UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: December 2018

Module Number: ME8301 **Module Name: Heat Transfer**

[Three Hours]

[Answer **all questions**, each question carries **10** marks]

Note: Clearly state any assumptionsmade in answering the questions.

Q1. a) In the analysis of heat conduction through multilayer solids, we assumed "perfect contact" at the interface of two layers. However,in reality, even flat surfaces that appear smooth to the eye turn out to be rather rough when examined under a microscope. Briefly explain the effect on heat transfer of such a microscopically rough contact surface.

[1.0 Mark]

b) What is the physical significance of the Biot number? Is the Biot number more likely to be larger for highly conducting solids or poorly conducting ones?

[1.0 Mark]

c) What is the physical significance of the Reynolds number? How is it defined for external flow over a plate of length *L*?

[1.0 Mark]

d) A 5mlong section of an air heating system of a house passes through an unheated space in the basement. The cross section of the rectangular duct of the heating system is 20 cm x 25 cm. Hot air enters the duct at 100 kPa and 60°C at an average velocity of 5 m/s. The temperature of the air in the duct drops to 54°C as a result of heat loss to the cool space in the basement. Determine the rate of heat loss from the air in the duct to the basement under steady conditions. Also, determine the cost of this heat loss per hour if the house is heated by a natural gas furnace that has an efficiency of 80 percent, and the cost of the natural gas is Rs. 105/therm (1 therm = 105,500 kJ). Take the specific heat of air at the average temperature of 57 °C as 1.007 kJ/kg. °C, and the specific gas constant as 0.287 kPa. m^3/kg. K.

[5.0 Marks]

e) The resistance wire of a 1200 W hair dryer is 80 cm long and has a diameter of 0.3 cm. Determine the rate of heat generation in the wire per unit volume, and the heat flux on the outer surface of the wire as a result of this heat generation.

[2.0Marks]

Q2. a) On a hot summer day, a student turns his fan on when he leaves his room in the morning. When he returns in the evening, will his room be warmer or cooler than the neighboring rooms? Briefly explain your answer. Assume all the doors and windows are kept closed.

[1.0 Mark]

b) Consider a hot baked potato. Will the potato cool faster or slower when we blow the warm air coming from our lungs on it instead of letting it cool naturally in the cooler air in the room? Briefly explain the answer.

[1.0 Mark]

c) The forming section of a plastics plant puts out a continuous plasticsheet that is 4 ft wide and 0.04 in thick at a velocity of 30 ft/min. The temperature of the plastic sheet is 200 °F when it is exposed to the surrounding air, and a 2ftlong section of the plastic sheet is subjected to air flow at 80 °F at a velocity of 10 ft/s on both sides along its surfaces normal to the direction of motion of the sheet.

i) Determine the rate of heat transfer from the plastic sheet to air by forced convection in Btu/h.

ii) Calculate the temperature of the plastic sheet at the end of the cooling section.

Take the density and specific heat of the plastic sheet as 75 lbm/ft^3 and 0.4 Btu/lbm.°F, respectively. The Prandtl number, thermal conductivity, and kinematic viscosity of air at the film temperature of 140 °F and 1 atm are 0.7202, 0.01623 Btu/h. ft. °F, and 0.204 x 10^{-3} ft^2/s, respectively.

Note:

The Nusselt number of air for a flat plate is given to be,

$$Nu = 0.664 Re_L^{0.5} Pr^{1/3}; \quad for\ laminar\ flow$$

and

$$Nu = 0.037\ Re_L^{0.8} Pr^{1/3}; \quad for\ turbulet\ flow.$$

[8.0 Marks]

Q3. a) Define the terms'emissivity' and 'absorptivity'. When are these two properties equal to each other?

[1.0 Mark]

b) Consider a window glass consisting of two 4 mm thick glass sheets pressed tightly against each other. Compare the heat transfer rate through this window with that of one consisting of a single 8 mm thick glass sheet under identical conditions.

