OR iii. In a certain double pipe heat exchanger, hot water flows at a rate of 50,000 kg/h and gas cooled from 95°C to 65°C. At the same time, 50,000 kg/h of cooling water at 30°C enters the exchanger. The flow conditions are such that the overall heat transfer coefficient remains constant at 2270 W/m^{2}K. Determine the heat transfer area required and the effectiveness, assuming the two streams are in parallel flow. Assume for both the streams c_p = 4.2 kJ/kgK. **6**

Q.6 i. Define the following term: **4**

(a) Total emissive power

(b) Monochromatic emissive power

ii. Derive an expression for shape factor in case of radiation exchange between two large parallel non-black surfaces. **6**

OR iii. What is a radiation shield? Derive an expression for radiation heat transfer between two large planes separated by radiation shield. **6**

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Total No. of Questions: 6 *Total No. of Printed Pages: 4*

Enrollment No......................................

Faculty of Engineering
End Sem Examination Dec-2023
ME3CO32 Heat & Mass Transfer

Programme: B.Tech. Branch/Specialisation: ME

Duration: 3 Hrs. **Maximum Marks: 60**

Note: All questions are compulsory. Internal choices, if any, are indicated. Answers of Q.1 (MCQs) should be written in full instead of only a, b, c or d. Assume suitable data if necessary. Notations and symbols have their usual meaning.
Use of HMT data book is permitted.

Q.1 i. The amount of heat flow through a body by conduction is- **1**

(a) Directly proportional to the surface area of the body

(b) Dependent upon the material of the body

(c) Directly proportional to the temperature difference on the two faces of the body

(d) All of these

ii. Conduction is a process of heat transfer- **1**

(a) From a hot body to a cold body, in a straight line, without affecting the intervening medium.

(b) From one particle of the body to another by the actual motion of the heated particles.

(c) From one particle of the body to another without the actual motion of the particles.

(d) None of these

iii. When heat is transferred by molecular phenomenon, it is referred to as heat transfer by- **1**

(a) Conduction (b) Convection

(c) Radiation (d) Scattering

iv. The heat transfer from a hot body to a cold body is directly proportional to the surface area and difference of temperatures between the two bodies. This statement is called- **1**

(a) Fourier's Law (b) Newton's law of heating

(c) Newton's law of cooling (d) Stefan's law

v. Temperature at the end tip of the fin having uniform cross-sectional area is- **1**
(a) Maximum (b) Minimum
(c) Similar to heat generation temperature (d) Unpredictable

vi. In the process of heat transfer through extended surfaces or fins, the entire surface area is at- **1**
(a) The same constant temperature (b) Different temperatures
(c) Maximum base temperature (d) Minimum temperature

vii. LMTD in case of counter flow heat exchanger as compared to parallel flow heat exchanger is- **1**
(a) Lower
(b) Higher
(c) Same
(d) Depends on the area of heat exchanger

viii. When is the arithmetic mean temperature difference of heat exchanger used instead of LMTD? **1**
(a) When the temperature profiles of two fluids of heat exchanger are sloping downward with curve
(b) When the temperature profiles of two fluids of heat exchanger are sloping upward with curve
(c) When the temperature profiles of two fluids of heat exchanger are straight
(d) None of these

ix. The emissive power of a body depends upon its- **1**
(a) Temperature (b) Wavelength
(c) Physical Nature (d) All of these

x. According to Stefan Boltzmann law, ideal radiators emit radiant energy at a rate proportional to- **1**
(a) Absolute temperature
(b) Square of temperature
(c) Fourth power of Celsius temperature
(d) Fourth power of absolute temperature

Q.2 i. State Fourier's law of heat conduction. Why is the negative sign used? **4**

ii. Explain what do you understand by critical thickness of insulation. Derive an expression for the critical radius of insulation for a hollow cylinder. **6**

OR iii. Define the term thermal diffusivity. Derive an expression of the rate of heat transfer in a plane wall with constant surface temperature without heat generation. **6**

Q.3 i. What is convection? Explain the type of convection. **4**

ii. Explain the development of thermal and hydrodynamic boundary layer on a flat plate, considering continuous flow on thin plate. At what condition these two boundary layers coincides with each other. **6**

OR iii. Determine the rate of heat loss from the wall of a building if a 15 km/hr wind is blowing parallel to its surface. The wall is 25 m long, 6 m high, its surface temperature is 50°C and the temperature of the ambient air is 27°C. The thermos physical properties of air at 38.5°C are: **6**
ρ = 1.139 kg/m^3, c_p = 1.0067 kJ/kgK, μ = 18.98 x 10^{-6}, ν = 16.82 x 10^{-6} m^2/s, k = 27 x 10^{-3} W/m K.

