Course Code: 1960325 **Roll No:** **MLRS-R19**

MARRI LAXMAN REDDY
INSTITUTE OF TECHNOLOGY AND MANAGEMENT
(AN AUTONOMOUS INSTITUTION)
(Approved by AICTE, New Delhi & Affiliated to JNTUH, Hyderabad)
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III B.Tech II Sem Regular End Examination, June 2022

Heat Transfer

(Mechanical Engineering)

Time: 3 Hours. **Max. Marks: 70**

Note: 1. Question paper consists: Part-A and Part-B.
2. In Part – A, answer all questions which carries 20 marks.
3. In Part – B, answer any one question from each unit.
Each question carries 10 marks and may have a, b as sub questions.

PART- A

(10*2 Marks = 20 Marks)

1.	a)	What are the applications of heat transfer?	2M	CO1	BL1
	b)	What do you understand by initial and boundary conditions?	2M	CO1	BL1
	c)	What is meant by Lumped heat analysis? explain with the help of an example.	2M	CO2	BL1
	d)	Define Fin efficiency and fin effectiveness.	2M	CO2	BL1
	e)	State Buckingham π theorem.	2M	CO3	BL1
	f)	What are the advantages and limitations of dimensional analysis?	2M	CO3	BL1
	g)	What is fouling factor? Explain.	2M	CO4	BL1
	h)	Define Grashof Number and Stanton Number.	2M	CO4	BL1
	i)	What is condensation? How does it occur?	2M	CO5	BL1
	j)	Write the use and importance of Plank's Law.	2M	CO5	BL1

PART- B

(10*5 Marks = 50 Marks)

2	a)	With relevant examples, explain mechanism of conduction, convection and radiation.	5M	CO1	BL4
	b)	Explain clearly basic laws of heat transfer.	5M	CO1	BL4
		OR			
3	a)	A Stainless steel plate is of 2 cm thick is maintained at a temperature of 550^{0}C at one face and 50^{0}C on the other. The thermal conductivity of stainless steel at 300^{0}C is 19.1 W/m K. Calculate the heat transferred through the material per unit area.	5M	CO1	BL3
	b)	In what way is the science of heat transfer different from thermodynamics? Explain.	5M	CO1	BL4
4	a)	Explain why the conductivity of metals decreases and conductivity of insulating material increases with increases in temperature.	5M	CO2	BL4
	b)	A metallic plate, 3cm thick is maintained at 400^{0}C on one side and 100^{0}C on the other side. How much heat is transferred through the plate? Take k for the metallic plate as k=370 W/m-K.	5M	CO2	BL3
		OR			
5	a)	Discuss briefly thermal and hydrodynamic boundary layer and obtain Reynold's analogy in forced convection.	5M	CO2	BL2

