechanical Vapor Recompression**). In case of compression performed by high pressure motive steam ejectors, the process is usually called **Thermocompression** or **Steam Compression**.	2 2
4B-(ii)	Expression for heat flow : $k=k_0(1+\dot{\alpha}T)$ Q= -kAdT/dr	1

	Area =A Putting the values of A and K in Fourier's law we get $Q = -kA\frac{dT}{dx}$ $= -k_0(1+\alpha T)A\frac{dT}{dx}$ $Q\,dx = -A[(k_0 + k_0\alpha T)dT]$ Integrating $Qx = -A\left[k_0 T + \frac{k_0}{2}\alpha T^2\right]$ $= -A\left[k_0(T_2 - T_1) + \frac{\alpha k_0}{2}(T_2^2 - T_1^2)\right]$ $= A\left[k_0(T_1 - T_2) + \frac{\alpha k_0}{2}(T_1 - T_2)(T_1 + T_2)\right]$ $= Ak_0(T_1 - T_2)\left[1 + \frac{\alpha}{2}(T_1 + T_2)\right]$ $Q = \frac{Ak_0(T_1 - T_2)}{x}\left[1 + \frac{\alpha}{2}(T_1 + T_2)\right]$	1 1 1 1 1
5	Any two	16
5-a	The **logarithmic mean temperature difference** (also known as **log mean temperature difference** or simply by its initialism**LMTD**) is used to determine the temperature driving force for heat transfer in flow systems, most notably in heat exchangers. The LMTD is a logarithmic average of the temperature difference between the hot and cold feeds at each end of the double pipe exchanger. The larger the LMTD, the more heat is transferred. The use of the LMTD arises straightforwardly from the analysis of a heat exchanger with constant flow rate and fluid thermal properties.	3

	Understanding the concept of log mean temperature difference or LMTD is very important for heat exchanger design especially for the heat exchangers with no phase change. The LMTD is the driven force for the heat exchange between the two fluids. As the LMTD value increases, the amounts of heat transfer between the two fluids also increase. The LMTD value is used for calculating the heat duty of the heat exchanger. The formula is: **Q = U * A * LMTD** Where, Q – Heat duty of the heat exchanger (in *watts*) U – Heat transfer co-efficient (in *watts/Kelvin/Meter square*) A – Heat transfer area (in meter square) Assume heat transfer is occurring in a heat exchanger along an axis *z*, from generic coordinate *A* to *B*, between two fluids, identified as *1* and *2*, whose temperatures along *z* are $T_1(z)$ and $T_2(z)$. The local exchanged heat flux at *z* is proportional to the temperature difference: $$q(z) = U(T_2(z) - T_1(z))/D = U(\Delta T(z))/D,$$ where *D* is the distance between the two fluids. The heat that leaves the fluids causes a temperature gradient according to Fourier's law: $$\frac{dT_1}{dz} = k_a(T_1(z) - T_2(z)) = -k_a \Delta T(z)$$ $$\frac{dT_2}{dz} = k_b(T_2(z) - T_1(z)) = k_b \Delta T(z)$$	5

Summed together, this becomes

$$\frac{d\,\Delta T}{d\,z} = \frac{d\,(T_2 - T_1)}{d\,z} = \frac{d\,T_2}{d\,z} - \frac{d\,T_1}{d\,z} = K\Delta T(z)$$

where $K=k_a+k_b$.

The total exchanged energy is found by integrating the local heat transfer q from A to B:

$$Q = \int_A^B q(z)dz = \frac{U}{D}\int_A^B \Delta T(z)dz = \frac{U}{D}\int_A^B \Delta T\,dz$$

Use the fact that the heat exchanger area Ar is the pipe length A-B multiplied by the interpipe distance D:

$$Q = \frac{UAr}{(B-A)}\int_A^B \Delta T\,dz = \frac{UAr\int_A^B \Delta T\,dz}{\int_A^B\,dz}$$

