7.5 Heat exchange between non blackbodies

Evaluation of radiative heat transfer between black surfaces is relatively easy because in case of blackbody all the radiant energy which strikes the surface is absorbed. However, finding view factor is slightly complex, but once it can be done, finding heat exchange between the black bodies is quite easy.

When non blackbodies are involved the heat transfer process becomes very complex because all the energy striking on to the surface does not get absorbed. A part of this striking energy reflected back to another heat transfer surface, and part may be reflected out from the system entirely. Now, one can imagine that this radiant energy can be reflected back and forth between the heat transfer surfaces many times.

In this section, we will assume that all surfaces are in the analysis are diffuse and uniform in temperature and that the reflective and emissive properties are constant over all surfaces.

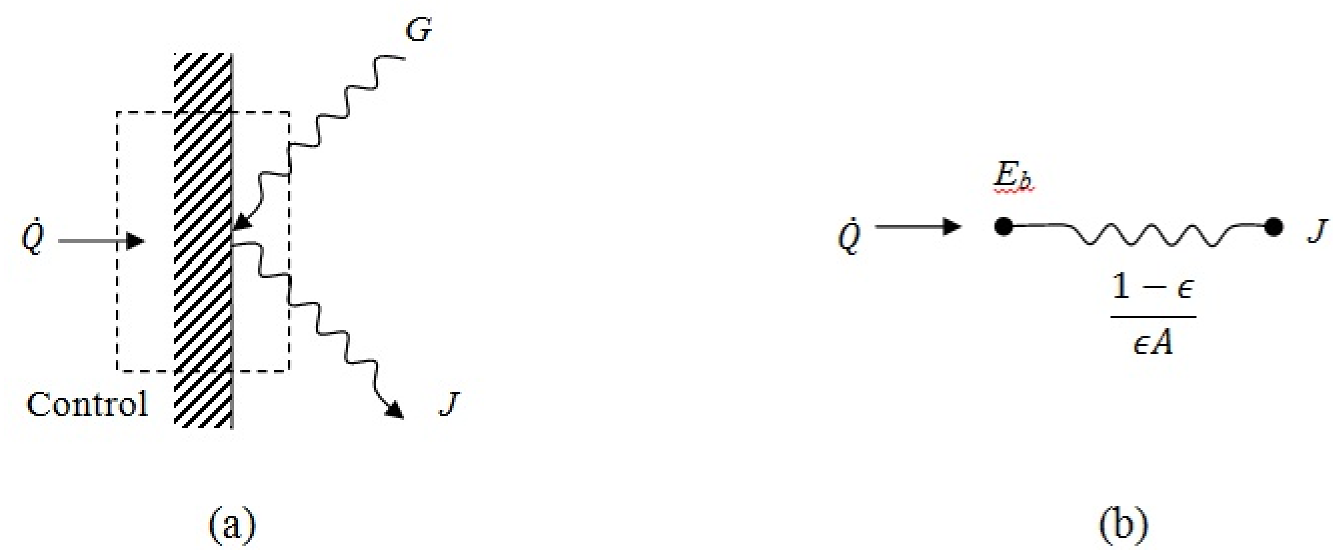

Fig. 7.6: (a) Surface energy balance for opaque surface (b) equivalent electrical circuit

It is also assumed that the radiosity and irradiation are uniform over each surface. As we have already discussed that the radiosity is the sum of the energy emitted and the energy reflected when no energy is transmitted (as opaque body), or

$$J = \epsilon E_b + \rho G \qquad (7.24)$$

where, ϵ is the emissivity and E_b is the blackbody emissive power. Because the transmissivity is zero due to opaque surface and absorptivity of the body (grey) will be equal to its emissivity by Kirchhoff's law.

$$\rho = 1 - \alpha = 1 - \epsilon$$

Thus, eq.7.24 becomes

$$J = \epsilon E_b + (1-\epsilon)G \tag{7.25}$$

The net energy leaving the surface is the difference between the radiosity and the irradiance (fig.7.6a),

$$\frac{\dot{Q}}{A} = J - G = \epsilon E_b + (1-\epsilon)G - G$$

$$\frac{\dot{Q}}{A} = \frac{\epsilon A}{1-\epsilon}(E_b - J)$$

$$\dot{Q} = \frac{E_b - J}{(1-\epsilon)/\epsilon A} \tag{7.26}$$

The eq.7.26 can be analogous to the electrical circuit as shown in fig.7.6(b). The numerator of the eq.7.26 is equivalent to the potential difference, denominator is equivalent to the surface resistance to radiative heat, and left part is equivalent to the current in the circuit.

In the above discussion we have considered only one surface. Now we will analyse the exchange of radiant energy by two surfaces, A_1 and A_2, as shown in the fig.7.7a.

