MEBS6006 Environmental Services 1

<u>Exercises on 'Advanced Psychrometry'</u>

All data obtained from the psychrometric chart are based on ASHRAE Psychrometric Calculator.

1. <u>Moist Air Sensible Heating</u>

Moist air at state 1 is heated up by a heating medium (e.g. electric heater or heating coil) to state 2. Find the rate of heating.

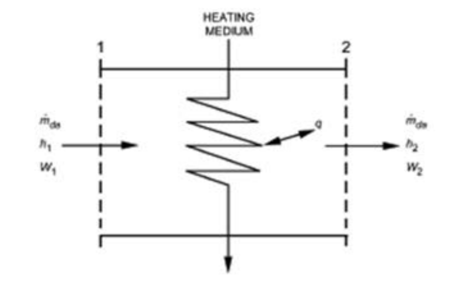
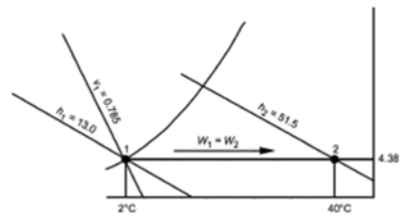


Fig. 2 Schematic of Device for Heating Moist Air



Volume flowrate $\dot{V}$ = 10m^3/s

State 1: moist air saturated at 2°C

State 2: moist air at 40°C

Energy equation:

$q = \dot{m}_{da}(h_2 - h_1)$

The properties of moist air at state 1 and state 2 are obtained:

State 1: air saturated at 2°C

h_1 = 12.98 kJ/kg$_{da}$

W_1 = 4.381 g/kg$_{da}$

v_1 = 0.7848 m^3/kg$_{da}$

Thus

$\dot{m}_{da} = \frac{\dot{V}}{v_1} = \frac{10}{0.7948} = 12.74$ kg$_{da}$/s

State 2: moist air at 40°C

$W_2 = W_1$ = 4.381 g/kg$_{da}$ (for sensible heating, no change in moisture ratio)

Thus

h_2 = 51.48 kJ/kg$_{da}$

$q = \dot{m}_{da}(h_2 - h_1) = 12.74(51.48 - 12.98) = 491$ kW

2. <u>Moist Air Cooling and Dehumidification</u>

Moist air at state 1 is cooled and dehumidified by a cooling coil to state 2. Water is condensed out from the air path. Find the heat absorbed by the cooling coil.

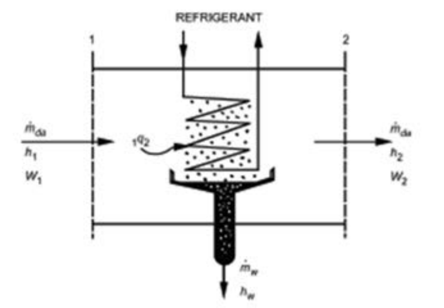


Fig. 3 Schematic of Device for Cooling Moist Air

Volume flowrate $\dot{V}$ = 5m^3/s

State 1: moist air saturated at 30°C DB, 50% RH

State 2: moist air saturated at 10°C

Water condensed out at 10°C

Energy and mass equations

$\dot{m}_{da}h_1 = \dot{m}_{da}h_2 + q + \dot{m}_w h_w$

$\dot{m}_{da}W_1 = \dot{m}_{da}W_2 + \dot{m}_w$

The properties of moist air at state 1 and state 2 are obtained:

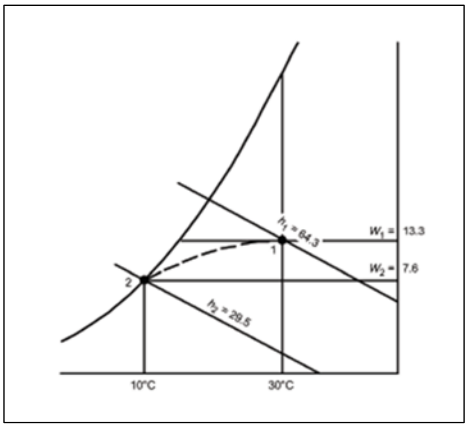
State 1: moist air saturated at 30°C DB, 50% RH

h_1 = 64.33 kJ/kg$_{da}$

W_1 = 13.369 g/kg$_{da}$

v_1 = 0.8769 m^3/kg$_{da}$

Thus
$\dot{m}_{da} = \frac{\dot{V}}{v_1} = \frac{5}{0.8769} = 5.70$ kg_{da}/s



State 2: moist air saturated at 10°C
h_2 = 29.35 kJ/kg_{da}
W_2 = 7.660 g/kg_{da}

