Dew Point - $T_{dp}$

- The Dew Point is the temperature at which water vapor starts to condense out of the air, the temperature at which air becomes completely saturated. Above this temperature the moisture will stay in the air.

- If the dew-point temperature is close to the air temperature, the relative humidity is high, and if the dew point is well below the air temperature, the relative humidity is low.

- The Dew Point temperature can be measured by filling a metal can with water and ice cubes. Stir by a thermometer and watch the outside of the can. When the vapor in the air starts to condensate on the outside of the can, the temperature on the thermometer is pretty close to the dew point of the actual air.

- The dew point temperature can be read by following a vertical line from the state-point to the saturation line. Dew point is represented along the 100% relative humidity line in the Mollier diagram.
Dry-Bulb Temperature - $T_{db}$

- Dry bulb temperature is usually referred to as air temperature, is the air property that is most common used. When people refer to the temperature of the air, they are normally referring to its dry bulb temperature. Dry-bulb temperature - $T_{db}$, can be measured by using a normal thermometer. The dry-bulb temperature is an indicator of heat content and is shown along the left axis of the Mollier diagram. The horizontal lines extending from this axis are constant-temperature lines.

Wet-Bulb Temperature - $T_{wb}$

- Wet bulb temperature is associated with the moisture content of the air. Wet bulb temperature can be measured with a thermometer that has the bulb covered with a water-moistened bandage with air flowing over the thermometer. Wet bulb temperatures are always lower than dry bulb temperatures but they will be identical with 100% relative humidity in the air (the air is at the saturation line). On the Mollier diagram, the wet-bulb lines slope a little upward to the left (dotted lines).
Heating of Air
Cooling and Dehumidifying Air
Mixing of Air of different Conditions

The heat balance for the mix can be expressed as:

\[ L_A h_A + L_C h_C = (L_A + L_C) h_B \]

where

\( L = \) mixing rate

\( h = \) enthalpy of the air

The moisture balance for the mix can be expressed as:

\[ L_A x_A + L_C x_C = (L_A + L_C) x_B \]

where

\( x = \) water content in the air

Calculating the mixture variables \( x_B \) and \( h_B \) makes it possible to calculate the mixing temperature \( t_B \).
Humidifying, Adding Steam or Water (liquid)
The psychrometric chart is a variant of the Mollier diagram used in some parts of the world. The process transforming a Mollier diagram to a psychrometric chart is shown below. First it has to be reflected in a vertical mirror, then rotated 90 degrees.
Evaporation from Water Surfaces

The amount of evaporated water can be expressed as:

\[ m_{\text{evap}} \approx \frac{A \cdot h_c}{c_p} (x_s - x_\infty) \]

- \( m_{\text{evap}} \) = amount of evaporated water (kg/s)
- \( A \) = water surface area (m²)
- \( h_c \) = heat transfer coefficient (W/m² K)
- \( c_p \) = mean specific heat for moist air (J/kg K)
- \( x_\infty \) = humidity ratio in the air (kg/kg)
- \( x_s \) = humidity ratio in saturated air at the same temperature as the water surface (kg/kg)
Problem 6 (page 22)

An indoor pool evaporates a certain amount of water, which is removed by a dehumidifier to maintain +25°C, φ=70% RH in the room (state 1 in figure). The dehumidifier, shown in figure, is a refrigeration cycle in which moist air flowing over the evaporator cools such that liquid water drops out, and the air continues flowing over the condenser. The air after the evaporator (state 2) has a temperature of +14°C. For an air flow of 0.10 kg/s dry air the unit has a coefficient of performance COP\textsubscript{R} =3.0.

Total pressure in the room is constant 101325 Pa.

Calculate
a) the amount of water that evaporates from the pool (steady state)
b) the compressor work input
c) the absolute humidity and enthalpy (kJ/kg of dry air) for the air as it returns to the room (state 3 in figure)
Problem dryer

Outdoor air

\( T=+14 \, ^\circ\text{C} \)
\( \Phi=60\% \text{ RH} \)

Heating coil

Wood dryer

Capacity: 500 kg/h

\( T=+40 \, ^\circ\text{C} \)
\( \Phi=90\% \text{ RH} \)

Volume flow of moist air: 20100 m³/h
$T_A = 14 \, ^\circ \text{C}, \quad \varphi_A = 60 \% \text{ RH}$

\[ p_{w_A} = 1599 \, \text{Pa}, \quad p_w = 0.60 \cdot 1599 = 959.4 \, \text{Pa} \]
\[ x_A = 0.622 \frac{959.4}{101325 - 959.4} = 0.00595 \, \text{kg} / \text{kg} \]
\[ h_A = 1.01 \cdot 14 + 0.00595(2502 + 1.84 \cdot 14) = 29.17 \, \text{kJ} / \text{kg} \]