Q.4 i. What is the difference between fin effectiveness and fin efficiency? **4**

ii. In an experiment to determine the thermal conductivity of a solid 2.5 cm diameter rod, its base is placed in a furnace with a large portion of it projecting into the room air at 22°C. After steady state condition prevail, the temperature at two points, 10 cm apart, are found to be 110°C and 85°C respectively. The convective heat transfer coefficient between the rod surface and the surrounding air is 28.4 W/m^{2}K. Determining the thermal conductivity of the rod material. Assume no heat loss from the free end of rod. **6**

OR iii. An electrical semi-conductor device generates heat equal to 480 x 10^{-3} W. In order to keep the surface temperature at the upper safe limit of 70°C, the generated heat has to be dissipated to the surroundings at 30°C. To accomplish this task, aluminium fins of 0.7 mm square section and 12 mm long are attached to the surface. The thermal conductivity of aluminium fins is 170 W/mK. If the heat transfer coefficient is 12 W/m^{2}K, calculate the number of fins required. Assume no heat loss from the tip of fins. **6**

Q.5 i. Define the term fouling in heat exchanger. What advantage does the NTU method have over the LMTD method? **4**

ii. State Fick's law of Diffusion. Find a relation for diffusion gas-A into gas-B. **6**

Marking Scheme

ME3CO32 (T)-Heat & Mass Transfer

Q.1	i)	(d) All of the above	1
		The amount of heat flow through a body by conduction is- directly proportional to the surface area of the body, directly proportional to the temperature difference on the two faces of the body and dependent upon the material of the body.	
	ii)	(c) From one particle of the body to another without the actual motion of the particles.	1
	iii)	(b) Convection	1
		Convection is the process of heat transfer by the bulk movement of molecules within fluids such as gases and liquids.	
	iv)	(c) Newton's law of cooling	1
	v)	(b) minimum	1
	vi)	(b) different temperatures	1
	vii)	(b) Higher	1
		Counter flow heat exchangers are inherently more efficient than parallel flow heat exchangers because they create a more uniform temperature difference between the fluids, over the entire length of the fluid path.	
	viii)	(c) when the temperature profiles of two fluids of heat exchanger are straight	1
	ix)	(d) All of the above	1
		According to Wein's displacement law, Emissive power from black body is a function of temperature. So, we can say that emissive power depends on temperature and wavelength.	
	x)	(d) Fourth power of absolute temperature	1
Q.2	i.	State Fourier's law of heat conduction.	2
		Why is the negative sign used?	2
	ii.	Explain what do you understand by critical thickness of insulation.	3
		Derive an expression for the critical radius of insulation for a hollow cylinder.	3
OR	iii.	Define the term thermal diffusivity.	2
		Derive an expression of the rate of heat transfer in a plane wall with constant surface temperature without heat generation.	4
Q.3	i.	What is convection?	1
		Explain the type of convection.	3
	ii.	Explain the development of thermal and hydrodynamic boundary layer on a flat plate, considering continuous flow on thin plate.	4
		At what condition these two boundary layers coincides with each other.	2
OR	iii.	Solution: Given Data: U= 15 km/hr = 15x100/3600 =4.166 m/s l = 25 m, b = 6 m , T_s = 50°C, T_o = 27°C, ρ = 1.139 kg/m^3, c_p = 1.0067 kJ/kgK, $\mu = 18.98 \times 10^{-6}$, $\nu = 16.82 \times 10^{-6}$ m^2/s, $k = 27 \times 10^{-3}$ W/m K	1
		Reynolds number: $Re = Ul/\nu = 6.19 \times 10^6$	
		Since $Re > 5 \times 10^5$ so flow is turbulent	1
		Prandtl number: $Pr = \mu c_p/k = 0.707$	
		Nusselt number for turbulent flow over flat plate, $Nu = hl/k = 0.036(Re)^{0.8}(Pr)^{0.33}$ $h = 9.40$ W/m^{2}K	2
		Heat loss from the wall, $Q = hA(T_s - T_o) = hlb(T_s - T_o)$ $Q = 32430$ W	2
Q.4	i.	fin effectiveness	2
		fin efficiency	2
	ii.	Solution: Given Data: d = 2.5 cm = 0.025 m T_∞ =22°C L = 10 cm = 0.1 m T_o = 110°C T_l = 85°C h = 28.4 W/m^{2}K	1
		Perimeter: $P = \pi d = 3.14 \times 0.025 = 0.0785$ m	1
		Cross sectional area: $A = \pi/4 * d^2 = 4.90 \times 10^{-4}$ m^2	
		For one end insulated fin, we have $\theta/\theta_o = (T- T_\infty)/(T_o/T_\infty) = \cosh[m(l-x)]/\cosh(ml)$ At x = l $\theta_l/\theta_o = (T- T_\infty)/(T_o/T_\infty) = \cosh[m(l-l)]/\cosh(ml)$	
		$(85-22)/(110-22) = \cosh(0)/\cosh(m \times 0.1)$ $\cosh(0.1 \times m) = 1.3968$	2
		$m = 8.63$	2
		also $m = \sqrt{(hp/kA)} = 8.63$ m^{-1} $k = 61.09$ W/mK	