In both integrals, make a change of variables from z to ΔT:

$$Q = \frac{UAr\int_{\Delta T(A)}^{\Delta T(B)} \Delta T\frac{d\,z}{d\,\Delta T}\,d(\Delta T)}{\int_{\Delta T(A)}^{\Delta T(B)} \frac{d\,z}{d\,\Delta T}\,d(\Delta T)}$$

With the relation for ΔT found above, this becomes

$$Q = \frac{UAr\int_{\Delta T(A)}^{\Delta T(B)} \frac{1}{K}\,d(\Delta T)}{\int_{\Delta T(A)}^{\Delta T(B)} \frac{1}{K\Delta T}\,d(\Delta T)}$$

Integration is at this point trivial, and finally gives:

	$$Q = U \times Ar \times \frac{\Delta T(B) - \Delta T(A)}{\ln[\Delta T(B)/\Delta T(A)]},$$ from which the definition of LMTD follows.	
5-b	Basis: 10500 kg/hr feed is fed to the evaporator.	1
	Material balance of solids:	
	Solids in feed= solids in the thick liquor	1
	0.04x10500=0.24 x m'	
	m'=1750kg/h.	1
	overall Material balance:	
	kg/h feed= kg/h water evaporated + kg/h thick liquor	1
	water evaporated= mv=10500-1750=8750kg/h	1
	Capacity of evaporator = **8750 kg/hr**	1
	steam fed= 9500 kg/h	
	steam economy= kg/h water evaporated/kg/h steam consumed	1
	= 8750/9500=**0.921**	1
5-c	$N_{Re} = Du\rho/\mu$	1
	D =16 mm = 0.016 m, u =3m/s	
	$\mu = 485 \times 10^{-6}$ Pa.s	
	$\rho = 984.1 kg/m^3$	
	$N_{Re} = 0.016 x 3 x 984.1/485 x 10^{-6} = 97395$	1
	$N_{Pr} = Cp\ \mu/k = 4187 x 485 x 10^{-6}/0.657 = 3.09$	1
	The equation to find out heat transfer coefficient for turbulent flow(Dittus-Bolter equation)	

	$hD/k = 0.023[(Du\rho/\mu)^{0.8}(Cp\ \mu/k)^{a}$ where a= 0.3 for cooling. $h=0.023\ (N_{Re})^{0.8} x\ (N_{Pr})^{0.3}$ x k/D $h=0.023(97395)^{0.8}(3.09)^{0.3}x(0.657/0.016)$ = **12972.6 W/m².k** The Sider-Tate eqn for turbulent flow is $NNu= hD/k = 0.023(Du\rho/\mu)^{0.8}(Cp\ \mu/k)^{1/3}(\mu/\mu_w)^{0.14}$ $h=0.023\ (97395)^{0.8}\ (3.09)^{1/3}(485x10^{-6}/920x10^{-6})^{0.14}\ x(0.657/0.016)$ h=**12267.7 W/m².k**	1 1 1 1 1
6	Any two	16
6-a	**Dropwise and filmwise condensation:**	1.5 mark each

Points	**Dropwise condensation**	**Filmwise condensation**
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	Heat transfer coefficients are relatively very low in

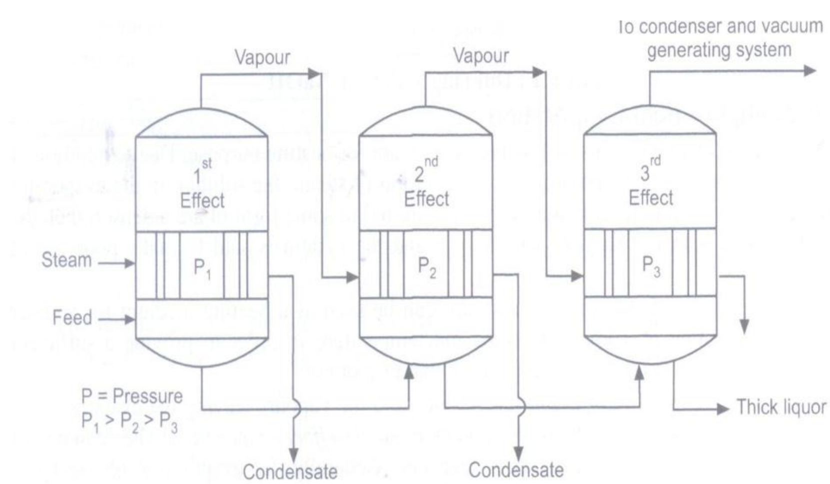
		not have to flow through film by conduction	case of film-wise condensation since the heat does have to flow through film by conduction	
	Surface type	Oily or greasy surfaces seem to tend towards drop-wise condensation	Smooth, clean surfaces seem to tend towards film-wise condensation	
	Stability	Drop-wise condensation is very difficult to achieve and unstable	Film-wise condensation is easily obtainable and stable	
	equations	If the students write equations for film coefficients on vertical and horizontal surfaces marks should be given	If the students write equations for film coefficients on vertical and horizontal surfaces marks should be given	

