MAHARASHTRA STATE BOARD OF TECHNICAL EDUCATION

SUMMER 2013 EXAMINATION

Model Answer

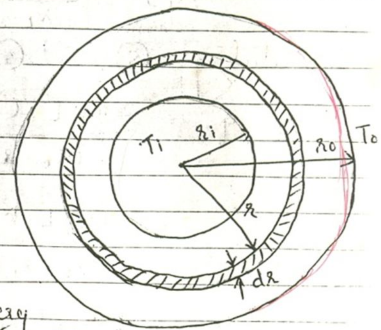
Subject & code : HTO(12204)

Important instructions to examiners :

1. The answers should be examined by keywords 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 given more importance.
4. While assessing figures, examiner may give credit for principal components indicated in a 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 answer and model answer.
6. In case of some questions credit may be given by judgment of relevant answer based on candidates understanding.

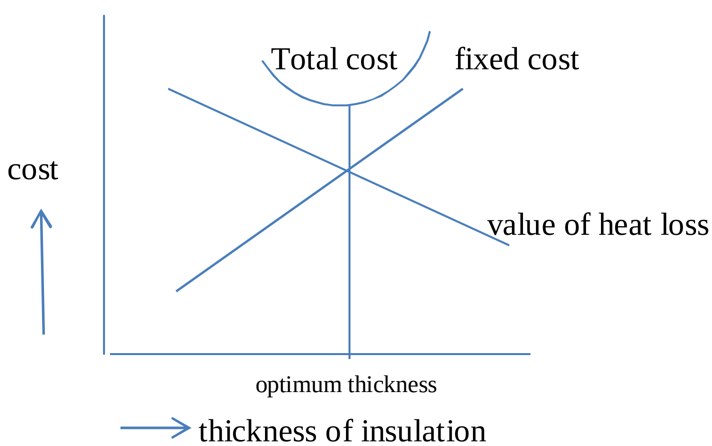
Q.No.	Answer	Mark	Total Mark
1.A-a	**Thermal conductivity** : It is a physical property of substance through which heat flows. It is defined as amount of heat flows per unit time through unit area when temperature difference is unity. **Relationship of thermal conductivity with temperature** : It is independent of temperature gradient , slightly depends on temperature. For small temperature ranges it is considered constant and for large temperature ranges it depends on temperature. $k = aT + bT^2 + cT^3 + \ldots\ldots$ where k is thermal conductivity. T is absolute temperature.	2 2	4

	a,b,c are constants.		
1.A-b	**Absorptivity (α̇):** It is defined as the fraction of radiation falling on a body which is getting absorbed. **Reflectivity (ρ) :** It is defined as the fraction of radiation falling on a body which is getting reflected. **Transmissivity (τ) :** It is defined as the fraction of radiation falling on a body which is getting transmitted. **The relation between the three are** : (α̇)+ (ρ)+ (τ) = 1	1 1 1 1	4
1.A-c	Two heat transfer equipment where latent heat is involved are: 1. Condenser : The equipment employed to condense a vapour or mixture of vapours . 2. Vaporiser : The equipment which vaporize a part of liquid. 3. Reboiler : The equipment employed to meet latent heat requirement at the bottom of distillation column.	2 marks each for any 2	4
1.A-d	**Significance of Reynold's number :** It is the ratio of inertial force to viscous force. **Significance of Nusselt number :** It is the ratio of wall heat transfer rate to heat transfer by conduction.	2 2	4

1.B-a	<u>Heat flow through a Cylinder</u> Consider a hollow cylinder. inside radius r_i outside radius r_o length of cylinder L inside temp. T_i outside temp. T_o ther. cond. of mat. k.  Consider a very thin cylinder of radius 'r', thickness of the wall of this cylinder is dr. Applying Fourier's law $q = -kA\frac{dT}{dr}$ But $A = 2\pi r L$ $\therefore q = -k\,2\pi r L\,\frac{dT}{dr}$ or $\frac{dr}{r} = -\frac{2\pi k L}{q}\,dT$ $\int_{r_i}^{r_o} \frac{dr}{r} = -\frac{2\pi k L}{q}\int_{T_i}^{T_o} dT$	2 2	6

