heated spray water. In any air washing installation the air should not enter the washer with a wet-bulb temperature less than 35 F. This is a precaution to eliminate the danger of freezing the spray water.

Method 1. Except for the small amount of energy added from outside by the recirculating pump in the form of shaft work, and for the small amount of heat leakage from outside into the apparatus, including the pump and its connecting piping, the process would be strictly adiabatic. Evaporation from the liquid spray would therefore be expected to bring the air immediately in contact with it to saturation adiabatically; and, since the liquid is recirculated, its temperature would be expected to adjust to the thermodynamic wet-bulb temperature of the entering air.

It does not follow from the foregoing reasoning that the whole air stream is brought to complete saturation, but merely that its state point should move along a line of constant thermodynamic wet-bulb temperature. The extent to which the leaving air temperature approaches the thermodynamic wet-bulb temperature of the entering air, or the extent to which complete saturation is approached, is conveniently expressed by a ratio known as humidifying effectiveness or saturating effectiveness, and is defined in Equation 1 as

$$e_h = \frac{t_1 - t_2}{t_1 - t'} \times 100 \qquad (1)$$

where

e_h = humidifying or saturating effectiveness, percent.
t_1 = dry-bulb temperature of the entering air, Fahrenheit.
t_2 = dry-bulb temperature of the leaving air, Fahrenheit.
t' = thermodynamic wet-bulb temperature of the entering air, Fahrenheit.

The following may be taken as representative of the humidifying or saturating effectiveness of a spray-type air washer for the arrangements stated:

Arrangement	Length Ft	Effectiveness—%
1 bank downstream	4	50–60
1 bank downstream	6	60–75
1 bank upstream	6	65–80
2 banks downstream	8 to 10	80–90
2 banks opposing each other	8 to 10	85–95
2 banks upstream	8 to 10	90–98

The degree of saturation depends upon the extent of contact between the air and water. Other conditions being the same, a low velocity of air flow is conducive to higher humidifying effectiveness.

Method 2. The preheating of the air increases both the dry- and wet-bulb temperatures, and lowers the relative humidity, but does not alter the humidity ratio (pounds of water vapor per pound dry air). At a higher wet-bulb temperature, but the same humidity ratio, more water can be absorbed per pound of dry air in passing through the washer, assuming that the humidifying effectiveness of the washer is not adversely affected by operation at the higher wet-bulb temperature. The analysis of the process occurring in the washer itself is the same as that explained under *Method 1*. The final desired conditions are secured by adjusting the amount of preheating to give the required wet-bulb temperature at the entrance to the washer.

Method 3. Even if the heat is added to the spray water, the mixing occurring in the washer itself may still be regarded as adiabatic. The state point of the mixture should move in a direction determined by the specific enthalpy of the heated spray. It is possible, by elevating the water temperature, to raise the air temperature, both dry-bulb and wet-bulb, above the dry-bulb temperature of the entering air.

In methods 1, 2, or 3, the air leaving the air washer may require reheating to produce in the conditioned space the required dry-bulb temperature and relative humidity.

Dehumidification and Cooling with Air Washers

Washers are also applicable to air cooling and dehumidification. Heat and moisture removed from the air produce a rise in the water temperature. If the entering water temperature is below the entering wet-bulb temperature, then a lowering of both the dry-bulb and wet-bulb temperatures is obtained. Dehumidification will result if the leaving water temperature is below the entering dew point temperature. Moreover, the final water temperature is determined by the sensible and latent heat pick-up and the quantity of water circulated. However, this final temperature must not exceed the final required dew point, one or two degrees below the dew point being common practice.

The air leaving a spray-type dehumidifier is substantially saturated. Usually the spread between dry- and wet-bulb temperatures is less than one degree. The spread between leaving air and leaving water will depend on the difference between entering dry- and wet-bulb temperatures and on certain features of design; such as length and height of spray chamber, air velocity, quantity of water, and character of the spray pattern. The rise in water temperature is usually between 6 and 12 F deg, although higher rises have been used successfully. The lower rises are ordinarily selected when the water is chilled by mechanical refrigeration because of possible higher refrigerant temperatures. It is often desirable to make an economic analysis of the effect of higher refrigerant temperature compared with the benefits of a greater rise in water temperature. With systems receiving water from a well or other source at an acceptable temperature, it may be desirable to design on the basis of a high rise and minimum flow of water.

The most common air washer arrangement for cooling and dehumidifying air has two spray banks and is eight to nine feet long. If the air washer has ability to cool and dehumidify the entering air to a wet-bulb temperature equal to the leaving water temperature, it is convenient to assign to such a washer a performance factor of 1.0. The actual performance factor of any washer is the actual enthalpy change divided by enthalpy change in a washer of 1.0 performance factor.

Calculation of the required performance factor, F_P, for

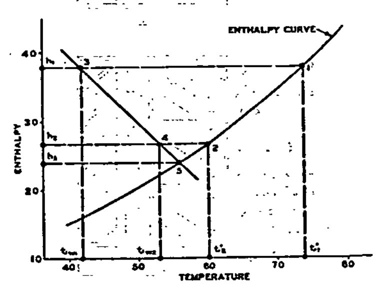

Fig. 6 .... Graphical Solution of Conditions Produced by a Dehumidifying Air Washer

any washer application involving cooling and dehumidifying can be made from Equation 2:

$$F_p = (h_1 - h_2)/(h_1 - h_3) \qquad (2)$$

where

h_1 = enthalpy at entering air wet-bulb temperature, Btu per pound.
h_2 = enthalpy at leaving air wet-bulb temperature at actual condition, Btu per pound.
h_3 = enthalpy at wet-bulb temperature leaving a washer with F_P = 1.0, Btu per pound.