	b) A plate 20 cm height and 1m wide is placed in air at 20^0C. If the surface of the plate is maintained at 100^0C calculate the boundary layer thickness and local heat transfer coefficient at 10cm from the leading edge. Also calculate the average heat transfer coefficient over the entire length of the plate.	5M	CO2	BL3
6	a) Describe Buckingham's method of π-terms to formulate a dimensionally homogenous equation.	5M	CO3	BL2
	b) A flat plate 1m wide and 1.5 m long is to be maintained at 90^0C in air when free stream temperature is 10^0C. Determine the velocity at which air must flow over the plate so that the rate of energy dissipation from the plate is 3.75 kW.	5M	CO3	BL3
	OR			
7	Air at 270C and 1 atm flows over a flat plate at a speed of 2m/s. Calculate the boundary layer thickness at a distance of 20 and 40 cm from the leading edge of the plate. Calculate the mass flow which enters the boundary layer between x= 20 cms and x = 40 cms. The viscosity of the air is at 270C is 1.85 × 10-5 kg/m s. Assume the unit depth in the z-direction.	10M	CO2	BL3
8	a) A flat electrical heater of 0.4 m × 0.4 m size is placed vertically in still air at 20^0C. The heat generated is 1200 W/m². Determine the value of convective heat transfer co-efficient and the average plate temperature.	5M	CO4	BL3
	b) Explain Grashoff number significance in natural convective heat transfer.	5M	CO4	BL4
	OR			
9	A Counter flow heat exchanger consisting of two concentric flow passages is used for heating 1200 kg/hr of oil (specific heat=2.1kJ/kgK) from an initial temperature of 27 ^{0}C. The oil is flowing through the inner pipe and the convective heat transfer coefficient on the oil side is 750 W/m²K. The inner and outer radii of the inner pipe are 12 mm and 15 mm and the thermal conductivity of the pipe materials is 350 W/mK. The oil is heated by hot water supplied at the rate of 400 kg/hr at the inlet temperature of 92 ^{0}C. The waterside heat transfer coefficient is 1470 W/m²K. The length of the heat exchanger is 9 m. What are the terminal temperatures of the two fluids?	10M	CO4	BL3
10	A drying plant needs hot air at 135^0C. This is obtained by passing 2.45 kg/Sec of atmospheric air at 1 bar pressure and 27^0C over tubes through which hot glycerin is circulated. The tubes have 20mm diameter, 1.5mm thickness, With a thermal conductivity of the material of the tube 50 W/m-K. The hot glycerin enters at 210^0C and leaves at 305^0C. Assuming counter flow, Find: (a) overall heat transfer coefficient (b) total heating surface and	10M	CO5	BL3
	OR			
11	a) (i) Distinguish between a black body and grey body. (ii) Prove that intensity of radiation is given by $I_b = E_b/\pi$	5M	CO5	BL2
	b) State and explain Kirchoff's identity? What are the conditions under which it is applicable.	5M	CO5	BL4

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EXAMINATION BRANCH

Academic Year	2021-22
Year & Semester	III & II
Regulation	R-19
Branch	MECHANICAL
Course Code	1960325
Course Name	HEAT TRANSFER
Course Faculty's	K.V.RAGHAVULU
Course Moderator	K.V.RAGHAVULU
Date of Exam	15-06-2022
Reporting Time & Sign	9:30 & [signature]

KEY PAPER

QNO	ANSWER	MARKS
	PART-A	
1) a) Ans:	- Design of thermal and nuclear power plants - Heat Engines - Steam generators - Condensers - Furnaces - Heat Exchangers - Refrigeration and air conditioning - Heat treatment of metals - thermal control of space vehicles.	

QNO	ANSWER	MARKS
b:	- Initial conditions describes the temperature distribution in a medium at the initial moment of time. - these are needed only for the time dependent (i.e unsteady 'or' transient) problems. In general: $T = f(x, y, z, t)$ time at initial, the above equation can be expressed as $t=0, \quad T = f(x, y, z)$ For a uniform initial temperature distribution is $t=0, \quad T = T_0 = \text{constant}.$	
c:	Fin efficiency = $\frac{\text{Actual heat transfer}}{\text{max. heat transfer}}$ $\eta_{fin} = \frac{\sqrt{PhKA_{cs}}(t_0 - t_a)}{hPl(t_0 - t_a)} = \sqrt{\frac{KA_{cs}}{hPl^2}}$	

QNO	ANSWER	MARKS
	Fin Effectiveness:	
	It's defind as the ratio of heat lost with fin to the heat lost without fin.	
	$\varepsilon_{fin} = \frac{Q_{with\ fin}}{Q_{without\ fin}}$.	
'e'	Buckingham's theorem:	
	"If there are n variables in dimensionally homogenous equation and if these contain 'm' fundamental dimensions (M, L, T), then the variables are arranged into (n-m) dimensionless terms.	
'f'	Advantage:	
	1). It expresses the functional relationship b/w the variables in dimensionless term.	
	2). By the proper selection of variables, the dimensionless parameters can be used to make certain logical deductions about problem.	

QNO	ANSWER	MARKS
11	limitations: 1). Dimensional analysis doesnot give any clue regarding the selection of variables. 2). the complete information is not provided by dimensional analysis. lumped heat analysis: - If the Biot number ($\frac{L}{KA}$) is less than 0.1 then it's called lumped heat analysis. - the internal resistance ($\frac{L}{KA}$) can be assumed to be small or negligible with convective resistance. - the process in which the internal resistance is assumed negligible in comparision with it's surface resistance is called Newtonian heating (or) cooling process.	

