Ref. No.: Ex/ME(M2)/PE/H/T/415E/2024

B.E. MECHANICAL ENGINEERING FOURTH YEAR FIRST SEMESTER - 2024

BIO-HEAT TRANSFER (HONS.)

Time: Three hours | Full Marks: 100

All parts of the same question must be answered at the same place.
Assume any relevant data if unfurnished.

Q.1

(a) What are the environmental parameters that dictate human comfort? On a temperature versus relative humidity diagram, show the zone of human comfort. Mention any other factor that controls the heat loss from human body to the surrounding environment. How does it affect heat loss from human body?

(b) With the help of a neat sketch, show the circulatory system which carries blood from the heart and back in a human body. Hence, explain with the aid of a diagram, how the variation of blood temperature takes place in the blood vessels during its journey through the circulatory system. **[10+10]**

Q.2

Draw a typical control volume, following Cartesian coordinate system, illustrating the idealised, unsteady, one-dimensional heat transfer in a tissue with metabolic heat generation Q and convective heat transfer due to the passage of blood.

Hence, derive the bio-heat transfer equation governing the temperature distribution in human tissue. State the significance of each term in the final equation and state your assumptions.

Write the different initial and boundary conditions required for solution of the bio-heat transfer equation. When does the convective boundary condition approach the condition of specified temperature at the boundary? **[20]**

Q.3

To estimate the natural thermal insulation provided by fur, for animals living in cold climatic condition, consider the body to be cylindrical in shape with the bare body radius R_i and the thickness of the fur as ΔR. The thermal conductivity of the fur is k. Hence find the conductive resistance provided by fur, per unit surface area of the body of the animal. Simplify, if possible, the expression for thermal resistance for large animals where $\Delta R/R_i << 1$.

[Turn over

Make a table of thermal resistance per unit surface area with $\Delta R/R_i$ for a small animal with R_i = 1.5 cm and a large animal with R_i = 35 cm. Consider three different fur thicknesses, ΔR = 1 cm, 2 cm and 3 cm. Thermal conductivity of fur is 0.05 W/(m.K). Plot the variations for small and large animals and comment on them. **[20]**

Q.4

(a) What is "wind chill"? Explain, with the help of a sketch of thermal boundary layers for stagnant air and high speed wind flow. Develop a relationship between wind chill and the ambient air temperature, skin temperature and convection coefficient.

(b) Calculate the energy dissipated at steady state per unit length at the surface of a working cylindrical muscle. The heat generated in the muscle is 5.8 kW/m^3, the thermal conductivity of the muscle is 0.419 W/m·K and the radius of the muscle is 1 cm. Starting from appropriate governing equation and boundary conditions, solve for the temperature variation in the muscle and calculate the maximum temperature rise ($T_{max} - T_{surface}$) in the muscle. **[10+10]**

Q.5

(a) How does the enthalpy of water change with temperature, considering the latent heats involved for phase change from ice to water and from water to steam?

(b) Derive an expression for freezing point depression for a dilute solution in terms of cryoscopic constant and molality of the solute.

(c) Consider symmetric freezing of a slab of pure liquid (width=2L). The entire liquid is initially at its freezing point T_m. The ambient temperature is T_a ($T_a < T_m$) and the convection coefficient is h. Stating appropriate assumptions, find an expression for the time required for the entire amount of liquid to freeze, in terms of pertinent parameters. The thermal conductivity of the frozen part is k, and the latent heat of fusion per unit mass is ΔH_f. **[5+7+8]**

Q.6

What are the components of a thermoregulatory system? Discuss how humans maintain core body temperature through thermoregulatory system during different biological activities, mental states and varying weather conditions. Show, how rate of heat production and rate of heat loss are regulated under varying atmospheric temperature, highlighting regions of hypothermia and hyperthermia. Show also the rate of body heat loss in terms of conductive, convective, radiative components and total loss. **[20]**