Summary

Radiative heat transfer

Radiation happens in an object that has a temperature higher than absolute zero, which is 0K, or -273 ℃. Heat transfer from a body with a high temperature to a body with a lower temperature by radiation is called heat radiation. Thermal radiation dose not require a medium, so the two bodies do not need to have physical contact. Since absolute zero is an idealized physical condition, thermal radiation happens almost in all objects, regardless of the material form of the object, whether it is solid, liquid or gas, basically we can say that everything around us keeps emitting thermal radiation to its surroundings, with the rate of emission increasing with the temperature.

Definitions of Emissivity

The emissivity(ε) of the surface of a material refers to the effectiveness of the surface in emitting energy as thermal radiation, it is mathematically defined as the ratio of the thermal radiation from the surface to the radiation from an ideal black surface at the same temperature; the value varies from 0 to 1. The greater the value of emissivity is, the closer the surface to a blackbody ($\varepsilon = 1$).

The emissivity of a real surface is affected by temperature of the surface as well as the wavelength and the direction of the emitted radiation.

Definitions of absorptivity

Absorptivity(α) of the surface of a material is a measure of the ability of a material to absorb radiation, i.e., its effectiveness in absorbing radiant energy. We use the ratio of the absorbed radiation to the incident radiant power to calculate the value of absorptivity, the value varying from 0 to 1.

Definitions of reflectivity

Reflectance(ρ) of the surface of a material is its effectiveness in reflecting radiant energy. It is the fraction of total energy transmitted by the body, we use the ratio of the reflected radiation to the incident radiant power to calculate the value of absorptivity, the value varying from 0 to 1.

Definitions of reflectivity

A view factor(F), The view factor is the fraction of radiation leaving one surface which is intercepted by a second surface. The intensity of the emitted radiation depends on the view factor of the surface relative to the sky.

It is the degree to which heat carried by radiation can be passed between two surfaces.

Heat exchange between two black surfaces

A black surface will emit a radiation of E_{b1} per unit area per unit time. If the surface is having A_1 unit area, then it will emit $E_{b1}*A_1$ Radiation in unit time. This radiation will go to the other black surface and totally absorb by it but at the same time The 2nd black body will emit its radiation $E_{b2}*A_2$ per second and it will go to 1st body and totally absorbed by it .The whole process happened simultaneously .So the net heat transfer between these surfaces will be the net heat per second (power) gained by any of the two surfaces (obviously same for both surfaces). The net heat transfer is the radiation leaving the entire surface 1 that strikes surface 2 subtracts the radiation leaving the entire surface 2 that strikes surface 1, which is, in formula: $A_1E_{b1}F_{1-2} - A_2E_{b2}F_{2-1}$.

Heat exchange between two grey surfaces

A gray surface will reflect/absorb a given fraction of the thermal radiation a blackbody surface would absorb. More importantly, the graybody/blackbody fraction is independent of radiation wavelength.

For a given grey body surface i, with the area A_i, emitting a radiation of E_{bi} per unit area per unit time. The net heat transfer is the radiation leaving the entire surface i subtracts the radiation incident on the entire surface i, which is, in formula: $A_i(J_i-G_i)$. The radiosity J_i can be calculated by the following formula: $\varepsilon E_{bi}+(1-\varepsilon)G_i$.

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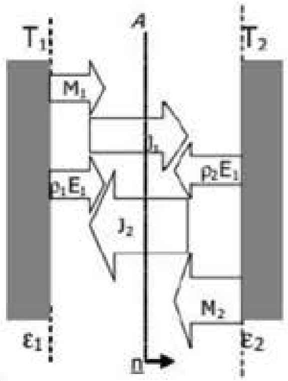
Week 5

Task 2

Find the net radiative heat exchange between the surface 1 and 2 where $A_1 = 1.5m^2, \epsilon_1 = 0.1, \epsilon_2 = 0.1,\ T_1 = 298$ K, $T_2 =$ 308 K, $\sigma = 5.67 * 10^{-8} \frac{W}{m^2 K^4}$.



Solution:

According to the formula,

$$\dot{Q}_{net_{2-1}} = \frac{A\sigma(T_2^4 - T_1^4)}{\frac{1}{\epsilon_2} + \frac{1}{\epsilon_1} - 1}$$

By introducing the values metioned in the question into the formula,

$$\dot{Q}_{net_{2-1}} = \frac{1.5m^2 \times \left(5.67 \times 10^{-8} \frac{W}{m^2 K^4}\right)(308^4 - 298^4)K^4}{\frac{1}{0.1} + \frac{1}{0.1} - 1}$$

$$\approx 4.9823\ W$$

Meanwhile, under situation, based on the following formula

$$F_{2-1} = \frac{1}{\frac{1}{\epsilon_2} + \frac{1}{\epsilon_1} - 1} = \frac{1}{\frac{1}{0.1} + \frac{1}{0.1} - 1} \approx 0.0526$$

Autem, when $F_{1-2} = 0.01$,

$$\dot{Q}_{net_{1-2}} = AF_{1-2}\sigma(T_2^4 - T_1^4)$$

$$= 1.5m^2 \times 0.01 \times \left(5.67 \times 10^{-8} \frac{W}{m^2 K^4}\right)(298^4 - 308^4)K^4$$

$$\approx -0.9466\ W$$

$$\because A_1 = A_2, \quad i.e., \quad \frac{A_1\sigma(T_1^4 - T_2^4)}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} = -\frac{A_2\sigma(T_2^4 - T_1^4)}{\frac{1}{\epsilon_2} + \frac{1}{\epsilon_1} - 1}$$

$$\therefore\ \dot{Q}_{net_{2-1}} = -\dot{Q}_{net_{1-2}} \approx 0.9466\ W$$

By comparing the two values of net heat exchange under different situation, we can see that the value of emessivity would greatly affect the radiative heat exchange between the surfaces.

Radiative resistance

Radiative resistance is a value to measure the energy depleted by loss resistance which is converted to heat radiation; the energy lost by radiation resistance is converted to radio waves.

It can be calculated by this formula:

$$R_i = \frac{1-\varepsilon_i}{A_i \varepsilon_i}$$

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