Thermal Radiation Equation

The relation shown in Equation 3 is usually applicable to systems in which radiant exchange takes place between the surfaces of solids, as sche-

$$q_r = \sigma A_1 F_A F_E \, (T_1^4 - T_2^4) \qquad (3)$$

matically shown in Fig. 3. Gaseous and luminous radiation are not considered in this discussion. Equation 3 states that the net radiation current per unit transfer area of surface 1, q_r/A Btu per hour per square foot, which *sees* surface 2 through a non-absorbing medium, is proportional to the

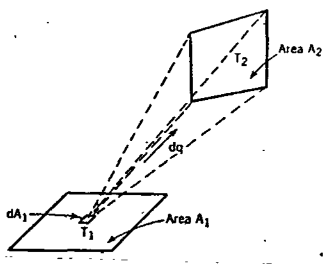

FIG. 3. RADIATION BETWEEN SURFACES

difference of the fourth powers of the absolute surface temperatures $(T_1^4 - T_2^4)$. The proportionality factor $(\sigma \; F_A F_E)$ may be conveniently separated into three parts:

σ = the Stefan-Boltzmann radiation constant.
= 1730 × 10^{-12} Btu per hour per square foot per degree Fahrenheit absolute temperature to the fourth power.

F_A = the configuration factor is dimensionless and ≤ 1. This factor accounts for the shape and relative position of the two surfaces. The value of $F_A = 1$ may be used in the cases of large parallel planes, long concentric cylinders or smaller bodies in large enclosures. (For other values see References.)

F_E = the emissivity factor is also dimensionless and ≤ 1. This factor accounts for the absorption and emission characteristics of the surfaces for the radiation which exists. Individual emissivities (e) should be taken from Table 6 and applied, for either radiation or absorption, as follows:

a. For a small body in a large enclosure, use the emissivity of the small body only: $F_E = \varepsilon_1$.
b. For rectangles or disks, either parallel or perpendicular and with a common side, use the product of the emissivities: $F_E = \varepsilon_1 \times \varepsilon_2$.
c. For large parallel planes, long concentric cylinders or large enclosed bodies, use both emissivities in the equation:

$$F_E = \frac{1}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

The radiation under black-body conditions, or for an emissivity of 1.0, is given in Table 7[5] for cold surfaces as low as −39 F to warmer surfaces as high as 139 F. The emissivities of a number of surfaces ordinarily encountered in engineering practice are shown in Table 6. For radiation table at higher temperatures, and further discussion of radiation calculations, see Chapter 45.

[5]Heat Insulation in Air Conditioning, by R. H. Heilman (*Industrial and Engineering Chemistry*, Vol. 28, July 1936, p. 782).

Combined Convection and Radiation

It should be noted that the previous equations and tables give the heat transfer by convection and by radiation computed separately. In many practical cases it is desirable to treat convection and radiation as a single combined process, using a first-power equation:

$$q_{rc} = h_{rc} \, A \, (t_1 - t_2) \qquad (4)$$

where q_{rc} is the total heat flow due to radiation and convection, in Btu per hour. Values of h_{rc}, the surface or film conductance for combined

TABLE 6. RADIATION FACTORS OR EMISSIVITIES, ε.
For the determination of factor F_E in Equation 3

CLASS	SURFACES	FRACTION OF BLACK-BODY RADIATION		
		At 50–100 F	At 1000 F	Solar Radiation
1	A small hole in a large box, sphere, furnace, or enclosure	0.97 to 0.99	0.97 to 0.99	0.97 to 0.99
2	Black non-metallic surfaces such as asphalt, carbon, slate, paint, paper	0.90 to 0.98	0.90 to 0.98	0.85 to 0.98
3	Red brick and tile, concrete and stone, rusty steel and iron, dark paints (red, brown, green, etc.)	0.85 to 0.95	0.75 to 0.90	0.65 to 0.80
4	Yellow and buff brick and stone, firebrick, fire clay	0.85 to 0.95	0.70 to 0.85	0.50 to 0.70
5	White or light-cream brick, tile, paint or paper, plaster, whitewash	0.85 to 0.95	0.60 to 0.75	0.3 to 0.5
6	Window glass	0.90 to 0.95	....	Transparent
7	Bright aluminum paint; gilt or bronze paint	0.4 to 0.6	....	0.3 to 0.5
8	Dull brass, copper, or aluminum; galvanized steel; polished iron	0.2 to 0.3	0.3 to 0.5	0.4 to 0.65
9	Polished brass, copper, monel metal	0.02 to 0.05	0.05 to 0.15	0.3 to 0.5
10	Highly polished aluminum, tin plate, nickel, chromium	0.02 to 0.04	0.05 to 0.10	0.10 to 0.40

radiation and convection, are given in Chapter 4, Table 1 and Fig. 1. Complete tables for the combined heat transfer of steam and hot water radiators, pipes, coverings, etc., will be found in the appropriate chapters.

When dealing with the effect of operating temperatures upon the combined heat transfer of a given piece of equipment (as for instance a steam radiator), another form of equation is frequently used:

$$q_{rc} = B \, A \, (t_1 - t_2)^n \qquad (5)$$

Values of n in this equation usually range from 1.3 to 1.5 (see Chapter 13). The chief advantage of this equation is the convenience of representing