	$[\ln r]_{r_i}^{r_o} = \frac{2\pi k L}{q}[-T]_{T_i}^{T_o}$ $\ln(\frac{r_o}{r_i}) = \frac{2\pi k L}{q}[T_i - T_o] \longrightarrow (4)$ Let $r_L = \frac{r_o - r_i}{\ln(r_o/r_i)}$ $\ln(r_o/r_i) = \frac{r_o - r_i}{r_L} \longrightarrow (5)$ Substituting (5) in (4) $q = \frac{2\pi k L (T_i - T_o)}{(r_o - r_i)/r_L}$ $= \frac{2\pi r_L L k (T_i - T_o)}{(r_o - r_i)}$ $q = \frac{k A_L (T_i - T_o)}{(r_o - r_i)}$ where $A_L = 2\pi r_L L$ $= 2\pi L \frac{(r_o - r_i)}{\ln(r_o/r_i)}$ r_L is called logarithmic mean radius. It is the radius which when applied to the integrated equation of a flat wall will give the correct rate of heat flow through a thick walled cylinder.	2	
1.B-b	Thickness B1 = 0.02m B2 = 0.01m B3 = 0.02m Thermal conductivity k1 = 0.105W/m.K K2 = 0.041W/m.K K3 = 0.105W/m.K	1	6

	Area A = $1m^2$ $R1 = B1/k1.A$ $=0.1905$ K /W $R2 = 0.244$ K/W $R3 = 0.1905$ K/W $R = R1 + R2 + R3$ $= 0.625$ K/W $Q = \Delta T/R$ $\Delta T = 303-263=40$ K $Q = 40/0.625=64W$	2 1 1 1	
2.a	Heat given out by thermic fluid $Q_h = m_h.c_{ph}.(T_{h1}-T_{h2})$ $= 5000*2.72*(423-363)$ $= 816000$ KJ Heat absorbed by Cold water $Q_c = m_c.c_{pc}.(T_{c2}-T_{c1})$ $= 15000*4.187*(T_{c2}-303)$ $Q_h = Q_c$ Equating Qc and Qh,T_{c2} can be calculated. Therefore outlet temperature of water = 316 K	2 2 1 3	8
2.b	Viscosity of fluid $\mu = 0.004$ N.S/m^2 Density $\rho = 1070$ kg / m^3 Cp = 2.72 KJ / Kg . K K = 0.256 W/mK MFR = 5500kg./h = 1.53kg./sec. VFR = $1.53/1070=1.43*10^{-3}$ m^3/sec Area = $1.256*10^{-3}$ m^2 Velocity u = VFR/Area = 1.14 m/sec $N_{RE} = Du\rho/\mu$ $= 12198$	 2 2 1	8

	Dittus Boelter equation is $N_{NU} = 0.023\ N_{RE}^{0.8}\ Npr^{0.4}$ $N_{NU} = hD/k$ Heat transfer coefficient $h = 1225.5 W/m^2K$	1 2	
2.c	**Thermal insulation** : Thermal insulation is used to prevent the loss of heat. Insulators are the materials used for insulation. Thermal insulators have low thermal conductivity values. **Optimum thickness:** The optimum thickness of insulation is arrived at by a purely economic approach. If a bare pipe were to carry a hot fluid, there would be a certain hourly loss of heat whose value can be determined from the cost of producing heat. Lower the heat loss, greater the thickness, initial cost and annual fixed charges. By assuming a number of thickness of insulation and adding the fixed charges to the value of heat loss, a minimum cost will be obtained and the thickness corresponding to it will be the optimum thickness. 	2 3 3	8
3.a	For turbulent flow in tubes/pipes , the Sieder-Tate equation that takes into account the variation of the viscosity of the fluid near the wall with thermal gradients is $hD/k = 0.023\ (Du\rho/\mu)^{0.8}\ (C_p\mu/k)^{1/3}\ (\mu/\mu_w)^{0.14}$	2	4