6-b	**Laminar flow**: The equation to find out heat transfer coefficient for laminar flow(Sider-Tate equation) $N_{Nu} = 1.86[(N_{Re})(N_{Pr})(D/L)]^{1/3}[\mu/\mu_w]^{0.14}$ Or, $hD/k = 1.86[(Du\rho/ \mu)(Cp\ \mu/k)(D/L)]^{1/3} (\mu/ \mu_w)^{0.14}$ where h= film heat transfer coefficient D= diameter of pipe line μ= viscosity of the liquid μw= viscosity of the liquid at the wall surface temp Cp= specific heat of the liquid	2 2

	L= length of pipe. k= thermal conductivity u= velocity of flow **Turbulent flow:** The equation to find out heat transfer coefficient for turbulent flow (Dittus-Bolter equation) $hD/k = 0.023[(Du\rho/ \mu)^{0.8}(Cp\ \mu/k)^{a}$ where a= 0.4 for heating a= 0.3 for cooling. where h= film heat transfer coefficient D= diameter of pipe line μ= viscosity of the liquid μw= viscosity of the liquid at the wall surface temp Cp= specific heat of the liquid L= length of pipe. k= thermal conductivity u= velocity of flow	2 2
6-c	**Forward feed and backward feed arrangements:**	1 mark each for any six points

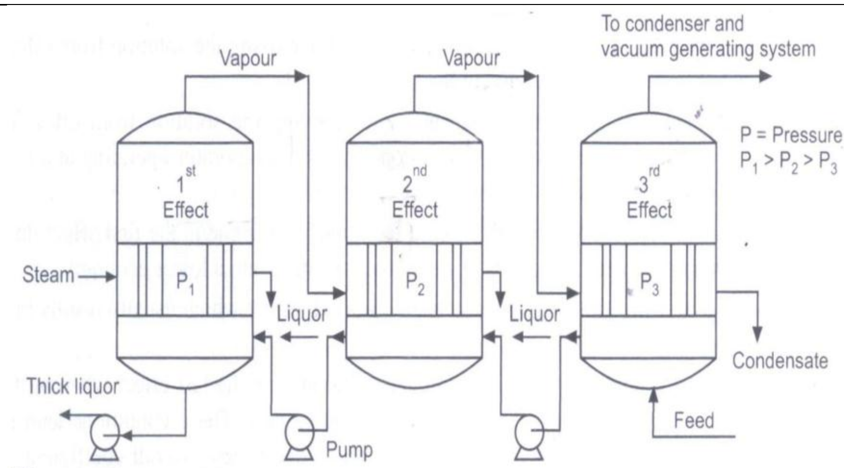
Forward feed	Backward feed
Flow of solution to be concentrated is parallel to steam flow.	Flow of solution to be concentrated is in opposite direction to steam flow.
Does not need pump for moving the solution from effect to effect.	Need pump for moving the solution from effect to effect.
As all heating of cold feed solution is done in first effect, less vapour is	Solution is heated in each effect , result in better economy.

produced , so lower 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.



1

Forward feed arrangement

	 **Backward feed arrangement**	1