with the square of the tube diameter, and inversely with the 0.63 power of the absolute viscosity in centipoises. In this formula, c and z are taken at the temperature of the body of the liquid rather than at the temperature of the film.

A formula given by McAdams and Frost from experiments on water, using film temperature is:

$$h = \frac{15.4\,K}{D}\left(1 + \frac{50}{r}\right)\left(\frac{DV}{z}\right)^{0.8}$$

r = ratio of length of tube to diameter.

As an approximation, the above formula may be used for liquid flowing outside tubes by using four times the hydraulic radius for D. The

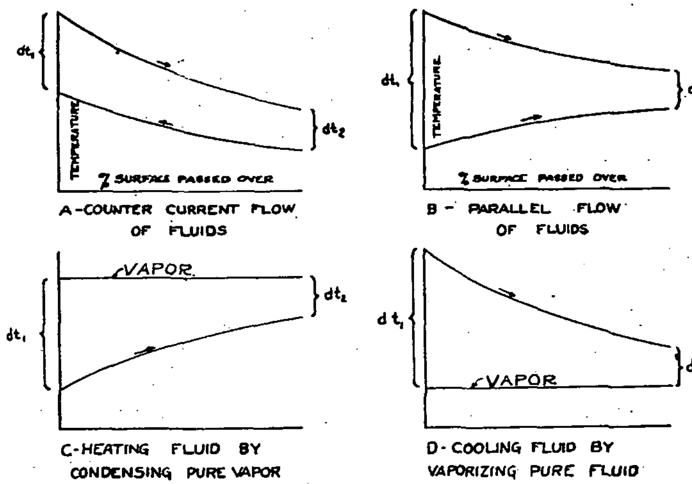

FIG. 2. TEMPERATURE DIFFERENCES FOR VARIOUS CONDITIONS OF HEAT TRANSFER

turbulence is usually much greater than is indicated by this means, especially when cross flow occurs.

The value of h found from the equations is, of course, only the heat transfer rate from the tube through one liquid film. If the problem to be considered is the transfer of heat from oil to oil, or from water to water, the reciprocals of the three heat transfers through heating film, tube, cooling film, and any scale or dirt, must be added to obtain the overall resistance.

In the absence of non-condensable gases, the coefficient of heat transfer from condensing steam to a tube may be from 1500 to 3000, or r_s = 0.0007 to 0.0003. Oil in the steam increases the resistance greatly and the resistance for condensing oil vapors, benzol, or other materials is much higher than for steam. The resistance of the tube wall to heat flow can be easily calculated, knowing the conductivity of the metal. It is based upon the logarithmic mean diameter of the tube, which can be taken as the arithmetic average diameter, with very little error in all ordinary

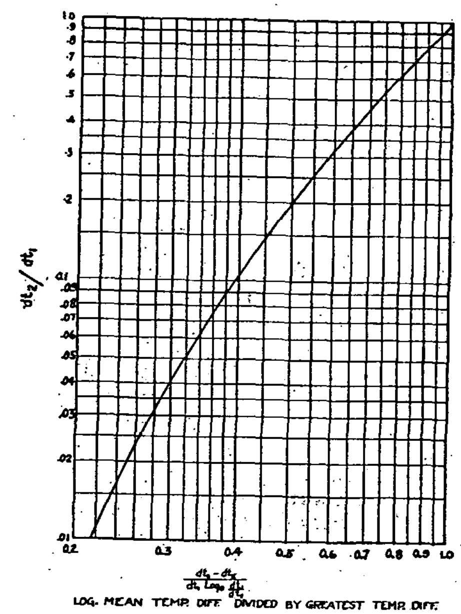

FIG. 3. CHART FOR CALCULATION OF LOGARITHMIC MEAN TEMPERATURE DIFFERENCE

cases. If a = thickness in inches, D_a = average diameter of tube, and K = heat conductivity in B.t.u. per hour per square foot per degree per foot thickness.

$$r_t = \frac{a}{12\,K} = \text{resistance of tube wall to heat flow.}$$

$$h_t = \frac{12\,K}{a} = \text{conductance of tube wall.}$$

Values of K are given in the following table for different metals. There is a slight variation in K with temperature, but this change can be disregarded in almost all cases.

	K
Silver	240
Copper	220
Aluminum	120
Bronze	64
Wrought Iron	26
Cast Iron	36
Steel	26
Lead	20

From the above table, the resistance of a copper tube ⅛ in. thick would be $\frac{0.125}{220 \times 12} = 0.000047$; while that of a steel tube of the same