MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION

(Autonomous)

(ISO/IEC - 27001 - 2005 Certified)

WINTER-19 EXAMINATION

Model Answer

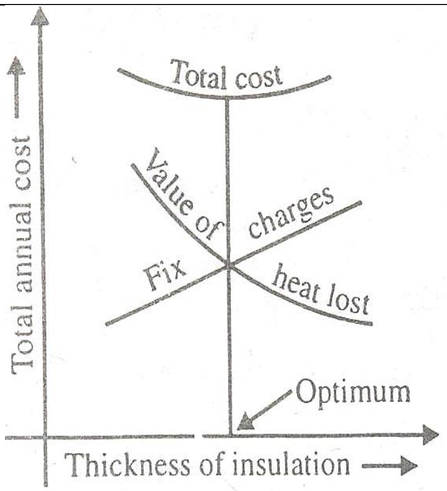
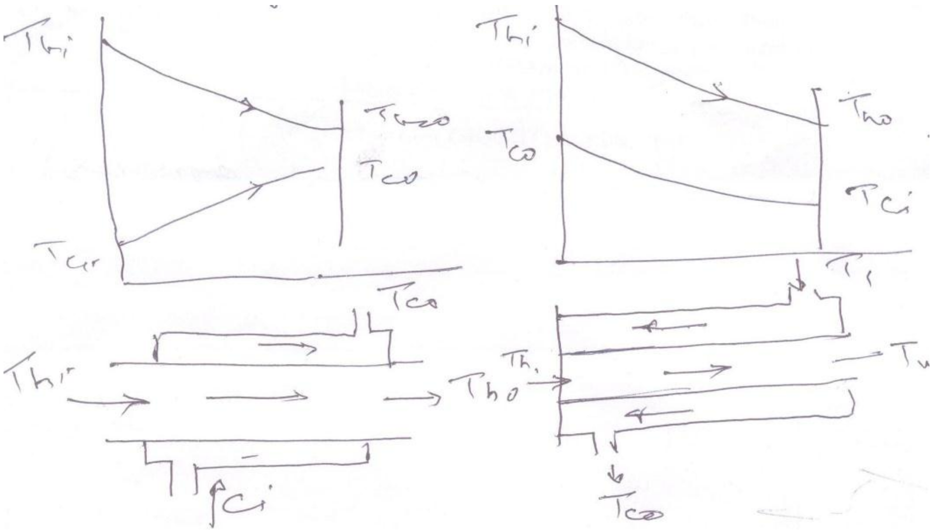
Subject: Heat Transfer Operation Subject code: 22510

Important Instructions to examiners:

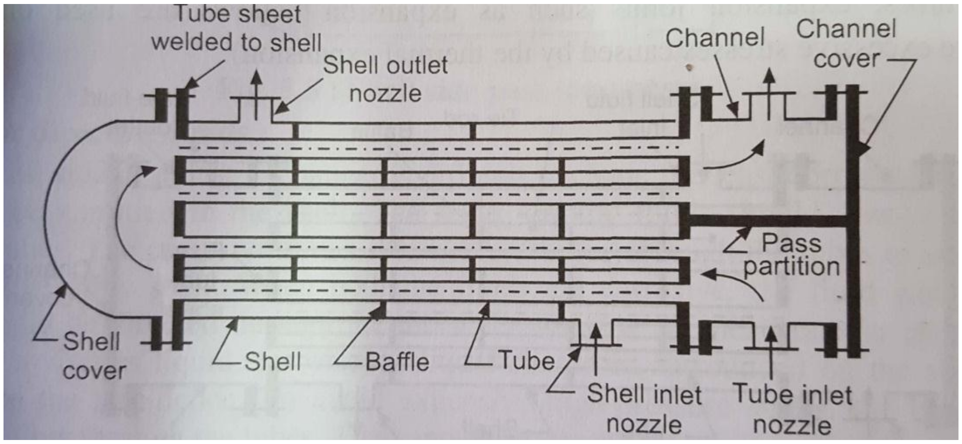
1) The answers should be examined by key words and not as word-to-word as given in the model answer scheme.
2) The model answer and the answer written by candidate may vary but the examiner may try to assess the understanding level of the candidate.
3) The language errors such as grammatical, spelling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

