The Islamic University
Collage of Medical Technology
Anesthesiology Techniques Department

Freshman Class

Medical Physics

Lecture (4)

Methods of heat transferring

By

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Methods of heat transferring: Heat can be transferred in three different modes: conduction, convection, an radiation

4.1 Conduction heat transfer : The transfer of energy from the more energetic particles of a substance to the adjacent less energetic ones as a result of interactions between the particles. In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion. In solids, it is due to the vibrations of the molecules in a lattice and the energy transport by free electrons.

4.1.1 Rate of heat conduction : The rate of heat conduction through a plane layer is proportional to the temperature difference across the layer and the heat transfer area, but is inversely proportional to the thickness of the layer.

$$\textbf{Rate of heat conduction } \alpha \ \frac{(\textbf{area})(\textbf{temperature difference})}{\textbf{thickness}}$$

$$\dot{Q} = \frac{Q}{t} = kA\,\frac{T_2 - T_1}{\Delta x} \qquad (2.4)$$

Where:

Q : the net heat (energy) transfer

t: is the time taken

Δx : is the thickness of the material conducting heat (distance between hot and cold sides)

ΔT = $T_2 - T_1$: is the difference in temperature between the cold and hot sides

k : is the thermal conductivity

A: is the surface area of the surface emitting heat.

Example: what rate is heat loss through a 1.19 m by 1.65 m glass window pane that is 20.3 cm thick when the inside temperature is 20.3°C and the outside temperature is 1.4° C ?

Solution:

A=1.19 m×1.65 m , Δx =20.3 cm T_1=20.3°C , T_2=1.4°C , the thermal conductivity of the glass k=0.96 W/m°C

$$\dot{Q} = kA\,\frac{T_2 - T_1}{\Delta x}$$

$\dot{Q}$ =0.96 W/m°C×1.19 m×1.65 m×(1.4°C−20.3°C)/ 20.3 cm

$\dot{Q}$ =0.96 W/m°C×1.19 m×1.65 m×(1.4°C−20.3°C)/ 20.3×10^{-2} m

$\dot{Q}$ = -175.49 W

Example: One of the possible mechanisms of heat transfer in human body is conduction through body fat. Suppose that heat travels through 0.03 m of fat in reaching the skin, which has a total surface area of 1.7 m^2 and a temperature of 34°C. Find the amount of heat that reaches the skin in half an hour, if the temperature at the body, interior is maintained at the normal value 37° C ? Thermal conductivity of body fat is k = 0.2 J/s.m.°C.

Solution:

$$\dot{Q} = \frac{Q}{t} = kA\,\frac{T_2 - T_1}{\Delta x}$$

$$Q = kA\,t\,\frac{T_2 - T_1}{\Delta x}$$

Q = 0.2 ×1.7 ×(37 −34)x 1800/ 0.03

Q = 61 kJ

4.2 Convection heat transfer

Convection: The mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion, The faster the fluid motion, the greater the convection heat transfer. In the absence of any bulk fluid motion, heat transfer between a solid surface and the adjacent fluid is by pure conduction.

4.2.1 Two types of convective heat transfer may be distinguished:

- **Free or natural convection:** the fluid motion is caused by buoyancy forces that are induced by density differences due to the variation of the temperature in the fluid.
- **Forced convection:** when a fluid is forced to flow over the surface by an internal source such as fans, by stirring, and pumps, creating an artificially induced convection current.

4.3 Radiation heat transfer: thermal radiation process by which energy, in the form of electromagnetic radiation, is emitted by a heated surface in all directions and travels directly to its point of absorption at the speed of light; thermal radiation does not require an intervening medium to carry it.

As radiation strikes an object, some energy may be absorbed, pass through or reflect offof the surface. **A black body** is an ideal object that does not reflect radiation or let energypass through. It absorbs all incident radiation and re-emits thermal energy at a rate dependent on the black body, not the incident radiation that heats it. A popular model of a black body is that of a cavity with a hole through which radiation enters. The walls of the cavity perfectly absorb the radiation and the surface of the body emits thermal energy. The rate that the body emits energy approaches a theoretical maximum, given by the **Stefan-Boltzmann law**. Stefan-Boltzmann law applies only to black bodies. It states the directly proportional relationship between the energy emitted from a unit area in one second, to the the fourth power of the temperature.

$$J^{*} = \sigma T^{4} \qquad (2.5)$$

The constant of proportionality σ, called the Stefan–Boltzmann constant, is derived from other known physical constants. the value of the constant is

$$\sigma = \frac{2\,\pi^5\,k^4}{15c^2h^3} = 5.670347\ x10^{-8}\ Wm^{-2}\ K^{-4} \qquad (2.6)$$

Example: when the person is radiating at 32°C, determine how much energy she looses each second , given that Stefan–Boltzmann constant 5.6 x 10^{-8} W. m^{-2}.K^{-4}

Solution:

$$J^{*} = \sigma T^{4}$$

$$J^{*} = 5.6 \times 10^{-8}\,(305)^{4}$$

$$J^{*} = 562 Wm^{-2}$$

4.5 Problems

1- Calculate the rate of heat conduction (in W) through house walls that are 11.0 cm thick and that have an average thermal conductivity twice that of glass wool. Assume there are no windows or doors. The surface area of the walls is 125 m^2 and their inside surface is at 20.0°C, while their outside surface is at 5.0°C.

2- A 10 cm thick block of ice with a temperature of 0 °C lies on the upper surface of 2400 cm2 slab of stone. The slab is steam-exposed on the lower surface at a temperature of 100 °C. Find the heat conductivity of stone if 4000 g of ice is melted in one hour given that the latent heat of fusion of ice is 80 cal ⁄ gm.

3- A metal rod 0.4 m long & 0.04 m in diameter has one end at 373 K & another end at 273 K. Calculate the total amount of heat conducted in 1 minute. (Given K = 385 J ⁄ m s °C)

4- An aluminium rod and a copper rod of equal length 2.0 m and cross-sectional area 2 cm2 are welded together in parallel. One end is kept at a temperature of 10 °C and the other at 30 °C . Calculate the amount of heat taken out per second from the hot end . (Thermal conductivity of aluminium is 200 W ⁄ m °C and of copper is 390 W ⁄ m °C).

5- he average rate at which energy is conducted outward through the ground surface at a place is 50.0 mW ⁄ m^2, and the average thermal conductivity of the near-surface rocks is 2.00 W ⁄ m K. Assuming surface temperature of 20.0 °C, find the temperature at a depth of 25.0 km.

6- The filament of a light bulb is cylindrical with length *l* = 20 mm and radius r = 0.05 mm. The filament is maintained at a temperature T = 5000 K by an electric current. The filament behaves approximately as a black body, emitting radiation isotropically. What is the total power radiated by the filament?

7- At 20°C, a piece of metal has a density of 60g. When immersed in a steam current at 100°C, 0.5g of the steam condenses on it. Provided that the latent heat of steam is 540 cal/g, calculate the specific heat of the metal.

8- Calculate the amount of heat added to 1 gram gold to change phase from solid to liquid. The heat of fusion for gold is 64.5 x 10^3 J/kg.

9- alculate the amount of heat released by 1 gram mercury to change phase from liquid to solid. Heat of fusion for mercury is 11.8 x 10^3 J/kg.