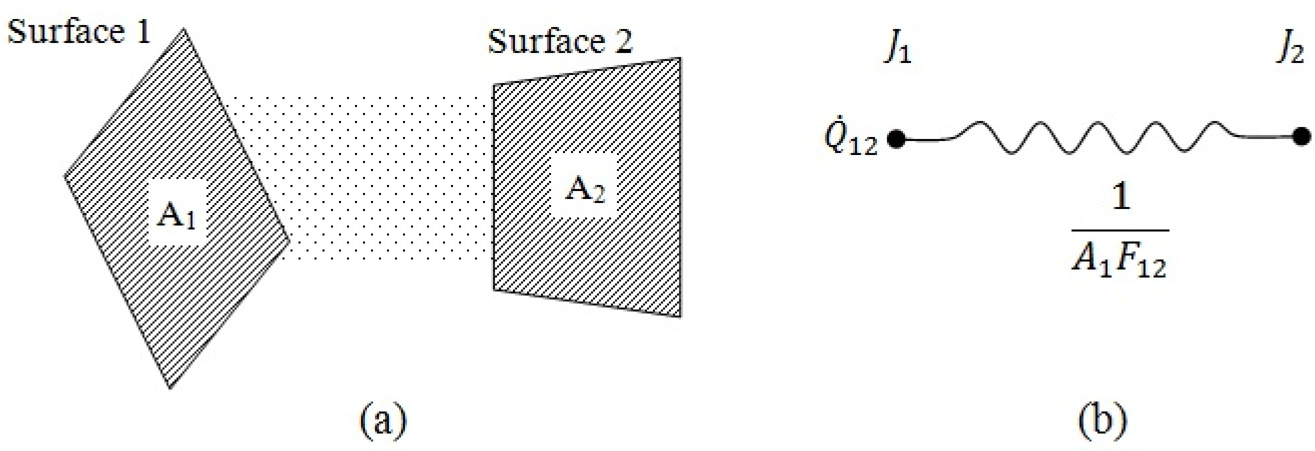

Fig. 7.7: (a) Energy exchange between two surfaces, (b) equivalent circuit diagram

The radiation which leaves surface 1, the amount that reaches surface 2 is

$$J_1A_1F_{12}$$

Similarly, the radiation which leaves system 2, the amount that reaches surface 1 is

$J_2A_2F_{21}$

The net energy transfer between the surfaces,

$$\dot{Q}_{12} = J_1A_1F_{12} - J_2A_2F_{21}$$

Reciprocity theorem states that

$$A_1F_{12} = A_2F_{21}$$

$$\Rightarrow \dot{Q}_{12} = (J_1 - J_2)A_1F_{12} = (J_1 - J_2)A_2F_{21}$$

$$\Rightarrow \dot{Q}_{12} = \frac{(J_1 - J_2)}{1/\,A_1F_{12}} \tag{7.27}$$

It also resembles an electrical circuit shown in fig.7.7b. The difference between eq.7.26 and 7.27 is that in eq.7.27 the denominator term is space resistance instead of surface resistance.

Now, to know, the net energy exchange between the two surfaces we need to add both the surface resistances along with the overall potential as shown in the fig.7.8. Here the surfaces see each other and nothing else.

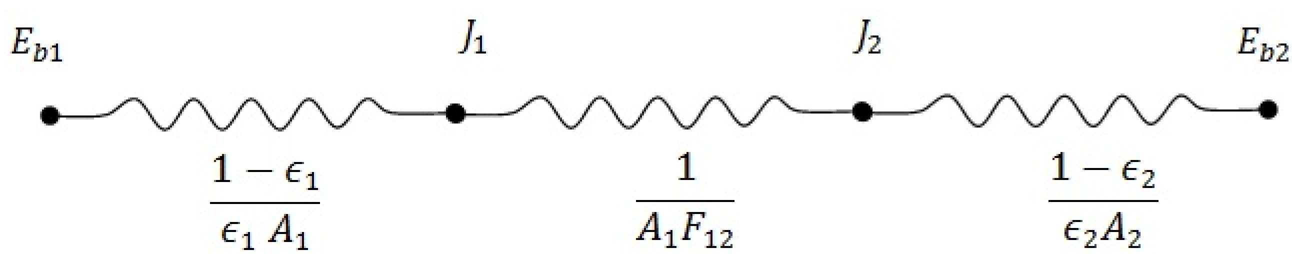

Fig. 7.8: Radiative nature for two surfaces which can see each other nothing else

$$\dot{Q}_{12} = \frac{E_{b1} - E_{b2}}{\frac{1-\epsilon_1}{\epsilon_1A_1} + \frac{1}{A_1F_{12}} + \frac{1-\epsilon_2}{\epsilon_2A_2}} \tag{7.28}$$