QNO	ANSWER	MARKS
	→ the temperature in this process is considered to be uniform at given time. such analysis is called lumped parameter analysis.	
g:	Fouling factor:	
	→ Due to the rust formation and fluid impurities in the tubes the thermal resistance is increased and eventually the performance of the heat Exchanger decreases.	
h:	Grashoff number:	
	→ Grashoff number is related with natural convection heat transfer. It's defined as the ratio of the product of inertia force to and buoyancy force to the square of viscous force.	
	$Gr = \frac{\text{inertia force} \times \text{Buoyancy force}}{(\text{viscous force})^2}$	

QNO	ANSWER	MARKS
(i)	condensation is a process the reverse of boiling process. condensation starts whenever a saturated vapour comes in contact with in surface whose temperature is lower than the saturation temperature corresponding to the vapour pressure.	
(J):	man planck showed by quantum generation argument that the spectral distribution of the radiation intensity of a black body is given by $$(E_\lambda)_b = \frac{2\pi c^2 h \lambda^{-5}}{\exp\left(\frac{ch}{\lambda kT}\right)^{-1}}$$	

QNO	ANSWER	MARKS
2(a):	mechanism of conduction, convection & radiation conduction: - conduction is transfer of heat from one part of the substance to other part of the same substance. - conduction in solids due to lattice vibration & free electrons - conduction in fluid due to collision & diffusion of molecules during their random motion. Ex: cooking, Heating a metal Rod. convection: - It's a mode of heat transfer b/w the solid surface and adjacent liquid that is in motion. → Natural convection is due to buoyancy effect and forced convection is due to external agency like fan or blower Ex: water heating, boiler tubes., Air circulation in room by fan.	

QNO	ANSWER	MARKS
	Radiation: - Heat transferred due to radient energy from one body to another, without any medium in the form of electromagnetic waves is called as radiation. Ex: Heat trasfered from sun to earth.	
'b'	Basic laws of heat transfer: ① conduction: Fourier law - Fourier law of heat conduction state that the rate of heat conduction is directly proportional to the area normal to the direction heat flow and temperature gradient in the direction of heat flow. $Q_{cond} \propto A \frac{dT}{dn}$ $\boxed{Q_{cond} = -kA\frac{dT}{dn}}$ ② convection - Newton law of cooling: - Newton law of cooling state that, the rate of convective heat transfer is directly proportional to the surface	

QNO	ANSWER	MARKS
	area exposed to the surrounding and temperature diff. b/w the surface and the surrounding.	
	$Q \propto hA(T_s - T_\infty)$	
	Radiation- Stefan Boltzman law:	
	→ Stefan - Boltzman law of radiation state that "thermal radiations emitted by a black body is directly proportional to the fourth power of it's absolute temperature of the surface area.	
	$Q = \sigma A T^4$	
3'a'	thick $t = 2cm = 0.02m$ $T_1 = 550+273 = 823K$ $T_2 = 50+273 = 323K$ $K = 19.1\ W/mK$	
	$Q = KA\frac{dt}{dx} = 19.1 \times 1 \times \frac{823-323}{0.02} = 477\ KW$	

QNO	ANSWER		MARKS
3b	Thermodynamics	Heat transfer	
	1. thermodynamics deals with the relation b/w heat and other form of energy.	1. Heat transfer deals with the analysis of the rate of heat transfer.	
	2. It deals with the system in equilibrium only.	2. it deals with the system in non-equilibrium only.	
	3. when a system changes from one equilibrium state to another, thermodynamics helps to determine the quantity of work and heat interactions.	3. when a system changes from one equilibrium state to another, heat transfer helps to predict the distribution of temperature and amount of heat of heat transfer due to temp.	

