The increased rate of heat transfer due to *forced convection* can be calculated from Equation 2b:

$$q_{fc} = 1 + 0.225V \quad (2b)$$

where

q_{fc} = heat transfer by forced convection, Btu per square foot per hour per degree Fahrenheit temperature difference.
V = velocity of air, feet per second.

This equation is approximately correct for large surfaces exposed to air currents at temperatures of approximately 70 to 80 F.

Problems in either forced convection or natural convection may be solved by the simple first-power equation if the convection coefficient is expressed as a unit conductance:

$$q_c = h\,A\,(t_1 - t_2) \quad (2c)$$

where

q_c = heat transmission by convection, Btu per hour.
A = surface area, square feet.
$t_1 - t_2$ = temperature difference between the surface and the air, degrees Fahrenheit.
h = unit conductance, from Table 5, Btu per square foot per hour per degree Fahrenheit temperature difference.

NOMENCLATURE AND DIMENSIONS FOR TABLE 5

c_p = fluid unit heat capacity at constant pressure, Btu per pound per degree Fahrenheit.
D = cylinder diameter, feet.
G = 3600 $V_s\gamma$ = fluid mass velocity, pounds per hour per square foot of flow cross-section.
γ = density, pounds per cubic foot.
h = unit conductance for thermal convection, Btu per hour per square foot per degree Fahrenheit.
k = unit thermal conductivity of the fluid, Btu per hour per square foot per degree Fahrenheit for one foot thickness.
r_H = hydraulic radius of the flow cross-section[c].
= flow cross-section area per wetted perimeter, feet.
s = fin spacing, feet.
t = average fluid film temperature, degree Fahrenheit.
Δt = temperature difference surface to main fluid, degree Fahrenheit.
V_s = fluid velocity, feet per second.
μ = fluid viscosity, pounds per hour per foot = viscosity in centipoises × 2.42.

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-

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

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

TABLE 5. APPROXIMATE UNIT CONDUCTANCES FOR THERMAL CONVECTION FOR SEVERAL FLOW SYSTEMS[a]

Expressed in Convenient Empirical Form

CASE	SYSTEM	UNIT CONDUCTANCE EQUATION[b]
	FORCED CONVECTION	
1.	Longitudinal flow in cylinders, turbulent region. Fluid being heated[c].	$\frac{hD}{k} = 0.0225\left(\frac{DG}{\mu}\right)^{0.8}\left(\frac{c_p\mu}{k}\right)^{0.4}$ For $\left(\frac{DG}{\mu}\right) > 3000$
2.	For longitudinal air flow in cylinders case 1 reduces to[c].	$h = 0.0036\,G^{0.8}/D^{0.2}$ For $\left(\frac{DG}{\mu}\right) > 3000$
3.	For longitudinal water flow in cylinders case 1 reduces to[c].	$h = 0.00486\,(1 + 0.01t)\,\frac{G^{0.8}}{D^{0.2}}$ For $\left(\frac{DG}{\mu}\right) > 3000$
4.	Air flow normal to a single right circular cylinder.	$h = 0.45\left(\frac{k}{D}\right) + 0.178\,G^{0.56}\left(\frac{k}{D}\right)^{0.44}$
5.	Air flow over staggered pipe banks.	$h = 0.061\left(\frac{k}{D}\right)^{0.31} G^{0.69}$
6.	Air flow over single spheres.	$h = 0.040\,\frac{G^{0.52}}{D^{0.48}}$ $0 < t < 250$ F
7.	Air flow over plane surfaces.	$h = 1 + 0.22\,V_s$ For $V_s < 16$ fps or $h = 0.53\,V_s^{0.8}$ 16 fps $< V_s <$ 100 fps
8.	Air flow normal to finned cylinders.	$h = 6.2\left(\frac{G}{3600}\right)^{0.8}\frac{s^{0.32}}{D^{0.52}}$ $0 < t < 250$ F
	FREE CONVECTION[d]	
9.	Single horizontal right circular cylinder in air.	$h = 0.23\left(\frac{\Delta t}{D}\right)^{0.25}$
10.	Vertical surfaces in air.	$h = 0.3\,(\Delta t)^{0.25}$
11.	Top surface of horizontal plates to air.	$h = 0.4\,(\Delta t)^{0.25}$
12.	Bottom surface of horizontal plates to air.	$h = 0.2\,(\Delta t)^{0.25}$

[a]Heat Transmission, by W. H. McAdams.
[b]Fluid properties should be evaluated at the arithmetic mean fluid temperature, $t_f = (t_{surface} + t_{fluid})$ divided by 2.
[c]These expressions are applicable to longitudinal flow in other than right circular cylinders provided the hydraulic radius is employed as the conduit dimension parameter. For non-circular cross-sections $D = 4\,r_H$.
[d]For low rates of heat transfer by free convection the exponent decreases towards zero, and for higher rates increases towards 0.33. The following equations employing an exponent equal to 0.25 are applicable in the intermediate range.