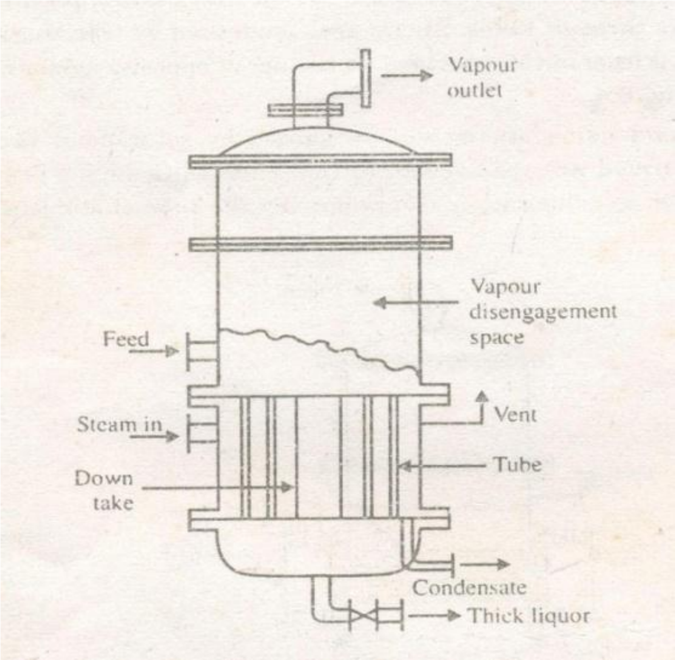
Q No	Sub Q.N	Answer	marks
1		**Answer any five**	**10**
1	a	**Steady state heat transfer**: Heat transfer where temperature remains same with respect to time and the rate of heat transfer doesnot vary with time.	2
1	b	**Film heat transfer coefficient**: Film heat transfer coefficient h is defined as the quantity of heat transferred in unit time through unit area at a temperature difference of 1^0 between the surface and surrounding.	2
1	c	**Unit of overall heat transfer coefficient** 1. In SI : W/m^2K 2. In MKS : $kcal/hr\ m^2K$	 1 1
1	d	**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. **Example**: Loss of heat from unlagged pipe.	1 1
1	e	**Four types of shell and tube heat exchanger:** 1. Fixed tube heat exchanger 2. Floating head heat exchanger 3. U- tube type heat exchanger 4. Kettle/ Reboiler type heat exchanger	½ mark each
1	f	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	1 1

		water evaporated per kilogram of steam fed to the evaporator.	
1	g	1. **Nusselt Number**N_{NU}= hd/k h – fim heat transfer coefficient d - diameter of pipe k – thermal conductivity of fluid 2. **Prandtl Number** N_{PR} -C_p μ/k C_p– specific heat of fluid μ - viscosity of fluid k – thermal conductivity	1 1
2		**Answer any three**	**12**
2	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.	2

		 **Optimum Thickness Of Insulation**	2
2	b	**Temperature – length curve:** 1. Parallel flow 2. Counter current flow  **Expression for ΔT_{LM} :** 1. Parallel flow 2. Counter current flow	2