QNO	ANSWER	MARKS
4'a)	thermal conductivity of metals 'k' generally varies with temperature. → with increase in temperature temperature thermal conductivity of insulators will increase. → with increase in temperature thermal conductivity of good conductors will decrease. → with increase in temperature thermal conductivity of many liquids will decrease. → with increase in temperature thermal conductivity of water and glycerin will increase. → with increase in temperature thermal conductivity of gases in general will increase.	
4b'	dx ⇒ $t_1 = 400+273$ $= 673\ k$ $t_2 = 100+273 = 373\ k$	

QNO	ANSWER	MARKS

$dx = 3\,cm$

$= 0.03\,m$

$K = 370\,W/m\text{-}K$

$Q = KA \dfrac{dT}{dx}$

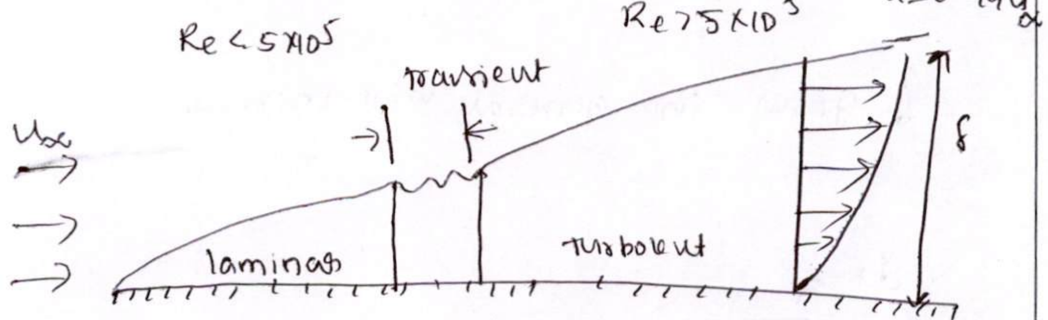
$= 370 \times 1 \times \dfrac{573 - 373}{0.03}$

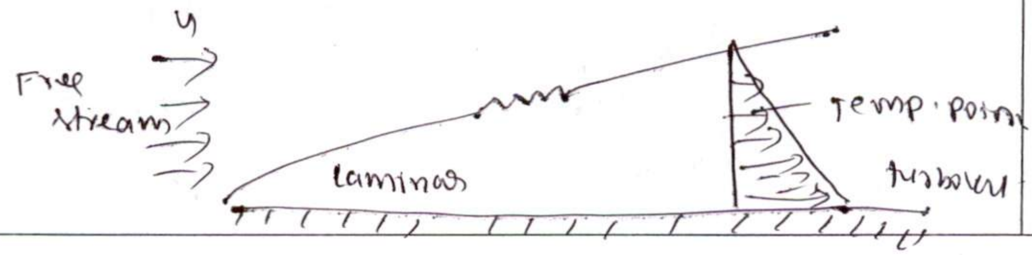
$= 3700\,kW$

5a:

Hydrodynamic boundary layer:

→ consider a parallel flow of a fluid with free stream velocity u_∞ over flat plate.



QNO	ANSWER	MARKS
	→ the Edge of the direction of flow is called leading Edge. the rear Edge is called trailing Edge. → the stationary layer of fluid slows down the neighbouring fluid layer as a result of friction b/w the two adjoining fluid layers at different velocities. this fluid layer then slows down the next layer and so on, like this velocity vary from 0 at the plate surface to 0.99 V_∞ at the boundary. this region of boundary layer in which variation of fluid "hydrodynamic boundary layer". **Thermal Boundary layer:**  	

QNO	ANSWER	MARKS
	→ The region above the solid surface in which temp. region in the direction normal to the surface exist called thermal boundary layer.	
5b:	$h = 20cm$ $W = 1m$ $T_\infty = 20°C$ $T_s = 100°C$ $h = ?$ $\delta_{th} = ?$ $x = 10cm$ haverage: i) $\delta = \frac{5x}{\sqrt{Re_x}}$ $= \frac{5 \times 0.10}{\sqrt{16.7 \times 10^{-6}}}$ 5×10^{4} $= 0.00626m$ $Re = \frac{\rho u D}{\mu}$ $= \frac{1 \times 0.10}{16.78 \times 10^{-6}}$ $= 5 \times 10^{4}$	

