Ref. No.: Ex/ME(M1)/PE/B/T/424F/2022

B.E. MECHANICAL ENGINEERING FOURTH YEAR SECOND SEMESTER, 2022

BIO-HEAT TRANSFER

Time: Four hours Full Marks: 70

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

Q.1

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? How can the building surface condition affect human comfort? **[10]**

Q.2

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]**

Q.3

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.4

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 $\Delta R/R_i << 1$.

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 = 30 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.5

(a) With the sketch of thermal boundary layers for stagnant air and moving air, explain the term "wind chill" and find a relationship between wind chill and the ambient air temperature, skin temperature and convection coefficient (velocity of air).

(b) Consider convective heat loss from an individual walking on a treadmill. For simplicity, assume that the subject is not clothed, and that the mean skin temperature increases by 1^0C during exercise. Compare the heat loss due to convection when the subject is seated to the heat loss when the subject is walking on the treadmill at 6.4 kilometers per hour. The surface area of the body is 1.7 m^2, the ambient air temperature is 20^0C, and the skin temperature at rest is 33^0C. The heat transfer coefficient at rest is 2.1 W/m^2·K and the heat transfer coefficient walking on a treadmill is $6.5(u)^{0.36}$ W/m^2·K, where u is the speed of treadmill in m/s. **[10+10]**

Q.6

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

(b) Consider symmetric (both surfaces at T_∞) freezing of a slab of pure liquid (width=2L). The entire liquid is initially at its freezing point T_m. 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. **[10+10]**