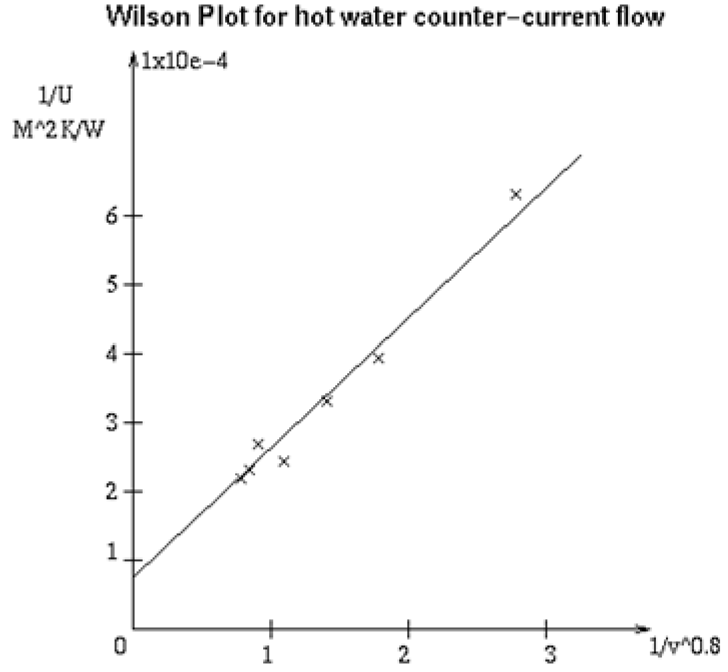
		$\Delta T_1 = T_{hi} - T_{ci}$ $\quad$ $\Delta T_1 = T_{hi} - T_{co}$ $\Delta T_2 = T_{ho} - T_{co}$ $\quad$ $\Delta T_2 = T_{ho} - T_{ci}$ $\Delta T_{LM} = (\Delta T_1 - \Delta T_2)/ \ln (\Delta T_1/ \Delta T_2)$ $\quad$ $\Delta T_{LM} = (\Delta T_1 - \Delta T_2)/ \ln (\Delta T_1/ \Delta T_2)$	2
2	c	**Properties of evaporating liquid** 1. Concentration: As the concentration increases, the solution becomes more and more individualistic. The viscosity and density increase with solid content. The boiling point of the solution also increases with solid content. 2. Foaming: Some of the materials have tendency to foam that causes heavy entrainment. 3. Scale: Some solutions deposit scale on the heat transfer surface that results in reduction of heat transfer rate. 4. Temperature sensitivity: Some materials especially pharmaceuticals and food products are damaged when heated to moderate temperatures even for short time. For concentrating such materials, special techniques are to be used that reduce temperature and time of heating. 5. Material of construction: Generally evaporators are made of mild steel. Whenever contamination and corrosion is a problem, special materials such as copper, nickel, stainless steel may be used.	1 mark each for any 4
2	d	**Absorptivity**: It is the fraction of total incident radiation which is absorbed by a body. **Reflectivity**: It is the fraction of total incident radiation which is reflected by a body.	1 1

		Transmissivity: It is the fraction of total incident radiation which is transmitted by a body. **Emissivity:** It is the ratio of total emissive power of a body to emissive power of a black body at the same temperature.	1 1
3		**Answer any three**	12
3	a	Rate of heat transfer by radiation Assume length of pipe = 1 m $e= 0.9\sigma = 5.67*10^{-8}$ W/(m^2.K^4) T_1 = 393 K T_2 = 293 K Do = 50mm = 0.05m Outside surface area per 1 meter length of pipe is $A = \pi$ Do L $=\pi\times0.05\times1 = 0.1570$ m^2 The net radiation rate per 1 m length of pipe is $Qr = e\sigma A (T_1^4 - T_2^4)$ $= 0.9 \times 5.67 \times 10^{-8}\times0.1570 (393^4 - 293^4)$ **= 132.0685 W/m** **OR** **Q_r / A = 841.2W/m^2**	1 1 1 1
3	b	**1-2 shell and tube heat exchanger**: 	4

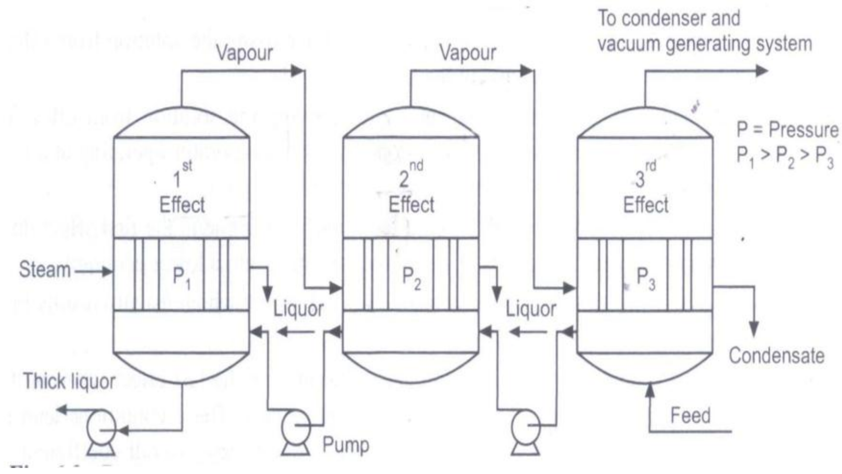
3	c	Heat lost by hot fluid	
		$Q_h = m_h Cp_h(T_{hi}-T_{ho})$	1
		$= 5000 * 2.72*(423-363) = 816000$ kJ/h	
		Heat gained by cold fluid	
		$Q_c = m_c\ Cp_c(T_{co}-T_{ci})$	1
		$= 15000*4.187*(Tco - 303)$	
		$Q_h = Q_c$	1
		$816000 = 15000*4.187*(Tco - 303)$	
		Outlet temperature of water = **315.99 K**	1
3	d	**Calendria type(Short tube) evaporator:**	
		 	2
		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	

