mometer located near the bulb of the instrument; curve (*C*) that traced by the automatic recording mechanism of the instrument; and straight line (*D*) the temperature at which the instrument was set.

The true fluctuation in temperature is about 8.9 deg. fahr. according to the sling psychrometer, although that shown by the mercury thermometer is only 3.5 deg. and that traced by the recorder about 1 deg.

Fig. 14 shows the extent to which the sensitivity of the regulator was increased by blowing air, at a velocity of 650 ft. per minute, over its bulb, all other conditions remaining the same. Equally good results were obtained by placing the thermostatic bulb in the exhaust duct leaving the room. This is a better arrangement, because the temperature of the air in the exhaust represents more nearly the average temperature of the room.

Table 1 gives data on the performance of several well known temperature regulators. Apparently thermostat 6 was not designed for the purpose for which it was tested.

In plenum systems of heating and ventilation, temperature fluctuations between 4 and 5 deg. fahr., are not of sufficient magnitude to produce discomfort, if the variation is partly above and partly below the proper temperature, so as to average the proper temperature, and if the oscillations in temperature occur frequently enough to avoid sensations of coldness or warmth. A systematic temperature variation of this order is, in fact, very agreeable because of its stimulating effect on the skin. However, little is now known concerning what should be the magnitude and cycle frequency, of such temperature oscillations. When these become known, the thermostat, in conjunction with mixing dampers, will probably lend itself remarkably well to controlling both of these factors.

In rooms ventilated spontaneously and heated by direct radiation, the problem of temperature control is much more difficult than in plenum systems. As a general rule, the tendency is toward overheating; because there is ample heating capacity—in fact too much for the average winter conditions—but no adequate means for cooling the room once it becomes overheated. The result is that the greater part of the temperature wave produced by the regulator lies above the proper room temperature and remains in this warm region too long, until the excess heat is dissipated to the air out-of-doors by transmission through the exposed wall and glass, or by opening windows.

Care should be taken to choose the most sensitive thermostat for this purpose, which should be set according to indications of the sling psychrometer.

Similar precautions should be taken in split systems of heating and ventilation. The temperature of the air delivered by the ventilation system should, under all conditions, be several degrees lower than the temperature at which the room thermostat is set. If this precaution is not taken, the duct thermostat might fall in synchronism with the room thermostat and produce overheating.

CHAPTER XVII

HEAT EXCHANGERS FOR WATER AND OIL

Factors in Heat Transfer, Critical Velocities, Variation of Heat Transfer, Design of Exchangers, Operating Quotations, Economics of Design.

IN problems of fluid friction and heat transfer to fluids, the concept of a fluid film has become of great use. This surface film varies in thickness with velocity and viscosity and, hence, heat transmission through the film, and friction drop of a flowing liquid are dependent upon these and other properties of the liquid. Results of various experimental determinations of friction drop and of heat transfer from the wall of a tube to a liquid flowing inside it are best correlated by the use of the Nusset type of equation:

$$\frac{hD}{K} = F\left(\frac{DV}{z}\right) f\left(\frac{cz}{K}\right)$$

where

h = heat transfer coefficient.
D = diameter of pipe in inches.
K = thermal conductivity.
V = mass velocity.
z = viscosity.
c = specific heat.
F, f = functions of the groups of variables.

The various factors are arranged in dimensionless groups, and the effect of each group upon the heat transfer rate is found, based upon experimental results.

In general, there are two flow conditions of a fluid inside a tube. These are determined by its physical properties and the diameter, length and condition of the tube through which it flows. The velocity of the liquid past the surface is the major factor in film thickness, but since this velocity is difficult to determine, the average velocity of the fluid is used in calculations. For very low velocities or for high viscosity, the fluid may be considered to move as a series of concentric cylinders sliding in one another. Under this condition the friction drop of a liquid along a tube varies directly with the velocity, if viscosity remains constant. For this type of flow, the average velocity is approximately half the maximum

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