[1.5 Marks]

c) Consider two identical 4 kg pieces of roast beef. The first piece is baked as a whole, while the second is baked after being cut into two equal pieces in the same oven. Will there be any difference between the cooking times of the whole and cut roasts? Briefly explain your answer.

[1.5 Marks]

d) Four identical power transistors with aluminum casing are attached on one side of a 1 cm thick 20 cm x 20 cm square copper plate (thermal conductivity is 386 W/m. K) by screws that exert an average pressure of 6 MPa. The base area of each transistor is 8 cm^2, and each transistor is placed at the center of a 10 cm x 10 cm quarter section of the plate. The interface roughness is estimated to be about 1.5 μm. All transistors are covered by a thick Plexiglas layer, which is a poor conductor of heat, and thus all the heat generated at the junction of the transistor must be dissipated to the ambient at 20 °C through the back surface of the copper plate. The combined convection/ radiation heat transfer coefficient at the back surface can be taken to be 25 W/m². K. If the temperature of the transistor is not to exceed 70 °C, determine the maximum power each transistor can dissipate safely, and the temperature jump at the case-plate interface. Take contact conductance as 42,000 W/m².K which corresponds to copper-aluminum interface for the case of 1.17-1.4μm roughness and 6 MPa pressure.

[6.0 Marks]

Q4. a) Briefly explain the following terms.

i) Boiling
ii) Condensation
iii) Evaporation
iv) Flow boiling
v) Pool boiling

[2.5 Marks]

b) Water is boiled at atmospheric pressure by a horizontal polished copper heating element of diameter 5 mm and emissivity 0.05 immersed in water. If the surface temperature of the heating wire is 350 °C, determine the rate of heat transfer from the wire to the water per unit length of the wire.
The properties of water at the saturation temperature of 100 °C are; enthalpy of vaporization is 2257 x 10^3 J/kg and density is 957.9 kg/m³. The properties of vapor at the film temperature of 225 °C are; density is 0.444 kg/m³, specific heat is 1951 J/kg K, viscosity is 1.75 x 10^{-5} kg/m. s, and thermal conductivity is 0.0358 W/m. K. Take Stefan-Boltzmann constant as 5.67 x 10^{-8} W/m². K⁴.

Note:
The heat flux for film boiling on a horizontal cylinder is given to be,

$$\dot{q}_{film} = 0.62 \left[\frac{g k_v^3 \rho_v (\rho_l - \rho_v)\left[h_{fg} + 0.4 c_{pv}(T_s - T_{sat})\right]}{\mu_v D (T_s - T_{sat})}\right]^{\frac{1}{4}} (T_s - T_{sat}).$$

where,
g= gravitational acceleration
ρ_l, ρ_v = densities of the liquid and vapor, respectively
μ_v= viscosity of the vapor
k_v= thermal conductivity of the vapor
T_s = surface temperature of the heating element
T_{sat}= saturation temperature of the fluid
h_{fg}= enthalpy of vaporization
D = diameter of the heating element
c_{pv}= specific heat of the vapor

[7.5 Marks]

Q5. a) How will the performance of a heatexchanger usuallydeteriorate with time as a result offouling?

[1.0 Mark]

b) Briefly explain three types of heat exchangers with theaid of sketches.

[1.5 Marks]

c) 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. The overall heat transfer coefficient of the heat exchanger is 640 W/m². K. Using the effectiveness-NTU method, determine the length of the heat exchanger required to achieve the desired heating. Assume the specific heat of water to be remain constant at 4.18 kJ/kg. K.

Note:

The NTU of the counter-flow heat exchanger is given to be,

$$NTU = \frac{1}{c-1}\ln\left(\frac{\varepsilon - 1}{\varepsilon c - 1}\right).$$

where,

ε = heat transfer effectiveness

c= capacity ratio

[7.5 Marks]