

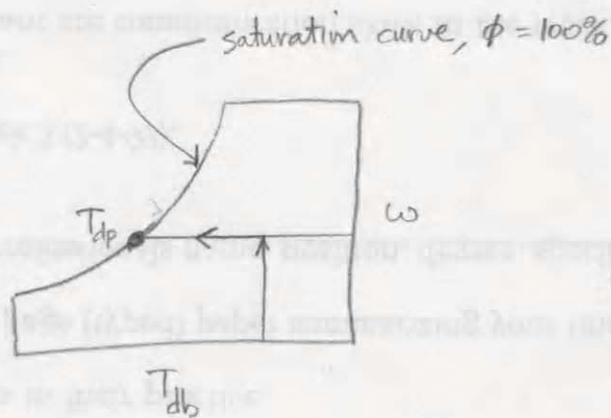
Psychrometric Chart

The thermodynamic state of moist air is determined by three properties, e.g. p, T_{db}, ϕ or p, T_{db}, ω or ...

For the purpose of air-conditioning design calculations we usually fix the pressure at 1 atm. (Psychrometric charts are available for other pressures.)

If the pressure is fixed only two remaining properties are needed to completely specify the state of moist air.

A psychrometric chart presents all the mixture properties of moist air over a range of conditions. The two primary axes are dry bulb temperature and humidity ratio



arrows indicate how to read T_{dp} for a given T_{db} and ω

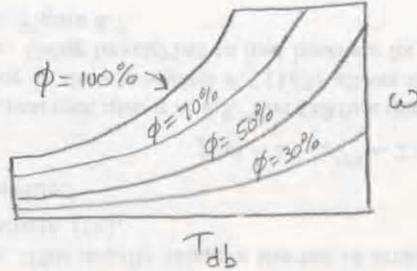
$$\omega = \frac{m_w}{m_a}$$

On a psychrometric chart ω may have units of $\frac{\text{gm water}}{\text{kg dry air}}$, or $\frac{\text{lb}_m \text{ water}}{\text{lb}_m \text{ dry air}}$ or grains

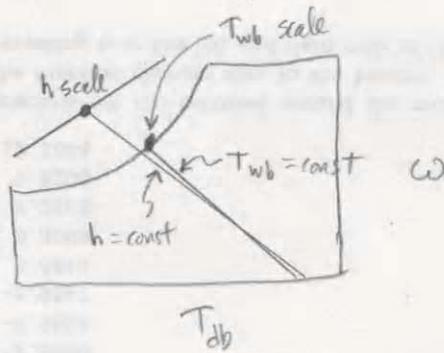
$$1 \text{ lb}_m = 7000 \text{ grains}$$

Psychrometric Chart - continued

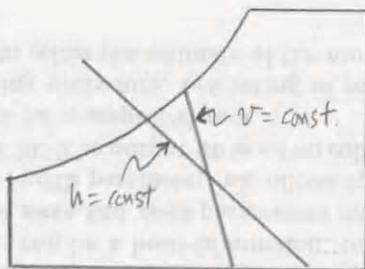
curves of constant ϕ



lines of constant h and constant T_{wb}

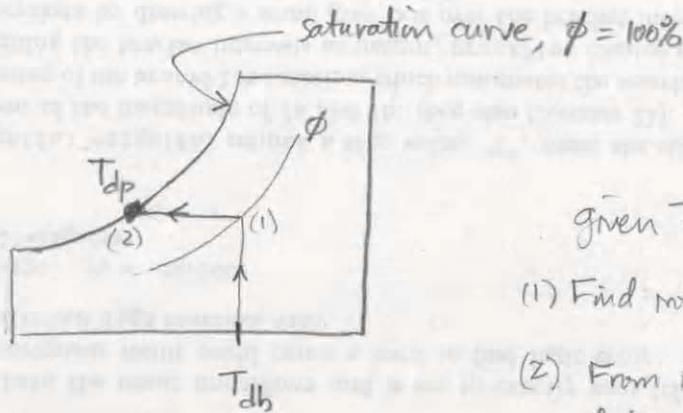


lines of constant v



Psychrometric Chart continued

Reading dew point temperature

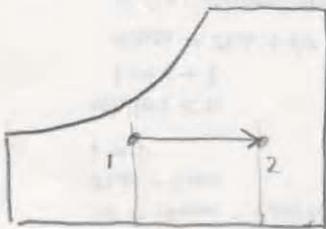


given T_{db} and ϕ :