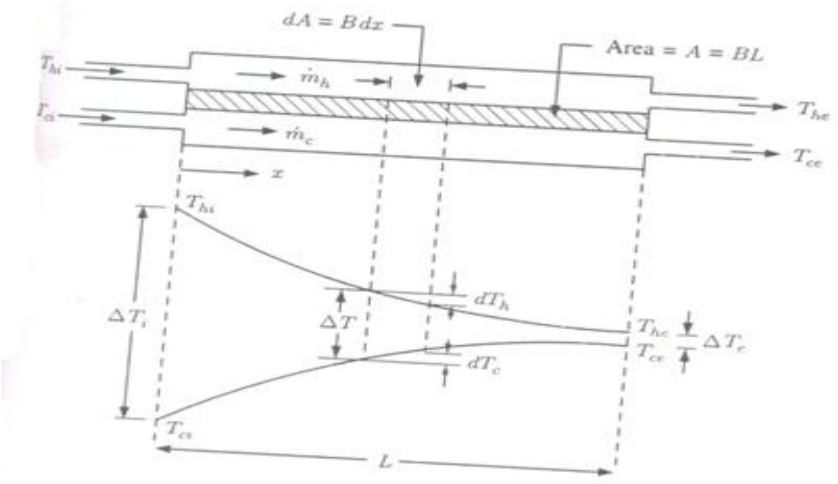
		bottom of the tubes. Solution to be evaporated is inside the tubes and steam flows outside the tubes in the steam chest. Baffles are incorporated in steam chest to promote uniform distribution of steam. The condensate is withdrawn at a point near lower tube sheet, while non condensable gas is vented to atmosphere from point near top tube sheet.	2
4		**Answer any three**	**12**
4	a	**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 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)	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
4	b	**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.	1

		 Wilson Plot for hot water counter–current flow $1/U = 1/h_i + C$ (Where C is constant as $C = 1/h_o + X_w/k$) Where c is a constant. For turbulent flow we can write $N_{nu} \alpha N_{Re}^{0.8}$ $h_i \; \alpha \; v^{0.8}$ $h_i = a \, . \, v^{0.8}$ 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.	1 1 1
4	c	Area $A = 1 \text{ m}^2$ Thickness B= 0.5 m K = 0.7 W/mK	1

		Temperature difference $\Delta T = 400-310 = 90$ K	1
		$Q= kA\ \Delta T/B$	1
		$= 0.7*1*90 / 0.5$	
		$=$ **126 W/m^2**	1
4	d	**LMTD for co current flow,**	
		$\Delta T_1 = T_{hi} - T_{ci} = 423 - 311 = 112$ K $\Delta T_2 = T_{ho} - T_{co} = 367 - 339 = 28$ K	
		$LMTD = \frac{\Delta T1-\Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} = \frac{112-28}{\ln(\frac{112}{28})} = 60.6K$	1.5
		LMTD for counter current flow,	
		$\Delta T_1 = T_{hi} - T_{co} = 423 - 339 = 84$ K $\Delta T_2 = T_{ho} - T_{ci} = 367 - 311 = 56$ K	
		$LMTD = \frac{\Delta T1-\Delta T2}{\ln(\frac{\Delta T1}{\Delta T2})} = \frac{84-56}{\ln(\frac{84}{56})} = 69.06K$	1.5
		LMTD for cocurrent flow = **60.6 K** LMTD for counter current flow = **69.06 K**	1
		Since LMTD for counter current is more, the fluid must be directed in counter current fashion.	
4	e	**Backward feed arrangement**	
		If the liquid is very viscous, then we have to adopt backward feed arrangement. In this arrangement, the feed solution and vapour flow is in opposite direction. Fresh feed is admitted to the last effect and steam to the first effect.	2

		Need pump for moving the solution from effect to effect. Solution is heated in each effect , result in better economy. 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 more. Not very common as it need pump. At low values of feed temperature higher economy. 	2
5		**Answer any two**	**12**
5	a	**Toderive Q=UA ΔT_{lm}**	



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,

1

$dq= -mhCphdTh$-------------------(2)

