UNIVERSITY OF RUHUNA

Faculty of Engineering

End-Semester 8 Examination in Engineering: November 2017

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

[Three Hours]

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

Note: Clearly state any assumptions you made in answering the questions.

Q1. a) Explain the following terms.

i) Steady heat transfer

ii) Transient heat transfer

iii) One-dimensional heat conduction

iv) Thermal contact resistance

[2.0 Marks]

b) Consider a 1 m high, 1.2 m wide double pane window consisting of two layers of 3 mm thick glass having thermal conductivity of 0.78 W/m K separated by a 10 mm wide stagnant air space (thermal conductivity 0.026 W/m K). Determine the steady rate of heat transfer through this double pane window and the temperature of its inner surface for a day during which the room is maintained at 22 °C while the temperature of the outdoor is -10 °C. The convection heat transfer coefficients (including the radiation effects) of the inner and outer surfaces of the window are 10 and 40 W/m^2 K, respectively.

[4.0 Marks]

c) A 2 mm diameter and 7 m long electric wire is tightly wrapped by a 2 mm thick plastic cover whose thermal conductivity is 0.15 W/m K. Measurements indicate that an electrical current of 15 A passes through the wire and a voltage drop of 10 V exist along the wire. If the insulated wire is exposed to a medium at 28 °C with a heat transfer coefficient of 12 W/m^2 K, determine the temperature at the interface of the wire and the plastic cover in steady operation. Also determine the effect of reducing the thickness of the plastic cover to 1 mm, whether it will increase or decrease the interface temperature.

[4.0Marks]

Q2. a) Compare the effect of following fluid flow conditions on heat transfer mechanism.

i) "Viscous versus Inviscid"

ii) "Compressible versus Incompressible"

iii) "Laminar versus Turbulent"

iv) "Natural versus Forced"

[4.0 Marks]

b) State the physical meanings of the Reynolds number, the Nusselt number, and the Prandtl number.

[1.5 Marks]

c) A stream of fluid at temperature T_∞ flows over an isothermal solid surface with surface temperature T_s.

i) Draw the temperature profile of the thermal boundary layer, when $T_\infty > T_s$.

ii) Define the thermal boundary layer thickness.

[3.0 Marks]

d) Consider a boiled egg on a plate which eventually cools to the surrounding air temperature. Omitting the heat lost due to radiation, briefly explain the physical mechanism of cooling of the boiled egg.

[1.5 Marks]

Q3. a) Define the following radiative properties.

i) Absorptivity

ii) Reflectivity

iii) Transmissivity

[1.5 Marks]

b) There are two large parallel plates at constant temperatures of 450 K and 300 K that are of 1 cm apart. Assuming all plate surfaces to be black (emissivity is 1), determine the rate of heat transfer between the plates per unit surface area of each of the below cases where the gap between the plates have different conditions.

i) Filled with atmospheric air

ii) Evacuated

iii) Filled with urethane insulation

iv) Filled with super insulation

Note: At 375 K, the thermal conductivity of air, urethane insulation, and super insulation are 0.0219, 0.026, and 0.00002 W/m K, respectively.

[6.0 Marks]

c) A 1200 W electric clothes iron is left on the ironing board with its base exposed to the air at 25 °C. The convection heat transfer coefficient between the base surface and the surrounding air is 35 W/m^2 K. If the base has an emissivity of 0.6 and a surface area of 0.03 m^2, determine the surface temperature of the base of the iron.

[2.5 Marks]

Q4. a) Sketch the typical boiling curve for water and indicate the four boiling regimes.

[2.0 Marks]

b) Briefly explain the terms "Pool boiling" and "Flow boiling".

[1.0 Mark]

c) The condenser of a steam power plant operates at a temperature of 40 °C and pressure of 7.38 kPa. Steam at this pressure condenses on the outer surfaces of horizontal tubes through which cooling water circulates. The outer diameter of the pipes is 3 cm, and the outer surfaces of the tubes are maintained at 30 °C.

Determine the rate of heat transfer to the cooling water circulating in the tubes and the rate of condensation of steam per unit length of a horizontal tube. The properties of water at the saturation temperature of 40 °C corresponding to 7.38 kPa are; enthalpy of vaporization is 2407×10^3 J/kg and density of the vapor is 0.05 kg/m^3. The properties of liquid water at the film temperature of 35 °C are; density is 994 kg/m^3, specific heat is 4178 J/kg K, viscosity is 0.72×10^{-3} kg/m s, and thermal conductivity is 0.623 W/m K.

Note:
The modified latent heat of vaporization of water is given by,

$$h_{fg}^* = h_{fg} + 0.68c_{pl}(T_{sat} - T_s)$$

The heat transfer coefficient for the condensation in a single horizontal tube is given by,

$$h_{horiz} = 0.729\left[\frac{g\rho_l(\rho_l - \rho_v)h_{fg}^* k_l^3}{\mu_l(T_{sat} - T_s)D}\right]^{1/4}$$

where,
g = gravitational acceleration
ρ_l, ρ_v = densities of the liquid and vapor states of the fluid, respectively
μ_l = viscosity of the liquid
k_l = thermal conductivity of the liquid
T_s = surface temperature of the plate
T_{sat} = saturation temperature of the condensing fluid
h_{fg} = enthalpy of vaporization
D = diameter of the pipe
c_{pl} = specific heat of the liquid

[7.0 Marks]

Q5. a) Briefly explain the following terms.

i) Types of heat exchangers
ii) Design considerations of a heat exchanger
iii) Fouling of heat exchangers
iv) Selection of a heat exchanger for a given application

[4.0 Marks]

b) Cold water enters a counter-flow heat exchanger at 15 °C at a flow rate of 9 kg/s, where it is heated by a 75 °C hot water steam that passes through the heat exchanger at a flow rate of 3 kg/s. Assuming the specific heat of water to remain constant at 4.18 kJ/kg K, determine the maximum heat transfer rate and the corresponding outlet temperatures of the cold and hot water streams.

[6.0 Marks]