QNO	ANSWER	MARKS
	$h = 0.332 \frac{k}{x} (Re)^{1/2} (Pr)^{1/3}$	
	$= 0.332 \frac{0.02732}{0.10} \times (5\times10^4)^{1/2} \times (0.7)^{1/3}$	
	$= 6.43\ w/m^2$	
	$\bar{h} = 2 \times 1.43$	
	$= 13\ w/m^2c$	
6'a'	Buckinghom method:	
	→ Buckinghum π- Terms are written interms of repeating variable and one other variable.	
	→ The following repeating variable are selected.	
	i) geometric property, diameter 'D' fundamental dimension 'L'	
	2) flow property, Fluid velocity, V, fundamental dimension LT⁻¹	
	3) flow property, Dynamic viscosity (μ), fundamental dimension $ML^{-1}T^{-1}$	

QNO	ANSWER	MARKS
	(iv) thermal conductivity, K having fundamental dimensions $MLT^{-3}\theta^{-1}$ ~~natural~~ Forced convection 'π' terms are expressed $\pi_1 = D^{a_1} V^{b_1} \mu^{c_1} K^{d_1} h$ $\pi_2 = D^{a_2} V^{b_2} \mu^{c_2} K^{d_2} \rho$ $\pi_3 = D^{a_3} V^{b_3} \mu^{c_3} K^{d_3} C_p$ Finally we get $\pi_1 = \frac{hD}{K}$ $\pi_2 = \frac{\rho V D}{\mu}$ Nu = f(Re, Pr) $\pi_3 = \frac{\mu C_p}{K}$. Forced convection $\pi_1 = D^{a_1} \rho^{b_1} \mu^{c_1} K^{d_1} h$ $\pi_2 = D^{a_2} \rho^{b_2} \mu^{c_2} K^{d_2} C_p$ $\pi_3 = D^{a_3} \rho^{b_3} \mu^{c_3} K^{d_3} (\Delta T \beta g)$ Finally	

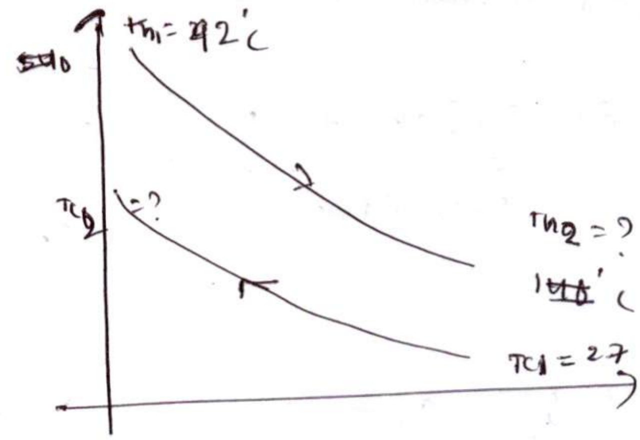
QNO	ANSWER	MARKS
	Finally will get : $\pi_1 = \frac{hD}{K}$ $\pi_2 = \frac{\mu C_p}{K}$ $\pi_3 = \frac{D^3 \Delta T \beta g}{\nu^2}$ $Nu = f(Pr, Gr)$	
7:	$V = 2 m/s$ $m = ?$ @ $x = 20cm$ $x = 40cm$ $\delta = ?$ Boundary layer thickness : $\rho = \frac{P}{RT}$ $= \frac{1 \times 10^5}{287(27+273)}$ $= 1.16 kg/m^3$	

QNO	ANSWER	MARKS
	$Re = \frac{\rho U x}{\mu}$ $= \frac{1.16 \times 0.4 \times 2}{19.8 \times 10^{-6}}$ $= 46869$ Boundary layr thickness $\delta = \frac{4.64 x}{\sqrt{Re_x}}$ $\delta = \frac{4.64 \times 0.4}{\sqrt{46869}}$ $= 0.00857$ $= 8.57\ mm$ $m_x = \int_0^{\delta} (dy \times 1)\, \mu \cdot s$ $= \int_0^{\delta} \rho u\, dy$ $= \rho U \left\{ \frac{3}{4}\left(\frac{y^2}{\delta}\right) - \frac{1}{8}\left(\frac{y^4}{\delta^3}\right) \right)$ $= \frac{5}{8} \rho U \delta$ $= \frac{5}{8} \times 1.16 \times 2 \times 0.00857$ $= 0.01242\ kg/s.$	