	This is Sieder-Tate Equation. Where, D= Diameater of Pipe u= Velocity of flowing fluid ρ= Density of flowing fluid μ= Viscosity of flowing fluid C_p = Specific heat of flowing fluid K= Thermal conductivity of flowing fluid μ_w = Viscosity of fluid at the wall temperature (μ/μ_w)= Sieder-Tate Correction factor	2	
3.b	i) **Evaporation** is an operation that is carried out in an industry as a means of concentrating a weak liquor/solution by vaporising a portion of the solvent. ii) **Boiling point Elevation:** The difference between boiling point of a solution and that of pure water at any given pressure is known as a boiling point elevation of the solution. The boiling point elevation is small for dilute solution and large for concentrated solutions of inorganic salts. iii) **Capacity of an Evaporator** is defined as the no. of kg of water vaporized/ evaporated per hr. iv) **Economy of an Evaporator**: It is defined as the no. of kg of water evaporated per kg of steam fed to the evaporator. It is also called as Steam Economy.	1 1 1 1	4

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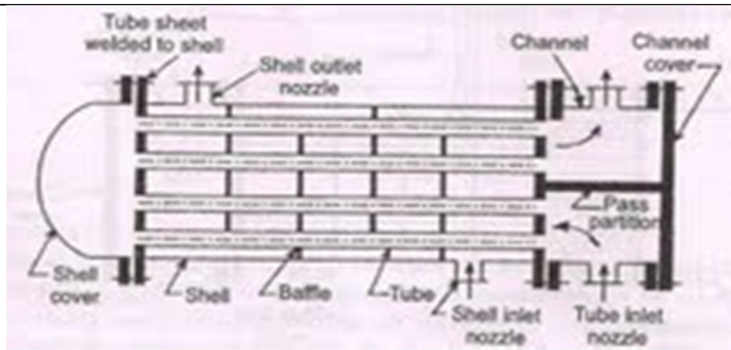
<tr><td>3.c</td><td>
</td><td>4</td><td>4</td></tr>
<tr><td>3.d</td><td><table>
<tr><th>EVAPORATION</th><th>DRYING</th></tr>
<tr><td>Evaporation is a Heat transfer operation</td><td>Drying is both mass and heat transfer operation</td></tr>
<tr><td>It is a method of concentrating a weak liquor.</td><td>It is an operation where last traces of moisture are removed.</td></tr>
<tr><td>The product is a solution</td><td>Product obtained is solid</td></tr>
</table></td><td>2 marks for any two points</td><td>4</td></tr>
<tr><td>3.e</td><td>The economy of an Evaporator can be increased by :
i) Use of multiple effect evaporation system: In this system the vapour produced in 1^{st} effect is fed to the steam chest of the second effect as a heating medium in which boiling take place at lower pressure and temperature and so on.
ii) Vapour recompression: It is also known as thermo compression. Here the vapour from the evaporator is compressed to increased its temperature and pressure so that it will condense at a temperature higher enough to permit its use as a heating media in the same evaporator.</td><td>2

2</td><td>4</td></tr>
<tr><td>4.A-a</td><td>Consider that a hot fluid is flowing through the circular pipe and cold fluid is flowing on the outside of the pipe. The heat will flow from a hot fluid to a cold fluid through series of resistances. The thermal conductivity of fluids are very low so that the resistance offered by the flim to the heat flow is very large though the film is thin.</td><td>2</td><td>4</td></tr>
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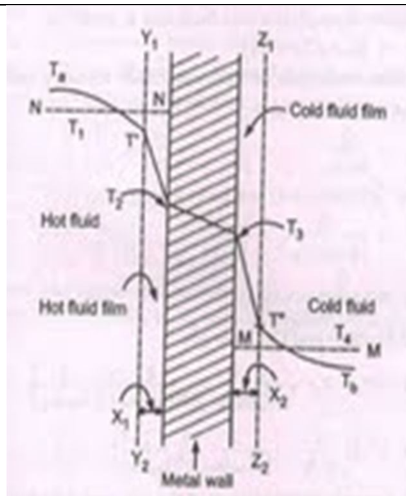