Water condensed out at 10°C
h_w = 42.02 kJ/kg_w

$\dot{m}_{da} W_1 = \dot{m}_{da} W_2 + \dot{m}_w$
$\dot{m}_w = \dot{m}_{da}(W_1 - W_2) = 5.70 \times (13.369 - 7.660) = 32.54$ g/s

$\dot{m}_{da} h_1 = \dot{m}_{da} h_2 + q + \dot{m}_w h_w$
$q = \dot{m}_{da}(h_1 - h_2) - \dot{m}_w h_w = 5.70 \times (64.33 - 29.35) - (32.54/1000) \times 42.02$
$q = 198$kW

3. <u>Adiabatic Mixing</u>
Two streams of moist air at State 1 and State 2 are mixed adiabatically. What is the condition of the air and volume of the final mixture?

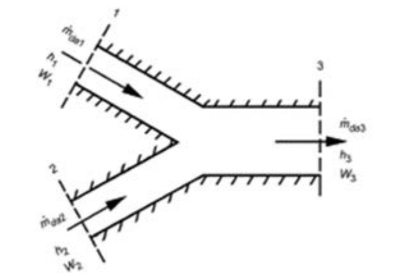


Fig. 6 Adiabatic Mixing of Two Moist Airstreams

State 1: air at 4°C DB, 2°C WB, volume flowrate 2m^3/s
State 2: air at 25°C DB, 50% RH, volume flowrate 6.25m^3/s

Energy and Mass equations
$\dot{m}_{da1} h_1 + \dot{m}_{da2} h_2 = \dot{m}_{da3} h_3$
$\dot{m}_{da1} + \dot{m}_{da2} = \dot{m}_{da3}$
$\dot{m}_{da1} W_1 + \dot{m}_{da2} W_2 = \dot{m}_{da3} W_3$

The properties of moist air at state 1 and state 2 are obtained:
State 1: air at 4°C DB, 2°C WB, volume flowrate 2m^3/s
h_1 = 12.98 kJ/kg_{da}
W_1 = 3.571 g/kg_{da}
v_1 = 0.7893 m^3/kg_{da}
Thus
$\dot{m}_{da1} = \frac{\dot{V}}{v_1} = \frac{2}{0.7893} = 2.53$ kg_{da}/s

State 2: air at 25°C DB, 50% RH, volume flowrate 6.25m^3/s
h_2 = 50.40 kJ/kg_{da}
W_2 = 9.923 g/kg_{da}
v_2 = 0.8578 m^3/kg_{da}
Thus
$\dot{m}_{da2} = \frac{\dot{V}}{v_2} = \frac{6.25}{0.8578} = 7.29$ kg_{da}/s

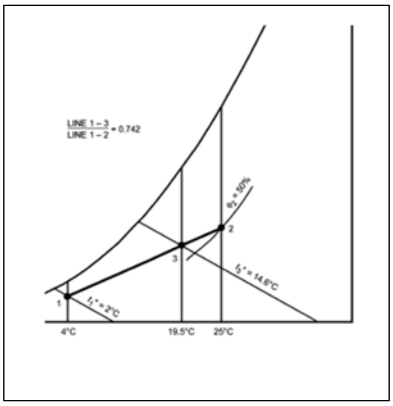
$\dot{m}_{da3} = m_{da1} + \dot{m}_{da2} = 2.53 + 7.29 = 9.82$ kg_{da}/s

$\dot{m}_{da1} h_1 + \dot{m}_{da2} h_2 = \dot{m}_{da3} h_3$
$(2.53 \times 12.98) + (7.29 \times 50.40) = 9.82 h_3$
$h_3 = 40.76$ kJ/kg_{da}

$\dot{m}_{da1}W_1 + \dot{m}_{da2}W_2 = \dot{m}_{da3}W_3$
$(2.53 \times 3.571) + (7.29 \times 9.923) = 9.82W_3$
$W_3 = 8.286$ g/kg$_{da}$

Using the enthalpy h_3 and moisture ratio W_3, the condition of the mixed air is obtained
DB = 19.71 °C
WB = 14.59 °C
RH = 57.79%
v_3 = 0.840 m^3/kg$_{da}$
Thus volume flowrate
$\dot{V}_3 = 9.82 \times 0.84 = 8.25$ m^3/s

On the psychrometric chart, it is also possible to draw a straight line between the points of State 1 and State 2, then find State 3 directly.



Using the equations
$\dot{m}_{da1}h_1 + \dot{m}_{da2}h_2 = \dot{m}_{da3}h_3$
$\dot{m}_{da1} + \dot{m}_{da2} = \dot{m}_{da3}$

$$\frac{\dot{m}_{da1}}{\dot{m}_{da2}} = \frac{h_2 - h_3}{h_3 - h_1}$$

By drawing a straight line and mark the appropriate ratio, the location of State 3 can also be identified.