$T_D = 40 \, ^\circ \text{C}, \quad \varphi_D = 90 \% \text{ RH}$

\[ p_{w_D} = 7375 \, \text{Pa}, \quad p_w = 0.90 \cdot 7375 = 6637.5 \, \text{Pa} \]
\[ x_D = 0.622 \frac{6637.5}{101325 - 6637.5} = 0.04360 \, \text{kg} / \text{kg} \]
\[ h_D = 1.01 \cdot 40 + 0.04360(2502 + 1.84 \cdot 40) = 152.70 \, \text{kJ} / \text{kg} \]

\[
V = \frac{m}{M} \frac{T}{p} = \frac{0.04360 \cdot 8314.51}{18.02 \cdot 6637.5} = 0.94914 \, \text{m}^3
\]
\[
\rho = \frac{m}{V} = \frac{1.0 + 0.04360}{0.94914} = 1.09952 \, \text{kg} / \text{m}^3
\]
\[
m_{\text{moist air}} = V \cdot \rho = 20100 \cdot 1.09952 = 22100.3 \, \text{kg} / \text{h}
\]
\[
m_{\text{dry air}} = \frac{m_{\text{moist air}}}{1.0 + x} = \frac{22100.3}{1.0 + 0.04360} = 21177.0 \, \text{kg} / \text{h}
\]

Adiabatic conditions for the dryer $\Rightarrow h_C = h_D$

$m_{\text{water in dryer}} = m_{\text{dry air}} (x_D - x_C)$

\[
x_C = x_D - \frac{m_{\text{water in dryer}}}{m_{\text{dry air}}} = 0.04360 - \frac{500}{21177.0} = 0.01999 \, \text{kg} / \text{kg}
\]
\[
h_C = h_D = 152.70 \, \text{kJ} / \text{kg}
\]

Heating coil $\Rightarrow x_B = x_C = 0.01999 \, \text{kg} / \text{kg}$

Mixing rate of outdoor air (mix)

\[
x_{\text{mix}} = (\text{mix}) \cdot x_A + (1 - \text{mix}) \cdot x_D
\]
\[
m_{\text{dry air}, A} = 0.627 \cdot 21177.0 = 13280.2 \, \text{kg} / \text{h}
\]
\[
h_B = (\text{mix}) \cdot h_A + (1 - \text{mix}) \cdot h_D
\]
\[
h_B = 0.627 \cdot 29.17 + (1 - 0.627) \cdot 152.70 = 75.23 \, \text{kJ} / \text{kg}
\]
\[
Q_{\text{heating coil}} = \frac{m_{\text{dry air}} (h_C - h_B)}{3600} = \frac{21177.0 (152.70 - 75.23)}{3600} = 455.7 \approx 456 \, \text{kW}
\]
Problem dryer with heat pump

Outdoor air

Condenser

Evaporator

Cooling coil

Wood dryer
Capacity: 500 kg/h

Volume flow of moist air: 20100 m³/h
\[ T_e = 14 \degree C, \quad \varphi_e = 60 \% \text{ RH} \]
\[ p_{ws} = 1599 \text{ Pa}, \quad p_w = 0.60 \cdot 1599 = 959.4 \text{ Pa} \]
\[ x_d = 0.622 \cdot \frac{959.4}{101325 - 959.4} = 0.00595 \text{ kg / kg} \]
\[ h_d = 1.01 \cdot 14 + 0.00595(2502 + 1.84 \cdot 14) = 29.17 \text{ kJ / kg} \]

\[ T_e = 40 \degree C, \quad \varphi_e = 90 \% \text{ RH} \]
\[ p_{ws} = 7375 \text{ Pa}, \quad p_w = 0.90 \cdot 7375 = 6637.5 \text{ Pa} \]
\[ x_e = 0.622 \cdot \frac{6637.5}{101325 - 6637.5} = 0.04360 \text{ kg / kg} \]
\[ h_e = 1.01 \cdot 40 + 0.04360(2502 + 1.84 \cdot 40) = 152.70 \text{ kJ / kg} \]

\[ T_e = 28 \degree C, \quad \varphi_e = 100 \% \text{ RH} \quad \text{(assumed)} \]
\[ p_{ws} = 3780 \text{ Pa}, \quad p_w = 3780 \text{ Pa} < 6637.5 \text{ Pa condensation occur} \]
\[ x_f = 0.622 \cdot \frac{3780}{101325 - 3780} = 0.02410 \text{ kg / kg} \]
\[ h_f = 1.01 \cdot 28 + 0.02410(2502 + 1.84 \cdot 28) = 89.82 \text{ kJ / kg} \]

