ELIZADE UNIVERSITY, ILARA-MOKIN, ONDO STATE, NIGERIA

DEPARTMENT OF MECHANICAL ENGINEERING

FIRST SEMESTER EXAMINATIONS

2018/2019 ACADEMIC SESSION

HOD'S SIGNATURE

COURSE: MEE 409 – Heat Transfer II (3 Units)

CLASS: 400 Level Mechanical Engineering

TIME ALLOWED: 3 Hours

INSTRUCTIONS: Answer any **FIVE** questions

Date: March, 2019

Question 1 (Fundamentals of Heat Transfer)

a. (i) What is the basic requirement for heat transfer (ii) List any four (4) important applications of heat transfer **[5 Marks]**

b. The modes of heat transfer are based on some laws, classify and list the laws under each. **[3 Marks]**

c. Differentiate between conduction and convection heat transfer in terms of their heat transfer mechanisms. **[2 Marks]**

d. The wall of an industrial furnace is constructed from 0.15-m-thick fireclay brick having a thermal conductivity of 1.7 W/m.K. Measurements made during steady state operation reveal temperatures of 1400 and 1150 K at the inner and outer surfaces, respectively. What is the rate of heat loss through a wall that is 0.5 m by 1.2 m on a side? **[2 Marks]**

Question 2 (Heat Transfer by Convection)

a. Differentiate between the following:
(i) Forced and Natural Convection (ii) External and Internal convection **[6 Marks]**

b. Why is convective heat transfer coefficient usually higher in Forced than Natural convection? **[2 Marks]**

c. An electric resistance heater is embedded in a long cylinder of diameter 30 mm. When water with a temperature of 25^0C and velocity of 1 m/s flows crosswise over the cylinder, the power per unit length required to maintain the surface at a uniform temperature of 90^0C is 28 kW/m. When air, also at 25^0C, but with a velocity of 10 m/s is flowing, the power per unit length required to maintain the same surface temperature is 400 W/m. Calculate and compare the convection coefficients for the flows of water and air. **[4 Marks]**

Question 3 (Convection-Pattern of Flow and Boundary Layer)

a. Briefly explain the classifications of turbulent boundary layers **[3 Marks]**

b. Differentiate between the following:

(i) Viscous and inviscid flow (ii) Compressible and Incompressible flow (iii) Steady and Transient flow (iv) No-slip and No-temperature-jump condition [6 Marks]

c. A tube 45 mm diameter and 3.2 m long is used to convey water flowing at a velocity of 0.78 m/s. If the mean water temperature is 50^0C, determine the heat transfer coefficient and the transfer rate when the wall is isothermal at 70^0C. **For water at 50^0C, take k=0.644 W/m.K, υ= 0.554×10^{-6} m^2/s and prandtl number, Pr =3.55.** Assume Dittus and Boelter, Nusselt number (Nu) = $0.023Re^{0.8}Pr^{0.4}$. [3 Marks]

Question 4 (Convection Differential Equations)

a. What is the difference between Couette and Poiseuille flow? [2 Marks]

b. Consider an incompressible, steady state two-dimensional Couette flow for which the moving plate is maintained at a temperature (T_L) and speed (U) of 32^0C and 12 m/s, respectively. The temperature of the stationary plate (T_0) which is kept at a distance L of 3 mm from the moving plate is 8^0C. If the fluid is engine oil, determine:

  i. The appropriate form of continuity equation
  ii. The velocity distribution between the plate
  iii. The temperature distribution between the plates
  iv. The surface heat flux to each of the plates
  v. The maximum temperature of the engine oil. Neglect the body force and internal energy generation. [10 Marks]

Hint:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}=0$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial x}+\upsilon\left[\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right]+F_x$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}+w\frac{\partial T}{\partial z}=\frac{k}{\rho c_p}\left[\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}\right]+\frac{1}{\rho c_p}(\phi+q^1)$$