4. <u>Adiabatic Mixing of Water Injected into Moist Air</u>
Moist air at State 1 is injected with steam to reach State 2. Find the dry bulb temperature of the State 2 air and the amount of steam injected.

State 1: DB 20°C, WB 8°C, $\dot{m}_{da}$ = 2kg$_{da}$/s
State 2: moist air with dew point at 13°C
Steam injected at 110°C

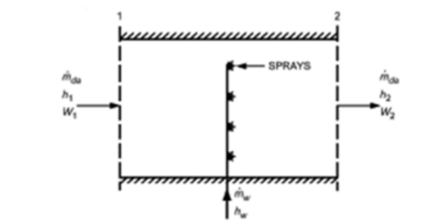


Fig. 8 Schematic Showing Injection of Water into Moist Air

Energy and Mass equations
$\dot{m}_{da}h_1 + \dot{m}_w h_w = \dot{m}_{da}h_2$
$\dot{m}_{da}W_1 + \dot{m}_w = \dot{m}_{da}W_2$

State 1 condition: h_1= 24.685 kJ/kg$_{da}$, W_1 = 1.81 g/kg$_{da}$
State 2 condition: W_2 = 9.37 g/kg$_{da}$
Steam condition: h_w = 2691.07 kJ/kg$_w$
$\dot{m}_{da}W_1 + \dot{m}_w = \dot{m}_{da}W_2$
$\dot{m}_w = 2 \times (9.37 - 1.81) = 15.12$ g/s (steam flow)

$\dot{m}_{da}h_1 + \dot{m}_w h_w = \dot{m}_{da}h_2$
$$(2 \times 24.685) + \left(\frac{15.12}{1000} \times 2691.07\right) = 2h_2$$
$h_2 = 45.03$ kJ/kg$_{da}$

State 2 condition: 21.1°C DB, 16.1°C WB

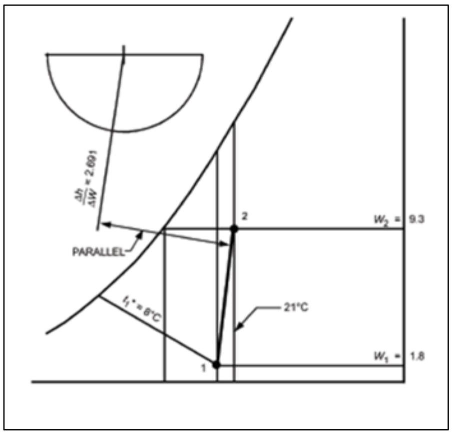
The equations can be rearranged as

$$\dot{m}_w h_w = \dot{m}_{da}(h_2 - h_1)$$
$$\dot{m}_w = \dot{m}_{da}(W_2 - W_1)$$

Thus

$$h_w = \frac{(h_2 - h_1)}{(W_2 - W_1)} = \frac{\Delta h}{\Delta W}$$

Using the $\frac{\Delta h}{\Delta W}$ relationship, it is possible to plot a parallel line from State 1 and project it to State 2.



5. Space Heat Absorption and Moisture Gain

A certain amount of sensible heat q_s (kW) and moisture is absorbed in the space moist air. If the space has a controlled temperature and humidity while the supply air is maintained at a constant temperature, what is the condition of the supply air? Determine the volume flowrate of the supply air.

State 1: supply air at 15°C DB
State 2: space air at 25°C DB, 19°C WB → h_2 = 54.008 kJ/kg$_{da}$, W_2 = 11.34 g/kg$_{da}$
Sensible heat gain = 9kW
Moisture gain $\dot{m}_w$= 0.0015 kg$_w$/s at 30°C → h_w = 2555.58 kJ/kg$_w$

Energy and Mass equations

$$\dot{m}_{da} h_1 + q_s + \sum \dot{m}_w h_w = \dot{m}_{da} h_2$$
$$\dot{m}_{da} W_1 + \sum \dot{m}_w = \dot{m}_{da} W_2$$

There are 3 unknowns in this system: $\dot{m}_{da}$, h_2, W_2, thus it is best to solve it graphically using the psychrometric chart

Combining the two equations

$$\frac{\Delta h}{\Delta W} = \frac{h_2 - h_1}{W_2 - W_1} = \frac{q_s + \sum \dot{m}_w h_w}{\sum \dot{m}_w} = \frac{9 + (0.0015 \times 2555.58)}{0.0015} = 8555.58$$ kJ/kg$_w$ = 8.56 kJ/g$_w$