\[ V = \frac{m R_e T}{p} = \frac{0.04360 \cdot 8314.51 \cdot (273.15 + 40)}{18.02 \cdot 6637.5} = 0.94914 \text{ m}^3 \]
\[ \rho = \frac{m}{V} = \frac{1.0 + 0.04360}{0.94914} = 1.09952 \text{ kg / m}^3 \]
\[ m_{\text{moist air}} = V \cdot \rho = 20100 \cdot 1.09952 = 22100.3 \text{ kg / h} \]
\[ m_{\text{dry air}} = \frac{m_{\text{moist air}}}{1.0 + x} = \frac{22100.3}{1.0 + 0.04360} = 21177.0 \text{ kg / h} \]

\text{adiabatic conditions for the dryer} \Rightarrow h_D = h_E

\[ m_{\text{water in dryer}} = m_{\text{dry air}} \left(x_E - x_D\right) \]
\[ x_D = x_E - \frac{m_{\text{water in dryer}}}{m_{\text{dry air}}} = 0.04360 - \frac{500}{21177.0} = 0.01999 \text{ kg / kg} \]
\[ h_D = h_E = 152.70 \text{ kJ / kg} \]

\text{Cooling coil} \Rightarrow x_C = x_D = 0.01999 \text{ kg / kg (no condensation occur)}

\text{Heat transfer to heat pump (evaporator)}
\[ Q_E = m_{\text{dry air}} \left(h_E - h_F\right) = \frac{21177.0}{3600} \left(152.70 - 89.82\right) = 369.89 \text{ kW} \]

\text{Condenser} \Rightarrow x_E = x_C = 0.01999 \text{ kg / kg}
Mixing rate of outdoor air (mix)
\[ x_m = (\text{mix}) \cdot x_d + (1 - \text{mix}) \cdot x_f \]
\[ \text{mix} = \frac{x_d - x_f}{x_d - x_f} = \frac{0.01999 - 0.02410}{0.00595 - 0.02410} = 0.226 \]

Amount of outdoor air: 22.6%

\[ m_{\text{dry air}, a} = 0.226 \cdot 21177.0 = 4795.5 \text{ kg / h} \]
\[ h_b = (\text{mix}) \cdot h_d + (1 - \text{mix}) \cdot h_f \]
\[ h_b = 0.226 \cdot 29.17 + (1 - 0.226) \cdot 89.82 = 76.11 \text{ kJ / kg} \]

\[ Q_{\text{condenser}} = m_{\text{dry air}} (h_c - h_b) = \text{need to calculate } h_c \]

From (log P – h) diagram for R717 we read:
- after evaporator: \( h_1 = 1780 \text{ kJ / kg} \) (1460 kJ / kg from CATT2)
- after compressor: \( h_2 = 2100 \text{ kJ / kg} \) (1776 kJ / kg from CATT2)
- after condenser: \( h_3 = 1010 \text{ kJ / kg} \) (700.6 kJ / kg from CATT2)
- before evaporator: \( h_4 = h_1 = 1010 \text{ kJ / kg} \) (700.6 kJ / kg from CATT2)

\[ Q_L = m_{R717} (h_3 - h_1) \]
\[ m_{R717} = \frac{Q_L}{h_3 - h_1} = \frac{369.89}{(1780 - 1010)} = 0.4804 \text{ kg / s} \]

\[ W_{\text{comp}} = m_{R717} (h_5 - h_4) = 0.4804(2100 - 1780) = 153.72 \approx 154 \text{ kW} \]

Heat transfer from condenser:
\[ Q_H = m_{R717} (h_3 - h_1) = 0.4804(2100 - 1010) = 523.61 \text{ kW} \]

This heat will heat the mixed air flow
\[ Q_H = m_{\text{dry air}} (h_c - h_b) \]
\[ h_c = \frac{Q_H}{m_{\text{dry air}}} + h_b = \frac{523.61}{21177.0} + 76.11 = 165.12 \text{ kJ / kg} \]

Adiabatic conditions in dryer \( \Rightarrow h_o = h_f = 152.70 \text{ kJ / kg} \)
\[ Q_{\text{cooling coil}} = m_{\text{dry air}} (h_c - h_f) = \frac{21177.0}{3600} (165.12 - 152.70) = 73.07 \approx 73 \text{ kW} \]

Wood dryer using only outdoor air consumes about 456 kW of heat
Wood dryer with a mechanical heat pump consumes electricity 154 kW and delivers 75 kW of heat

ps: no efficiency have been included.