PHYS2

Heat Transfer
Radiation - Convection

Heat Transfer

Radiation is a mode of heat transfer in which heat is transferred between bodies by energy propagating electromagnetic waves. Anything whose temperature is above the surrounding will always radiate of significant amount. The Stefan-Boltzmann governs radiation heat transfer.

The Radiant heat exchange between two surfaces can be computed from Stefan-Boltzmann Law

$$Q/t = e\,\sigma\,A\,[\,(T_1)^4 - (T_2)^4\,]$$

Heat Transfer

$$Q/t = e\,\sigma\,A\,[\,(T_1)^4 - (T_2)^4\,]$$

Where:

Q/t = heat transmitted by radiation per unit time (J/s or W)

e = emissivity factor

$e = 1.0$ (blackbody)

$e = 0$ (whitebody)

when $0 < e < 1.0$, consider to be graybody

$$\sigma = 5.67 \times 10^{-8}\,\frac{W}{m^2 - K^4}$$

A = radiating surface area, m^2, in^2, ft^2 etc.

Heat Transfer

T_1 = absolute temperature of surface radiating the heat, K, R

T_2 = absolute temperature of surface receiving the heat, K, R

THE CONCEPT OF A PERFECT BLACK BODY

Perfect black body is a body that absorbs all electromagnetic radiation. It absorbs all wavelength such no reflection occurs. When radiant energy falls on a body, part may be absorbed, part reflected, and the remainder transmitted through the body. In mathematical form;

$$a + r + t = 1$$

Heat Transfer

$$a + r + t = 1$$

Where:

a = absorptivity or the fraction of the total energy absorbed

r = reflectivity or the fraction of the total energy reflected

r = transmitted or the fraction of the total energy transmitted through the body

Planck’s Law

All substances emit radiation, the quantity and quality of which depends upon the absolute temperature and the properties of the material, composing the radiating body.

Heat Transfer

Kirchhoff's Law

For bodies in thermal equilibrium with their environment, the ratio of total emissive power to the absorptivity is constant at any temperature.

Stefan Boltzmann Law

For bodies in thermal equilibrium with their environment, the ratio of total emissive power to the absorptivity is constant at any temperature.

Heat Transfer

Convection is the mechanism of heat transfer whereby heat energy is transmitted by moving fluids.

Dimensionless Group in analysis of heat convection:

Reynolds Number, Re

Is a dimensionless number interpreted as the ratio of the inertial forces to viscous forces in the fluid.

$$\text{Re} = \frac{V\ D\ \rho}{\mu_d}$$

Heat Transfer

Where:

V = velocity, m/s, ft/s

D = diameter, m,ft

ρ = density, kg/m3, lb/ft3

μ_{d} = viscosity, Pa-s

Prandlt Number, Pr

Is the ratio of the diffusion of momentum to the diffusion of heat

Heat Transfer

$$\text{Pr} = \frac{\mu_d \, Cp}{k}$$

Where:

μ_d = dynamic viscosity, Pa-s

Cp = specific heat

k = thermal conductivity

Nusselt Number, Nu

Is the ratio of the temperature gradient at the wall to overall temperature difference.

Heat Transfer

$$\text{Nu} = \frac{h\ D}{k}$$

Where:

$\mathrm{h} = \text{heat transfer coefficient}$

$\mathrm{D} = \text{diameter}$

$\mathrm{k} = \text{thermal conductivity}$

Grashof Number, Gr

Is the ratio of buoyancy of force to the viscous force.

Heat Transfer

$$\text{Gr} = \frac{D^3\ \rho^2\ \beta\ g\ \Delta T}{\mu_{\mathrm{d}}{}^2}$$

Where:

$\mu_{\mathrm{d}} =$ dynamic viscosity, Pa-s

$\beta =$ coefficient of volume expansion

$\rho =$ density

k = thermal conductivity

ΔT = temp diff between the surface and the fluid

g = gravity

Heat Transfer

Convective Heat Transfer with known specific heat:

$$Q = m\ C_p\ \Delta T\text{, Watts}$$

Where:

m = mass flow rate, kg/s, lb/s

C_p = specific heat

ΔT = temperature difference

Surface Convection

$$Q = h_c\ A\ \Delta T\text{, Watts}$$

Heat Transfer

$$Q = h_c A (t_1 - t_2), \text{ Watts}$$

Where:

h_c = surface coefficient associated with convection, W/m^2

A = heat transfer area, m^2

t_1 = hot surface temperature

t_2 = fluid temperature

Sample problem

1. The temperature of the flame in a furnace is 1277ºC and the temperature of its surrounding is 277ºC. Calculate the maximum theoretical quantity of heat energy radiated in kJ per minute per square meter to the surrounding area.

2. The hot combustion gases of a furnace are separated from the ambient air and its surrounding which are 25ºC by a brick wall 0.15m thick. The brick has a thermal conductivity of 1.2 W/m-K and a surface emissivity of 0.8. Under steady state conditions and outer surface temperature of 100ºC is measured. Free convection heat transfer to the air adjoining this surface is characterized by a convection coefficient of 20 W/m^2-K. What is the brick inner surface temperature?

Sample problem

3. Air is flowing at a velocity of 3 m/s perpendicular to a long pipe. The outside diameter of the pipe is 6 cm and temperature at the outside surface of the pipe is maintained at 100ºC. The temperature of the air far from the tube is 30ºC. Air properties are given as follows: thermal conductivity 0.03 W/m-K; kinematic viscosity 18×10^{-6} m^2/s. Using Nusselt number correlation, $Nu = 0.024 \times Re^{0.8}$, calculate the heat rate per unit length from the pipe to air

Sample problem

4. A 200 W heater has a spherical casing of diameter 0.2 m. The heat transfer coefficient for conduction and convection from the casing to the ambient air is obtained from $Nu = 2 + 0.6Re^{0.5} \times Pr^{0.33}$, with $Re = 10^4$ and $Pr = 0.69$. The temperature of the ambient air is 30ºC and the thermal conductivity of air is 0.02 W/m-K.

   a. Determine the heat flux from the surface

   b. Find the surface temperature of the casing

5. A vertical pipe 80 mm diameter and 2m in length is maintained at a constant temperature of 120ºC. the pipe is surrounded by atmospheric air at 30ºC. Find heat loss by natural convection.

Sample problem

5. cont.

Properties of water at 75ºC

$\rho = 1.0145$ kg/m^3

$\nu = 20.55$ x 10-6 m^2/s

$\text{Pr} = 0.693$

k = 30.06 x 10^{-3} W/m-K

***Natural Convection over Surfaces, (HMT, 5th ed)

$\text{Nu} = 0.59(\text{Gr Pr})^{1/4}, \quad 10^5 < \text{Gr Pr} < 10^9$

Nu = 0.10(Gr Pr)$^{1/3}$, $10^9 <$ Gr Pr $< 10^{13}$