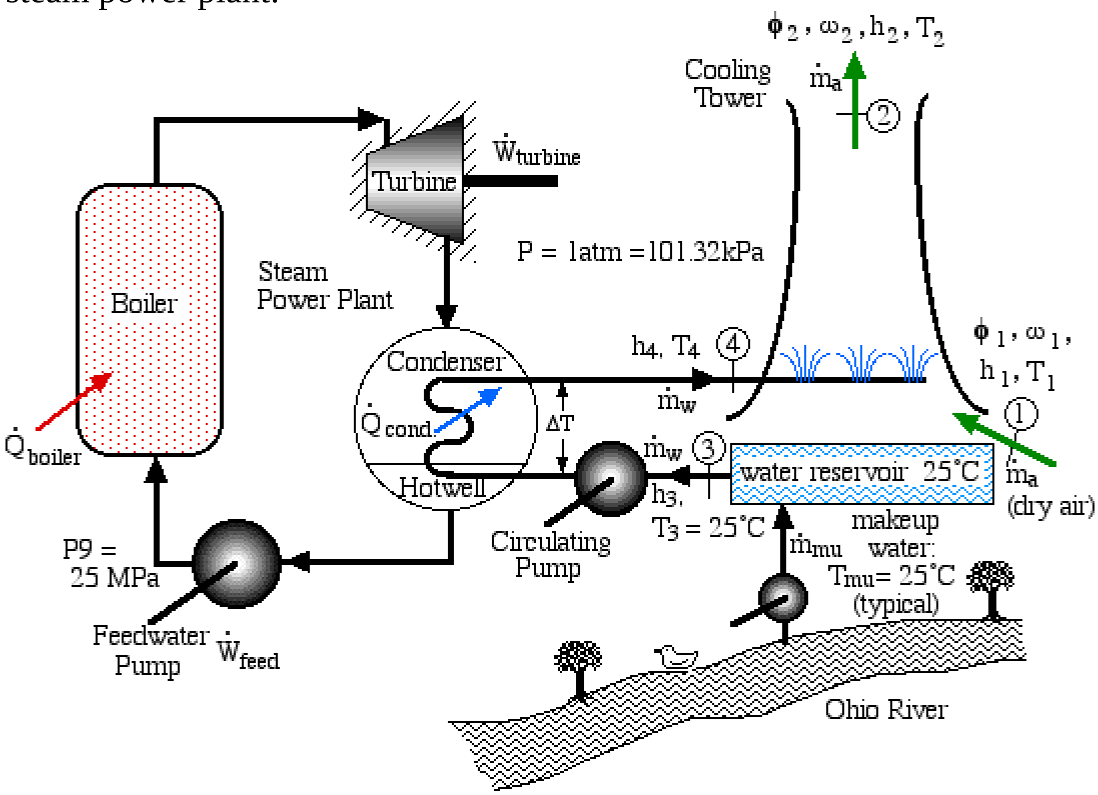
Air - Water Vapor Mixtures Part III

Cooling Towers for Steam Power Plants

In the following we show a schematic diagram of a cooling tower in the context of a steam power plant:



mass flow:

Referring to the diagram above the mass flow rate of the makeup water is given by the difference in specific humidity ω at the inlet and outlet air streams multiplied by the mass flow rate of the dry air. Thus the mass flow balance equations for the cooling tower become:

Dry air: $\dot{m}_a$

Vapor: $\dot{m}_{vap1} = \omega_1 . \dot{m}_a$

$$\dot{m}_{vap2} = \omega_2 . \dot{m}_a$$

$$\dot{m}_{makeup} = \dot{m}_a (\omega_2 - \omega_1)$$

Liquid water (Condenser cooling):

$$\dot{m}_4 = \dot{m}_3 = \dot{m}_w$$

energy:

Since no work is done and no heat transferred externally, the cooling tower energy equation reduces to an enthalpy balance equation. Combining the mass flow equations with the energy equation leads to the final equation relating the mass flow rate of the dry air to the circulating cooling water of the condenser, as follows:

$$\cancel{\dot{Q}} - \cancel{\dot{W}} = \sum \dot{m}_e . h_e - \sum \dot{m}_i . h_i = 0$$

where subscripts e and i refer to exit and inlet ports

$$\dot{m}_a . h_2 + \dot{m}_w . h_3 = \dot{m}_a . h_1 + \dot{m}_w . h_4 + \dot{m}_{mu} . h_3$$

$$\dot{m}_a . (h_2 - h_1) - \dot{m}_a . (\omega_2 - \omega_1) . h_3 = \dot{m}_w . (h_4 - h_3)$$

$$\boxed{\dot{m}_a = \frac{\dot{m}_w . (h_4 - h_3)}{(h_2 - h_1) - (\omega_2 - \omega_1) . h_3}}$$

The mass flow rate of the liquid water at stations (3) and (4) is normally provided from the condenser energy equation of the steam power plant. Recall from **Chapter 10a** that the specific humidity ω is related to the various pressures and the relative humidity φ by the following relations:

$$\omega = \frac{\dot{m}_{vapor}}{\dot{m}_{dry-air}} = 0.622 \left(\frac{P_v}{P - P_v} \right) = 0.622 \left(\frac{\phi . P_g}{P - \phi . P_g} \right)$$

The pressure P_v is the partial pressure of the vapor, P_g is the saturation pressure at temperature T, and P is the total pressure (air + vapor), usually taken as one atmosphere (101.325 kPa). In **Chapter 10b** we saw how all of these relations can be most conveniently evaluated graphically on a **Psychrometric Chart**. Notice that we have extended the moisture specific humidity range on this chart from 30 to 40 grams/kg-air in order to accommodate the extremely high humidity normally encountered at at station (2), which is the reason why we normally see a cloud above the cooling tower.

Note that the enthalpies of the vapor (h_1 and h_2) and those of the liquid (h_3, h_4, h_{mu}) can be conveniently evaluated as follows:

$$h_{air+vapor} \approx T + \omega . (2500 + 2\ T) \approx T + 2500 . \omega \text{ [kJ/kg]} \quad \text{(Izzi' s method)}$$

$$h_{liquid} \approx C_{H2O} T = 4.18\ T \text{ [kJ/kg]}$$

The temperature T is in degrees Celsius, and the specific heat capacity of dry air C_P is approximately 1.00 [kJ/kg°C] and that of liquid water approximately 4.18 [kJ/kg°C].

In the above analysis we have assumed that the temperature of the makeup water T_{mu} equals the temperature of the cooled circulating water T_3. Alternatively the values of enthalpy for the vapor ($h_1$and h_2) can also be conveniently read directly from the Psychrometric Chart.

Source: http://www.ohio.edu/mechanical/thermo/Applied/Chapt.7_11/Chapter10c.html