Knowing the performance factor of a particular air washer, the actual conditions of operation can be graphically determined as shown in Fig. 6. Points 1 and 2 are plotted on the saturation curve representing total heat at the entering and leaving air wet-bulb temperatures, t_1' and t_2'. Point 5 represents the condition at which leaving air wet-bulb and leaving water temperatures would be the same. This point is determined by solving Equation 1 for h_3.

$$h_3 = h_1 - \frac{(h_1 - h_2)}{F_P}$$

A diagonal line is drawn through Point 5 with a negative slope equal to the water-to-air weight ratio. Points 3 and 4, at which this diagonal line intersects horizontal lines through points 1 and 2, show the required entering and leaving water temperatures t_{w1} and t_{w2}. A check of the solution can be made from the fundamental heat balance equation,

Heat absorbed by the water = heat removed from the air.

The graphical method as described can be used to arrive quickly at solutions of air-washer cooling and dehumidifying problems where there are a number of unknown factors, including quantity of water to be used and the entering and leaving water temperatures. The actual performance factor of a particular washer must, however, be obtained from the manufacturer's data.

Another method sometimes used to express the performance of a dehumidifier is given in terms of the relationship of the leaving to entering spread between air and water temperatures.

$$F_{p1} = 1 - \frac{(t_2' - t_{w2})}{(t_1' - t_{w1})} \qquad (3)$$

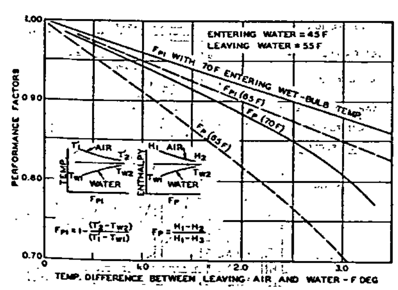

Fig. 7 .... Comparison of Performance Factors for Given Set of Conditions

where

t_1' = thermodynamic wet-bulb temperature of entering air, Fahrenheit.
t_2' = thermodynamic wet-bulb temperature of leaving air, Fahrenheit.
t_{w1} = entering water temperature, Fahrenheit.
t_{w2} = leaving water temperature, Fahrenheit.

Performance factors expressed in these terms normally vary from about 70 percent for a single bank washer 6 ft long to practically 100 percent for a unit 8 ft long with two spray banks, one opposed.

It must be remembered that the performance factors obtained by these two methods are not equal as is seen in Fig. 7. The representative curves in Fig. 7 are based on entering wet-bulb temperatures of 65 F and 70 F with a leaving difference between air and water of 1.5 F deg and a water temperature rise of 10 F deg. The calculation of F_P is independent of rise in water temperature. However, the equation for F_{P1} does involve the difference between entering and leaving water temperature. For example, the performance factor for 65 F entering wet-bulb temperature and 1.5 F degrees leaving difference falls from 0.925 for 10 F deg rise in water to 0.912 for 7 F deg rise, assuming the leaving difference is still 1.5 F deg. This emphasizes the desirability of stating which of the two performance concepts are being applied when considering factors. As an added precaution, it would be well to also give the washer requirement in terms of leaving temperature difference between air and water for a given set of conditions.

Air Cleaning

The dust removal efficiency of air washers depends largely on the size of the particle, its density and *wettability* and its solubility in water. Efficiency is highest for the larger more wettable particles, separation being accomplished almost entirely by impingement of particles on the wetted surface of the eliminator plates. Since force of impact increases with size of solid, this together with the adhesive quality of the wetted surface determines the washer's usefulness as a dust remover. Experience has shown that the spray itself is relatively ineffective in removing most atmospheric dusts. Air washers are of little use in removing soot particles because of the absence of an adhesive effect from the greasy surface. They are also not effective in removing smoke because of inadequate inertia of the small particles (less than one micron) to impinge and be held on the wet plates. Instead, the particles follow the path of the air between the plates as they are unable to pierce the water film covering the plates. Cell-type washers, however, are efficient air cleaners. In practice, they remove from 70 to 90 percent by weight of the airborne solid matter, which includes most particles exceeding 5 microns in size and many down to 1 micron. However, they should not be used in cotton mills and other installations where large volumes of fibrous or linty material are present in the air, unless it is filtered out completely ahead of the washer.

Maintenance

Uninterrupted performance depends largely on a regular cleaning and inspection schedule. Frequency varies with operating conditions; however a weekly inspection schedule is common practice. The spray system requires the most attention. Partially clogged nozzles are indicated by a rise in spray pressure, while the symptom of eroded orifices is a fall in pressure. Strainers can minimize this problem. For continuous operation a bypass around pipe line strainers or duplex strainers is required. Air washer tanks should be drained and dirt deposits removed at regular intervals. Eliminators and baffles should be inspected periodically and repainted to