The dotted lines Y_1,Y_2 and Z_1,Z_2 represent the boundaries of thin flims. The flow to the left of Y_1,Y_2 and right of Z_1,Z_2 is turbulent. The temperature gradient from the bulk of hot fluid to the metal wall is represented by T_a, T’,T_2.
Where the T_a is maximum temperature of hot fluid,
T’ is the temperature at the boundary between turbulent and viscous region
T_2 is the temperature at the actual interface between fluid and solid.
Similarly, the temperature gradient in the cold fluid is represented by the lines T_3, T” ant T_b.
The average temperature (T_1) of the hot fluid is shown by the line marked as NN and the average temperature (T_4) of the cold fluid is represented by the line MM.
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<tr>
<td>4.A-b</td>
<td>When a heat exchanger is used for transfer of sensible heat from a hot fluid to a cold fluid heat transfer equation can be written as
Q= Heat given by hot fluid = Heat accepted by cold fluid
Q= m_h Cp_h (T_{hi}-T_{ho}) = m_c Cp_c (T_{co}-T_{ci})
This is for Heat exchanger.
When heat exchanger is use for transfer of latent heat it may be called as</td>
<td>

2</td>
<td>4</td>
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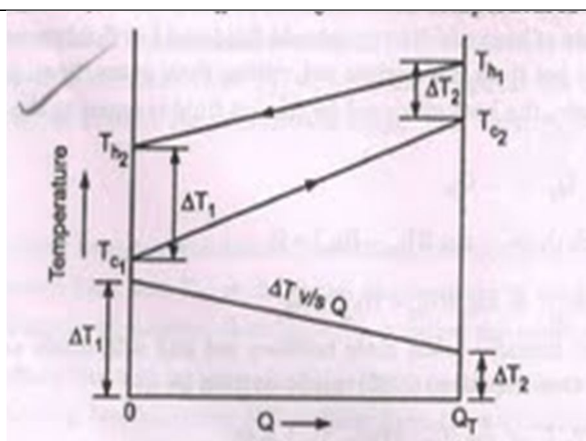
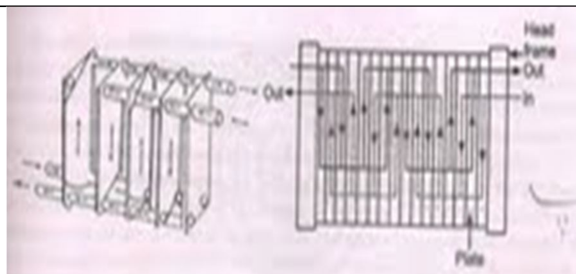
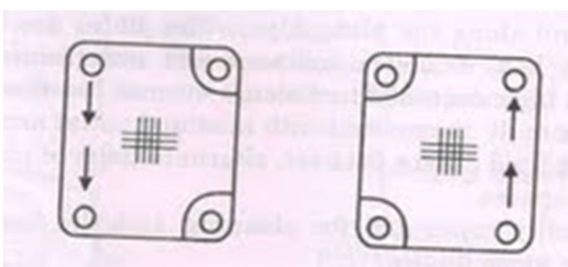
	Vaporiser or condenser. $Q= m_s \lambda_s= mc\ Cp_c\ (T_{co}-T_{ci})$ Where, ms= Mass flow rate of steam/hr. λs= Latent heat of condensation or Latent heat of vaporization	2	
4.A-c	When a saturated vapour comes into contact with a cold surface, it condenses and if condensate does not wet the surface, the droplets are formed on the surface. These droplets grow and ultimately fall from or fall down the surface under the influence of gravity leaving behind bare metal surface on which further condensation takes place. The condensation occurring by this mechanism is known as drop wise condensation. 1) In this condensation, a large portion of surface is directly exposed to the vapour. Because of this the heat transfer coefficient in drop wise condensation are 4 to 8 times larger than those for film wise condensation. 2) In drop wise condensation there is no additional resistance to heat transfer while in film wise condensation the film flowing down gives additional resistance, so rate of heat transfer is low.	 2 2	4
4A-d	 Mathematical expression for LMTD in Heat Exchanger,	1	4

