Ref. No. PE/T222/2017

B. POWER 2^{ND} YR. 2^{ND} SEM. EXAMINATION, 2017

SUBJECT: ***HEAT TRANSFER***

Time: Three Hours **(Full Marks 100)**

Answer Question number 1, and any *FOUR* from the rest

Assume the following properties of air and water unless otherwise specified:

AIR: $\rho = 1.16$ kg m^{-3}, $\nu = 1.86\times10^{-5}$ m^2 s^{-1}, $C_p = 1.014$ kJ kg^{-1} K^{-1}, $Pr=0.7$

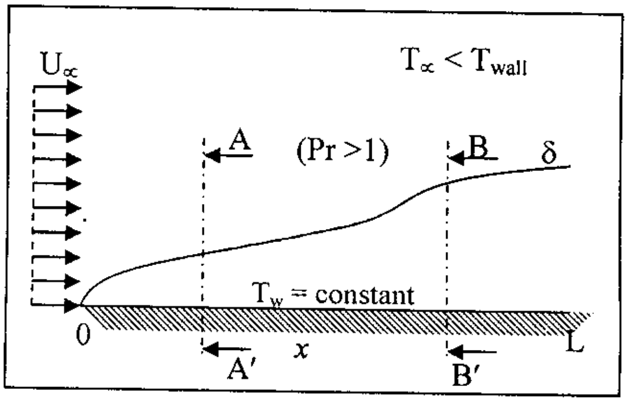
WATER: $\rho = 1000$ kg m^{-3}, $\nu = 1.0\times10^{-6}$ m^2 s^{-1}, $C_p = 4.186$ kJ kg^{-1} K^{-1}, $Pr=7.0$

A few useful heat transfer correlations are provided in Table 1 (last page)

1. Answer Any Four

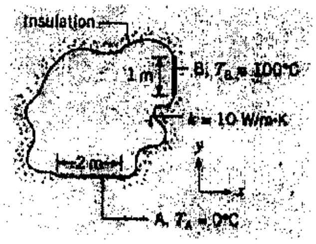
i. What do you mean by *Thermally Fully Developed* (TFD) flow in a pipe? For turbulent flow, what is the L/D ratio beyond which the TFD persists in case of turbulent flow? **5**

ii. From the following sketch, draw a neat sketch of the thermal boundary layer and the $h(x)$ and $\bar{h}(x)$ profiles. Also draw the temperature and velocity profile across the section AA′ and BB′. **5**



iii. A copper sphere of diameter D is hung in a quiescent air in zero gravity condition. Estimate the Nusselts number without the help of Table 1. Neglect radiation. **5**

iv. In the two-dimensional body illustrated in the figure, the temperature gradient at A is found to be $\partial T/\partial y$ = +30 K/m. What are the $\partial T/\partial x$ and $\partial T/\partial y$ at surface B? **5**



v. What do you mean by critical radius of insulation? Deduce the expression for critical radius of insulation for a cylindrical geometry **5**

vi. Velocity and temperature profiles for laminar flow in a tube of radius R = 10 mm has the forms: $u(r) = 0.5$ m/s and $T(r) = 350 + 80(r/R)^2 - 24(r/R)^4$ K, respectively. Determine the corresponding value of the bulk mean temperature and Nu. **5**

2. In a boiler furnace, the hot flue gas (consider thermophysical properties are same as those of air), flowing out of the furnace region at a mean velocity of 10 m/s, temperature is measured by an R-type thermocouple inserted in the furnace space. What is the actual gas temperature if the thermocouple reads 1000 K? The bead of the thermocouple has a diameter of 800 micron, and the bead surface emissivity is 0.9. Consider the furnace walls to be blackbody at 700 K. **20**

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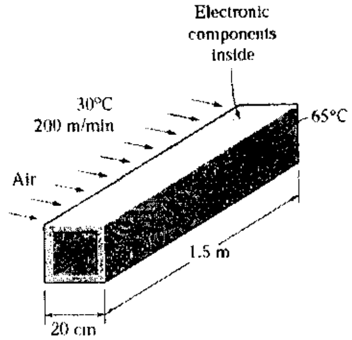
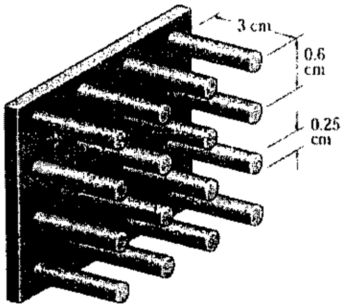
3. A hollow cylinder with inner radius of a and outer radius of b is heated at the inner surface at a rate of q_0 W/m^2 and it dissipates heat by convection from the outer surface into a fluid at temperature T_∞ with a heat transfer coefficient h. There is no energy generation, and the thermal conductivity of the solid is assumed to be constant. Develop and expression for the determination of the temperatures T_1 and T_2 of the inner and outer surfaces of the cylinder. Also, calculate the temperatures T_1 and T_2 for a= 3 cm, b= 5 cm, h = 400 W/m^{2}K, T_∞=100 °C, k = 15 W/mK, and q_0= 10^5 W/m^2. **20**

4. The components of an electronic system are located in a 1.5-m-long horizontal duct whose cross section is 20 cm × 20 cm. The components in the duct are cooled by air at 30°C flowing over the duct with a velocity of 200 m/min. If the surface temperature of the duct is not to exceed 65°C, determine the total power rating of the electronic devices that can be mounted into the duct. For cross flow over a cylinder or rectangular parallelepiped, the Nu correlation is:

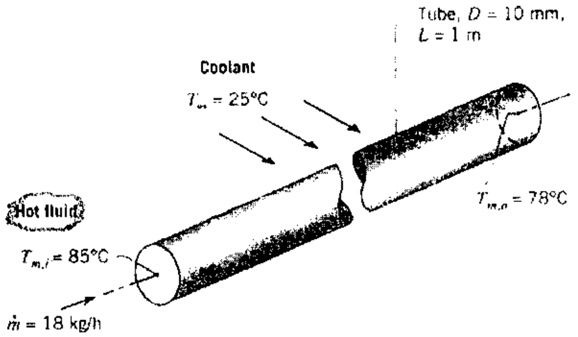
$$\overline{Nu_D} = 0.3 + \frac{0.62\,Re_D^{1/2}\,Pr^{1/3}}{\left[1+(0.4/Pr)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re_D}{282000}\right)^{5/8}\right]^{4/5}.$$ **20**



5. A hot surface at 100 °C is to be cooled by attaching an array of 17 cm-long, 0.25-cm-diameter aluminum pin fins (k = 237 W/m K) to it, with a center-to-center distance of 0.6 cm. The temperature of the surrounding medium is 30 °C, and the heat transfer coefficient on the surfaces is 35 W/m^2 K. Determine the rate of heat transfer from the surface for a 1-m × 1-m section of the plate. Also determine the overall effectiveness of the finned surface. **20**



6. A hot fluid passes through a thin-walled tube of 10 mm diameter and 1 m length, and a coolant at T_∞= 25°C is in cross flow over the tube (see Fig. below). When the flow rate through the tube is 18 kg/h and the inlet and outlet bulk mean temperatures are $T_{m,i}$ = 85 °C and $T_{m,o}$ = 78 °C, respectively. Assuming hydrodynamic and thermally fully developed flow within the tube, determine the heat transfer coefficient outside the tube. The thermophysical properties of the hot fluid are ρ= 1079 kg/m^3, c_p = 2637 J/kgK, μ = 0.0034 N.s/m^2, and k = 0.261 W/mK. **20**



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7. Water (c_{pw}=4.18 kJ/(kg.K) flowing at a rate of 0.667 kg/s enters a countercurrent, double-pipe heat exchanger at 308K and is heated by an oil stream entering at 383K at a rate of 2.85 kg/s (c_{po}=1.89 kJ/kg.K). The overall heat transfer coefficient of the heat exchanger is 300 W/(m^2.K) and the heat transfer area in the exchanger is 15 m^2. Calculate the heat-transfer rate and the exit fluid temperatures. **20**

8. An electrically heated vertical plate 0.3 m high and 1 m wide is maintained at a uniform temperature of 124 °C in quiescent atmospheric air of 30 °C in a blackbody enclosure that is also maintained at 30 °C. The plate has an emissivity of 0.9. Calculate the rate of heat loss from the plate due to radiation and free convection, if the plate loses heat from both sides. **20**

Table 1: Heat transfer correlations

Nu Correlations (Geometry)	**Condition** Flow, Temp.	Property
$Nu_x = 0.332\, Re_x^{1/2}\, Pr^{1/3}$ (Flat Plate)	Laminar, forced convection, T_w	$0.6 \le Pr \le 50$
$Nu_x = 0.75 Re_x^{1/2} Pr^{1/2}$ (Flat Plate)	Laminar, forced convection q''	$Pr << 1$
$Nu_x = 0.0296\, Re_x^{0.8}\, Pr^{1/3}$ (Flat Plate)	Turbulent, forced convection $5.0\times10^5 \le Re \le 10^8$, T_w	$0.6 \le Pr \le 60$
$\overline{Nu_D} = 0.3 + \frac{0.62\, Re_D^{1/2}\, Pr^{1/3}}{\left[1+(0.4/Pr)^{2/3}\right]^{1/4}}\left[1+\left(\frac{Re_D}{282000}\right)^{5/8}\right]^{4/5}$ (Cross flow over Cylinder)	All $Re_D.Pr > 0.2$	
$\overline{Nu_D} = 2 + (0.4 Re_D^{0.5} + 0.06 Re_D^{2/3}) Pr^{0.4} (\mu/\mu_s)^{0.25}$ (Cross flow over Sphere)	$3.5 < Re_D < 7.6\times10^4$	$0.71 < Pr < 380$, $1 < \mu/\mu_s < 3.2$*
$\overline{Nu_L} = \left\{0.825 + \frac{0.387\, Ra_L^{1/6}}{\left[1+(0.492/Pr)^{9/16}\right]^{8/27}}\right\}^2$ (flat plate)	Free convection for all Ra_L	
$\overline{Nu_D} = 2 + 0.6\, Re_D^{1/2}\, Pr^{1/3}$ D	Falling droplet	

* Fluid properties are evaluated at T_∞

$$\varepsilon_{PARALLEL} = \frac{1-exp\left[-NTU(1+C_r)\right]}{1+C_r}$$

$$\varepsilon_{COUNTER} = \frac{1-exp\left[-NTU(1+C_r)\right]}{1-C_r\, exp\left[-NTU(1-C_r)\right]} \quad (C_r < 1)$$

$$= \frac{NTU}{1+NTU} \qquad C_r = 1$$