$= mc\ CpcdTc$ ----------------------(3)

Now $\Delta T = Th- Tc$ -----------------(4)

On differentiating

$d(\Delta T) =dTh- dTc$ -------------------------------------(5)

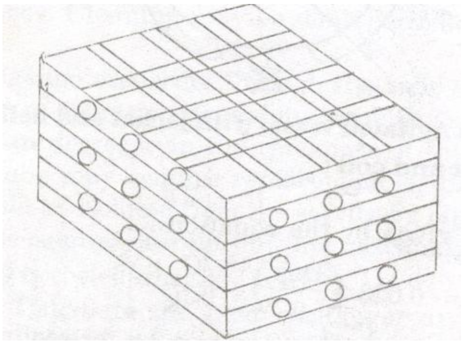
1

substituting for dq, dTh and dTc from equations (1), (2) and (3) into equation (5) , we obtain

$d(\Delta T)/ \Delta T= - (1/(mhCph) + 1/(mc\ Cpc)) U\ B\ dx$

ΔTe

		$\int_{\Delta Ti} d(\Delta T)/ \Delta T = - (1/(mhCph) + 1/(mc\ Cpc))\ U\ B\int_0^L dx$ $\ln (\Delta Te/ \Delta Ti) = - (1/(mhCph) + 1/(mc\ Cpc))\ U\ A$ ---------------------------(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 $q = m_hCp_h (T_{hi}-T_{he})$ -----------------------------(7) $= mc\ Cpc (T_{ce}- T_{ci})$ --------------------------(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) 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 1
5	b	**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	1 3

		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
5	c	Basis: 5000 kg/hrfeed is fed to the evaporator. Material balance of solids: Solids in feed= solids in the thick liquor 0.05x5000=0.2 x m’ m’=1250kg/h. overall Material balance: kg/h feed= kg/h water evaporated + kg/h thick liquor water evaporated(m_v)=5000-1250=3750kg/h Energy balance is $m_s\lambda_s = m*c_{pf} *(T-T_f) + m_v\lambda_v$ m_s 2185= 5000*4.187*(378-298) + 3750* 2257 steam fed(m_s)= 4640.06 kg/h steam economy= kg/h water evaporated/kg/h steam consumed = 3750/4640.06 =**0.808**	1 1 1 1 1 1
6		**Answer any two**	**12**
6	a	Basis: 1 m length	

		$r_1 = 0.0325m$ $r_2 = 0.0825m$	
		$r_{L1} = (r_2-r_1) / \ln(r_2/r_1) = 0.0537m$	1
		$A_{L1} = 2\pi r_L L = 0.3371\ m^2$	
		$K_1 = 0.14$ W/mK	
		$R_1 = B_1 / K_1 A_{L1}$	
		$= 0.05/0.14 * 0.3371$	1
		= 1.059 K/W	
		$r_2 = 0.0825m$ $r_3 = 0.1225m$	
		$r_L = (r_3-r_2) / \ln(r_3/r_2) = 0.101m$	1
		$A_{L2} = 2\pi r_L L = 0.6355\ m^2$	
		$K_2 = 0.035$ W/mK	
		$R_2 = B_2 / K_2 A_{L2}$	
		$= 0.04/0.035 * 0.6355$	1
		= 1.798 K/W	
		$R = R_1 + R_2$	
		= 2.857 K/W	1
		Temp.drop ΔT= 115 K	
		Heat loss Q= $\Delta T / R$	
		= 115 / 2.857	1
		= **40.3 W**	
6	b	Outside diameter (do) = 130 mm =0.13 m	
		Inside diameter (di) = 20 mm =0.02m	2
		Thickness (x) = (0.13-0.02)/2 = 0.055m	
		Thermal conductivity (k) = 46.52 W/mK	
		1/U = 1/hi + x/k + 1/ho	2
		Find out value of U assuming the values of hi and ho	2

		"If students assumed appropriate values of hi, ho and attempted to solve give appropriate marks."	
6	c	**Viscous liquid :** Viscous liquid 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 liquid:** High pressure liquid is passed through tube side **Reason**: To avoid expensive high pressure shells (in order to save the cost of expensive material for shell). **Corrosive liquid**: High pressure liquid is passed through tube side **Reason**: To avoid expensive alloy shells (in order to save the cost of expensive material for shell).	1 1 1 1 1 1