	$\Delta T_{lm}= (\Delta T_2-\Delta T_1)/\ln(\Delta T_2/ \Delta T_1)$ Where, ΔT_{lm}= Logirithmic mean or the log mean temperature difference (LMTD) Assumptions to be made while deriving that expressions are : 1) Overall heat transfer coefficient U is constant. 2) Specific heats of hot and cold fluids are constant. 3) Heat flow to and from the ambient is negligible. 4) Flow is steady and may be parallel or counter current type.	2 1	
4.B-a	  Advantage of Plate type Heat Exchanger: 1.The surface area of this exchanger can simply be increased or decreased by adding or removing the plates. 2.Low pressure drop 3.Very compact, requires very small floor space 4. Ease in dismantling for inspection and cleaning 5. High heat transfer coefficient.	5 1 mark for any one advantage	6
4.B-b	The heat transfer area of the tube and pipe is increased substantially by attaching the metal pieces. The metal pieces employed to extend or	2	6

	increased the heat transfer surface are known as fins. Types of extended surfaces are: 1) Longitudinal fins 2) Trasverse fins **Applications in chemical industry:** When heat exchange takes between two fluid with large difference in surface coefficient (like steam and air) the value of overall heat transfer coefficient tends to go to lower value .so to increase rate of heat transfer of side with lower heat transfer coefficient is increased by using fins.	2 2	
5.a	a) The overall resistance to heat flow from hot fluid to cold fluid is made of three resistances in series. They are: • Resistance offered by film of hot fluid • Resistance offered by metal wall • Resistance offered by film of cold fluid The rate of heat transfer through the metal wall is given by Q=k Aw(t2-t3)/xw ---------- (1) Whereas xw= Thickness of pipe wall Aw=log mean area of pipe K=thermal conductivity of material of pipe The rate of heat transfer through the cold fluid film is given by Q=h0A0 (t3-t4)--------(2) Where h0 is the outside film coefficient or individual heat transfer coefficient. The rate of heat transfer through the hot fluid film is given by Q=hiAi(t1-t2)---------(3) Thus t1-t2=Q/hiAi -----(4) Equations 1,2 can be rearranged as t2-t3= Q/(kAw/xw) --------(5) and	2 2 2	8

	t3-t4= q/h0A0 ----------(6) Adding equations 4,5,6 we get (t1-t2)+(t2-t3)+(t3-t4)= Q[1/hiAi +1/(kAw/xw)+1/h0A0]-----------(7) Thus t1-t4= Q[1/hiAi +1/(kAw/xw)+1/h0A0]------------(8) Where t1 and t4 are the average temperature of the hot and cold fluid respectively. Therefore equations 2&3 in terms of overall heat transfer coefficient can be written as Q= UiAi(t1-t4) ---------(9) Q= U0A0(t1-t4)----------(10) Where Ui and U0 are the overall heat transfer coefficient based on inside and outside area respectively. Eqn 10 cqn be rearranged as (t1-t4)= Q/U0A0 Comparing eqn (8) and(11) we get 1/U0A0=1/hiAi +1/(kAw/xw)+1/h0A0 1/U0=1/hi(A0/Ai) +xw/k(A0/Aw)+1/h0 ------(11) Where A0= the outside area of the tube Ai= the inside area of the tube. For thin walled tubes A0=Ai=Aw Thus eqn 11 converted to 1/U=1/hi +xw/k+1/h0 Where U is overall heat transfer coefficient and hi and h0 are individual heat transfer coefficient.	2	
5.b	entry exit 423k ----hot fluid---------------------------- 353k 303k----------cold fluid-------------------318k **For co current flow** T1= (423-303) =120K	2	8