OR iii. Solution.

Given data: $Q_{fins} = 480 \times 10^{-3}$ W

$T_o = 70°C$

$T_\infty = 30°C$

$w = t = 0.7$ mm $= 0.7 \times 10^{-3}$ m (Square section)

$l = 12$ mm $= 0.012$ m

$k = 170$ W/mK

$h = 12$ W/m^{2}K

Perimeter: $P = 4w = 2.8 \times 10^{-3}$ m

Cross sectional area: **1**

$A = w^2 = 0.49 \times 10^{-6}$ m^2 **1**

$m = \sqrt{(hp/kA)} = 20.08$ m^{-1}

Heat transfer through one fin with insulated tip, **2**

$Q_{fin} = \sqrt{[hpkA} \, (T_o - T_\infty) \tanh(ml)]$

$= 0.01579$ W

Number of fins required = Heat transfer through all fins / Heat transfer through one fin **2**

$= Q_{fins} / Q_{fin}$

$= 30$

Q.5 i. Define the term fouling in heat exchanger. **2**

What advantage does the NTU method have over the LMTD method? **2**

ii. State Fick's law of Diffusion. **3**

Find a relation for diffusion gas-A into gas-B. **3**

OR iii. Solution:

Given data for parallel flow heat exchanger:

Hot Fluid:

$m_h = 50000$ kg/h $= 13.88$ kg/s

$T_{h1} = 95°C$

$T_{h2} = 65°C$

$c_{ph} = 4.2$ kJ/kgK $= 4200$ J/kgK

Cold Fluid:

$m_c = 50000$ kg/h $= 13.88$ kg/s

$T_{c1} = 30°C$

$c_{pc} = 4.2$ kJ/kgK $= 4200$ J/kgK **1**

$U = 2270$ W/m^{2}K

Heat transfer: $Q = m_h c_{ph}(T_{h1} - T_{h2}) = 1748880$ W

Heat capacity of hot fluid:

$C_h = m_h c_{ph} = 58296$ W/k

$C_h = C_c = C_{min} = C_{max}$ **1**

$Q = \varepsilon C_{min}(T_{h1} - T_{h2})$

$\varepsilon = 0.4615$ **1**

also $Q = m_c c_{pc}(T_{c2} - T_{c1})$

$T_{c2} = 60°C$

$LMTD = (\theta_l - \theta_2) / \log_e(\theta_l / \theta_2)$ **2**

Where $\theta_l = T_{h1} - T_{c1} = 65°C$

$\Theta_2 = T_{h2} - T_{c2} = 5°C$ **1**

$LMTD = 23.39°C$

$Q = UALMTD$

$A = 32.93$ m^2

Q.6

i. Total emissive power **2**

Monochromatic emissive power **2**

ii. The amount of energy has left plane-1 per unit time(Q_1) **2**

The amount of energy has left plane-2 per unit time(Q_2) **2**

The net radiant energy from plane-1 to plane-2 per unit time(Q_{1-2}) **2**

iii. What is a radiation shield? **2**

The net heat transfer between the planes (Without shield) **2**

The net heat transfer between the planes (With shield) **2**

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