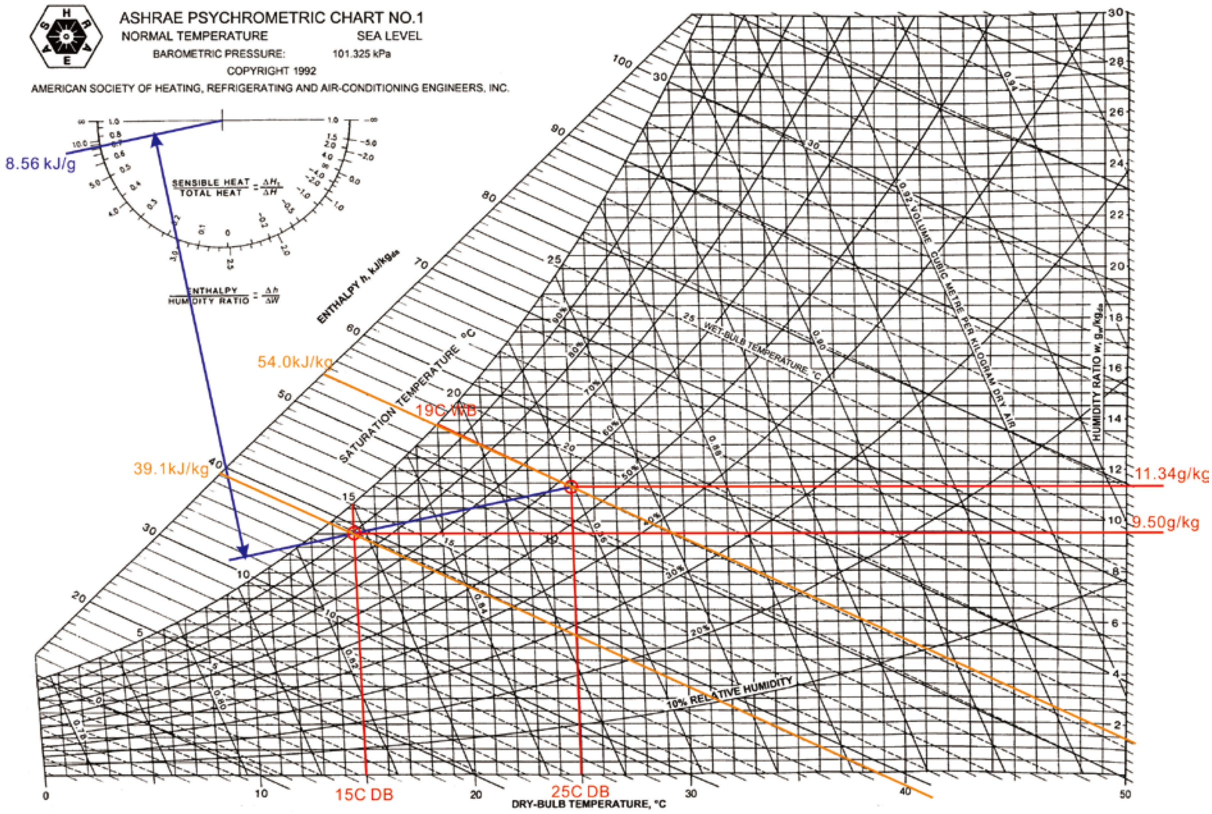
From the psychrometric chart, supply air condition is RH ~ 89% at 15°C,
thus h_1 = 39.088 kJ/kg$_{da}$, W_1 = 9.50 g/kg$_{da}$

Substituting into the energy balance equation

$$\dot{m}_{da} = \frac{9 + (0.0015 \times 2555.58)}{(54.01 - 39.09)} = 0.86$$ kg$_{da}$/s

Specific volume of supply air = 0.828 m^3/kg$_{da}$

Supply volume = 0.86 kg$_{da}$/s × 0.828 m^3/kg$_{da}$ = 0.71 m^3/s


ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
SEA LEVEL
BAROMETRIC PRESSURE: 101.325 kPa
COPYRIGHT 1992
AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SENSIBLE HEAT / TOTAL HEAT = ΔHs / ΔH
ENTHALPY / HUMIDITY RATIO = Δh / ΔW
8.56 kJ/g
ENTHALPY h, kJ/kg da
SATURATION TEMPERATURE °C
54.0kJ/kg
19C WB
39.1kJ/kg
WET-BULB TEMPERATURE, °C
VOLUME CUBIC METRE PER KILOGRAM DRY AIR
HUMIDITY RATIO w, gw/kg da
11.34g/kg
9.50g/kg
10% RELATIVE HUMIDITY
15C DB
25C DB
DRY-BULB TEMPERATURE, °C