	T2= (353-318)= 35K L.M.T.D= (T1-T2)/lnT1/T2= (120-35)/ln120/35=69.16K. **For counter current flow** T1=423-318=105 T2=353-303=50 L.M.T.D.= T1-T2/ln(T1/T2)= 105-50/ln(105/50)= 74.22	2 2 2	
5.c	**Comparison of forward feed and backward feed arrangements** 1. In forward feed the flow of the solution to be concentrated in parallel to the steam/vapour flow. In backward feed the flow of the solution to be concentrated in opposite to the steam/vapour flow. 2. Forward feed arrangement does not need a pump for moving the solution from effect to effect as vacuum is maintained in the last effect. Backward feed arrangement need sa pump for moving the solution from effect to effect as transfer of the solution is to be done from the evaporator operating at low pressure to that operating at high pressure. 3. In forward feed as all heating of the cold feed solution is done in the 1^{st} effect less vapour is produced per kg of steam fed resulting to an lower economy. In backward feed the solution is heated in each effect which usually results in better economy than that with forward feed. 4. In case of forward feed the maintenance and power cost is less in comparison to backward feed. Forward feed is more economical in steam than backward feed.	2 2 2 2	8
6.a	a) **Black body**= a body for which a=1,r=t=0,i.e.,which absorbs all the incident radiant energy, is called a black body. It neither reflects nor transmits but absorbs all the radiation incident on it, so it is treated as an ideal radiation receiver. It is not necessary that the surface of the body be black in colour. **Gray body**= A body having the same value of the monochromatic	2 2	4

	emissivity at all wavelength is called as gray body. a gray body is the one of which emissivity is independent of wavelength.		
6.b	a) It states that the total energy emitted per unit time by a black body is directly proportional to the forth power of its absolute temperature. $Eb \alpha T^4$ $Eb= \sigma T^4$ Where, T= temperature in K σ = Stefan Boltzmann constant $\sigma = 5.67 \times 10^{-8}$ w/(m2.K4)	2 2	4
6.c	a) $Q/A=e \sigma (T1^4-T2^4)$ e= 0.9 $\sigma= 5.67 \times 10^{-8}$ w/(m2.K4) $Q/A= 0.9 \times 5.67 \times 10^{-8}((377)^4-(283)^4)$ $=5.1013 \times 10^{-8}(2.02 \times 10^{10}-0.69 \times 10^{10})$ $=5.1013 \times 10^{-8} \times 10^{10}(2.02-0.64)$ =703.97 W/m2 *Since the value of e is not given any value assumed by the student should be considered.*	2 2	4
6.d	**Objective of evaporation**: The objective of evaporation is to concentrate a weak or dilute solution consisting of a non volatile solute and a volatile solvent. **Properties of evaporating liquid** 1. concentration 2. foaming 3. scale 4. temperature sensitivity 5. material of construction	2 ½ mark each for any four points	4

6.e	When the heat transfer equipment is put into service, after some time scale, dirt and other solid deposit on both sides of the pipe wall, providing two more resistance to the heat flow .the added resistance must be taken into account in the calculation of the overall heat transfer coefficient. The additional resistance reduced the original value of U and the required amount of heat is no longer transferred by the original heat transfer surface. Hence dirty overall coefficient is always less than clean overall coefficient. The equation of overall heat transfer coefficient is $1/U=1/hi + xw/k + 1/ho$ The equation of dirty overall heat transfer coefficient is $1/Ud=1/hi + xw/k + 1/ho + Rd$ Thus $U > Ud$	3 1	4