b. For rectangles or disks, either parallel or perpendicular and with a common side, use the product of the emissivities: $F_E = \epsilon_1 \times \epsilon_2$.

c. For large parallel planes, long concentric cylinders or large enclosed bodies, use both emissivities in the equation:

$$F_E = \frac{1}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1}$$

The radiation under black-body conditions, or for an emissivity of 1.0, is given in Table 7[4] 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 31.

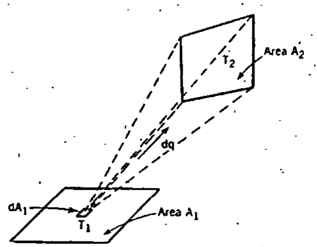

FIG. 3. RADIATION BETWEEN SURFACES

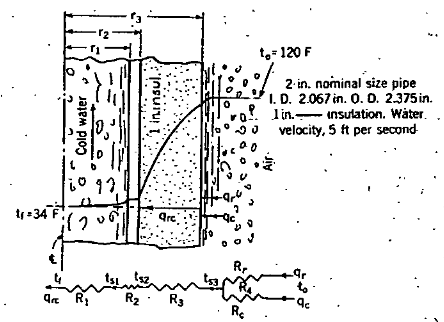

FIG. 4. HEAT TRANSFER CONDITIONS IN THE INSULATED COLD WATER LINE

NOMENCLATURE AND DIMENSIONS FOR TABLE 5

c_p = fluid unit heat capacity at constant pressure, Btu per (pound) (degree Fahrenheit).

D = cylinder diameter, feet.

G = 3600 $V_s \rho$ = fluid mass velocity, pounds per (hour) (square foot of flow cross-section).

ρ = density, pounds per cubic foot.

h_c = unit conductance for thermal convection, Btu per (hour) (square foot) (degree Fahrenheit).

k = unit thermal conductivity of the fluid, Btu per (hour) (square foot) (degree Fahrenheit per one foot thickness).

R_H = hydraulic radius of the flow cross-section = flow cross-section area per wetted perimeter, feet.

s = fin spacing, feet.

t = average fluid film temperature, degree Fahrenheit.

$t_1 - t_2$ = temperature difference surface to main fluid, degree Fahrenheit.

V_s = fluid velocity, feet per second.

μ = fluid viscosity, pounds per (hour) (foot) = viscosity in centipoises × 2.42.

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

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].	$\frac{h_c D}{k} = 0.0225 \left(\frac{DG}{\mu}\right)^{0.8} \left(\frac{c_p \mu}{k}\right)^{0.4}$, For $\left(\frac{DG}{\mu}\right) > 3000$
2.	For longitudinal air flow in cylinders case 1 reduces to[c].	$h_c = 0.0036\, G^{0.8}/D^{0.2}$ For $\left(\frac{DG}{\mu}\right) > 3000$
3.	For longitudinal water flow in cylinders case 1 reduces to[c].	$h_c = 0.00486\,(1 + 0.01t)\,\frac{G^{0.8}}{D^{0.2}}$ For $\left(\frac{DG}{\mu}\right) > 3000$
4.	Air flow normal to a single right circular cylinder.	$h_c = 0.45 \left(\frac{k}{D}\right) + 0.178\, G^{0.56} \left(\frac{k}{D}\right)^{0.44}$
5.	Air flow over staggered pipe banks.	$h_c = 0.061 \left(\frac{k}{D}\right)^{0.31} G^{0.69}$
6.	Air flow over single spheres.	$h_c = 0.040\, \frac{G^{0.52}}{D^{0.48}}$ $0 < t < 250$ F
7.	Air flow over plane surfaces.	$h_c = 1 + 0.22\, V_s$ For $V_s < 16$ fps or $h_c = 0.53\, V_s^{0.8}$ 16 fps $< V_s <$ 100 fps
8.	Air flow normal to finned cylinders.	$h_c = 6.2 \left(\frac{G}{3600}\right)^{0.6} \frac{s^{0.33}}{D^{0.52}}$ $0 < t < 250$ F
	FREE CONVECTION[d]	
9.	Single horizontal right circular cylinder in air.	$h_c = 0.23 \left(\frac{t_1 - t_2}{D}\right)^{0.25}$
10.	Vertical surfaces in air.	$h_c = 0.3\,(t_1 - t_2)^{0.25}$
11.	Top surface of horizontal plates to air.	$h_c = 0.4\,(t_1 - t_2)^{0.25}$
12.	Bottom surface of horizontal plates to air.	$h_c = 0.2\,(t_1 - t_2)^{0.25}$

[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.