QNO	ANSWER	MARKS
	(ii) Heat transfer Q: $Nu = \frac{hL}{k} = 0.664 \times Re^{1/2} Pr^{1/3}$ $h = \frac{k}{L} = 0.664\, Re^{1/2} Pr^{1/3}$ $= \frac{0.02749}{0.4} \times 0.664 \times (46869)^{1/2} (0.7)^{1/3}$ $= 8.77\ W/m^2 \cdot C$ $Q = hA(T_s - T_\infty)$ $= 8.77 \times (0.4 \times 1)(60-27)$ $= \frac{115.76 \times 3600}{1000}$ $= 416.7\ kJ/h$	

QNO	ANSWER	MARKS
8;	Grashoff number: → Grashoff number is related with natural convective heat transfer. It's defined as the ratio of the product of intertia force and buoyancy force to the square of viscous force. thus $Gr = \frac{(\text{inertia force})(\text{Buoyancy force})}{(\text{viscous force})^2}$ $Gr = (\rho u^2 L^2)\frac{(\rho \beta g \cdot \Delta T L^3)}{\mu u L^3}$ $Gr = \frac{\rho^2 \beta g \Delta T L^3}{\mu^2}$	

QNO	ANSWER	MARKS
9).		



$h_i = 750 W/m^2K$.

$d_i = 12m$

$d_o = 15 mm$

$k = 350 W/mK$.

$m_{oil} = \frac{1200}{3600}$

$= 0.33 kg/s$ $\qquad$ $Cp_{oil} = 2.1 KJ/kgK$.

$m_{w} = \frac{400}{3600}$

$= 0.111 kg/s$

$h_o = 1470 W/m^2K$.

length of heat exchanger = 9m

$Q = m_h C p_h (t_{h1} - t_{h2})$

$= UA \frac{\theta_1 - \theta_2}{\ln(\theta_1/\theta_2)}$

the Effectiveness of counter flow heat exchanger

$$\varepsilon = \frac{1 - \exp[-NTU)(1-R)]}{1 - R \exp[(-NTU)(1-R)]}$$

QNO	ANSWER	MARKS
	effectiveness = 0.695 $\varepsilon = \frac{c_h[t_{h1}-t_{h2}]}{C_{min}[t_{h1}-t_{c1}]} = \frac{c_c[t_{c2}-t_{c1})}{C_{min}(t_{h1}-t_{c1}]}$ $c_h = C_{min}$ $0.696 = \frac{92 - t_{h2}}{90 - 273}$ $t_{h2} = 48.15^\circ C$ $\varepsilon = \frac{c_c(t_{c2}-t_{c1})}{C_{min}(t_{h1}-t_{c1})}$ $= C_{max}\left[\frac{t_{c2}-t_{c1}}{(t_{h1}-t_{c1})}\right]$ $\quad \frac{C_{min}}{C_{max}} = R = 0.5$ $0.696 = 2\left[\frac{t_{c2} - 27}{92-27}\right]$ $t_{c2} = 48.924^\circ C$	

QNO	ANSWER	MARKS
11).	Black body: - For perfectly absorbing body, $\alpha = 1$, $\rho = 0$, $\tau = 0$, such body is called a 'black body'. In practice, a perfect black body ($\alpha = 1$) does not exist. However it's concept is very important. grey body: - if the radiative properties, α, ρ, τ of a body are assumed to be uniform over the entire wave length spectrum, the such a body is called gray body. A gray body is also defined as one whose absorptivity of a surface does vary with temperature and wave length of the incident radiation.	

QNO	ANSWER	MARKS
'b'	Kirchhoff's law: → The law states that at any temperatures the ratio of total emissive power E to the total absorptivity α is a constant for all substances which are in thermal equilibrium with their environment. → Let us consider a large radiating body of surface are A which encloses a small body(1) of surface area A_1. → Let the energy fall on the unit surface of the body at the rate E_b. of this energy, generally, a fraction α_1 will be absorbed by the small body.	