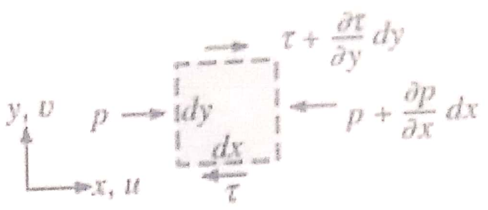
$$\phi=\mu\left(2\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2+\left(\frac{\partial w}{\partial z}\right)^2\right]+\left(\frac{\partial v}{\partial x}+\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial w}{\partial y}+\frac{\partial v}{\partial z}\right)^2+\left(\frac{\partial u}{\partial z}+\frac{\partial w}{\partial x}\right)^2\right)$$

Properties of liquids

Temp. T, °C	Density ρ, kg/m^3	Specific Heat c_p, J/kg · K	Thermal Conductivity k, W/m · K	Thermal Diffusivity α, m^2/s	Dynamic Viscosity μ, kg/m · s	Kinematic Viscosity ν, m^2/s	Prandtl Number Pr	Volume Expansion Coeff. β, 1/K
				Engine Oil (unused)				
0	899.0	1797	0.1469	9.097×10^{-8}	3.814	4.242×10^{-3}	46,636	0.00070
20	888.1	1881	0.1450	8.680×10^{-8}	0.8374	9.429×10^{-4}	10,863	0.00070
40	876.0	1964	0.1444	8.391×10^{-8}	0.2177	2.485×10^{-4}	2,962	0.00070
60	863.9	2048	0.1404	7.934×10^{-8}	0.07399	8.565×10^{-5}	1,080	0.00070
80	852.0	2132	0.1380	7.599×10^{-8}	0.03232	3.794×10^{-5}	499.3	0.00070
100	840.0	2220	0.1367	7.330×10^{-8}	0.01718	2.046×10^{-5}	279.1	0.00070
120	828.9	2308	0.1347	7.042×10^{-8}	0.01029	1.241×10^{-5}	176.3	0.00070
140	816.8	2395	0.1330	6.798×10^{-8}	0.006558	8.029×10^{-6}	118.1	0.00070
150	810.3	2441	0.1327	6.708×10^{-8}	0.005344	6.595×10^{-6}	98.31	0.00070

Question 5

a. Consider the control volume shown for the special case of steady-state conditions with v = 0, $T=T(y)$, and ρ = const. (i) Derive the x-momentum equation and simplify it as much as possible. (ii) Prove that $u = u(y)$ if v = 0 everywhere. [8 Marks]



b. The heat transfer coefficient h(W/m^{2}K) in forced convection is influenced by the tube diameter D(m), fluid velocity u(m/s), and fluid properties such as density ρ (kg/m^3), dynamic viscosity μ(Ns/m^2), thermal conductivity k (W/mK) and specific heat c_p (J/kgK). Find the functional expression for forced convection heat transfer between a fluid through a tube and its wall using either **Rayleigh** or **Buckingham's Pi approach**. [4 Marks]

Question 6 (Heat Exchangers)

a. What are heat exchangers? [2 Marks]
b. Briefly explain the mechanisms of heat exchangers [3 Marks]
c. List the methods required in the analysis of heat exchangers [2 Marks]
d. A counter-flow double-pipe heat exchanger is to heat water from 20°C to 80°C at a rate of 1.2 kg/s. The heating is to be accomplished by geothermal water available at 160°C at a mass flow rate of 2 kg/s. The inner tube is thin-walled and has a diameter of 1.5 cm. If the overall heat transfer coefficient of the heat exchanger is 640 W/m^2 · °C, determine the length of the heat exchanger required to achieve the desired heating. Take the specific heats of water and geothermal fluid to be 4.18 and 4.31 kJ/kg·°C, respectively. **[5 Marks]**

Hint: $\Delta T_{lm} = \frac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1/\Delta T_2)}$; $\dot{Q} = U A_s \Delta T_{lm}$

Question 7 (Radiation)

a. Define the following? (i) Radiation (ii) Blackbody [4 Marks]
b. State Planck's Law [2 Marks]
c. Consider a 20-cm-diameter spherical ball shown in **fig. Q6(c)** at 800 K suspended in air as shown. Assuming the ball closely approximates a blackbody, determine: *(a) the total blackbody emissive power, (b) the total amount of radiation* emitted by the ball in 5 min, and *(c) the spectral blackbody emissive power at* a wavelength of 3 μm. [6 Marks]