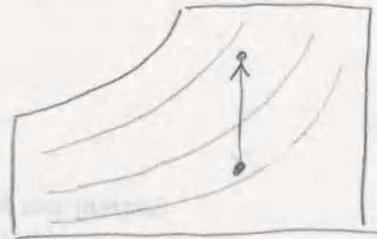
- (1) Find intersection of T_{db} and ϕ
- (2) From intersection of T_{db} and ϕ , follow line of constant ω to the saturation curve. Read T_{dp} from tick marks on saturation curve.

Basic A-C Processes - simple heating (cooling) and simple humidification (dehumidification)

Heating only



Humidification only:



simple heating results in a change in T_{db} without any change in ω . Note that ϕ does change.

Simple humidification results in a change in ω without any change in T_{db} .

⇒ Many A-C processes involve heating (cooling) and humidification (dehumidification)

Air-Conditioning Processes

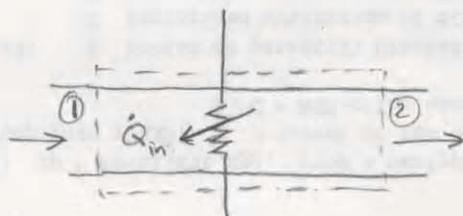
We will now examine several basic A-C processes.

We develop the mass and energy conservation relationships for each process and indicate the starting and ending states on a psychrometric chart.

Simple Heating (or simple cooling)

In simple heating or cooling, T_{db} changes while ω is constant.

Apparatus:



Analysis:

mass conservation: $\dot{m}_{a,1} = \dot{m}_{a,2} = \dot{m}_a$

$$\dot{m}_{a,1} \omega_1 = \dot{m}_{a,2} \omega_2$$

sub $\dot{m}_{a,1} = \dot{m}_{a,2} = \dot{m}_a$: $\dot{m}_a \omega_1 = \dot{m}_a \omega_2$

$$\therefore \omega_1 = \omega_2$$

energy conservation:

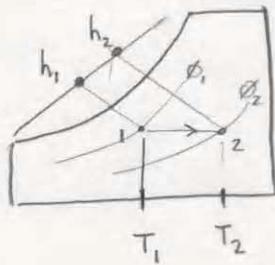
$$\dot{Q}_m - \dot{W}_{out} = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_m h_m$$

$$\boxed{\dot{Q}_m = \dot{m}_a (h_2 - h_1)}$$

Simple Heating (continued)

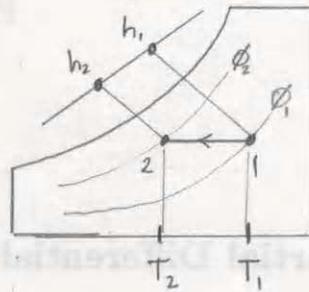
On a psychrometric chart, simple heating or cooling processes have end states on a horizontal ($\omega = \text{constant}$) line

Heating



heating $\phi_2 < \phi_1$ and $\omega_2 = \omega_1$

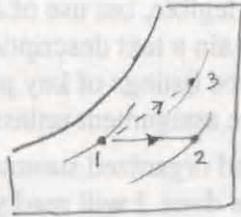
Cooling



cooling: $\phi_2 > \phi_1$, $\omega_2 = \omega_1$

Heating with Humidification

First consider a simple heating process.



When air is heated without moisture addition the relative humidity is decreased

$$\omega_2 = \omega_1 \text{ but } \phi_2 < \phi_1$$

ϕ_2 may be so low that the room environment becomes uncomfortable.

Depending on state of the supply air (the air entering the heating unit), it may be desirable to heat and humidify the air. This corresponds to process 1 \rightarrow 3 in the preceding sketch. The goal is to provide a comfortable environment for the humans occupying the space.

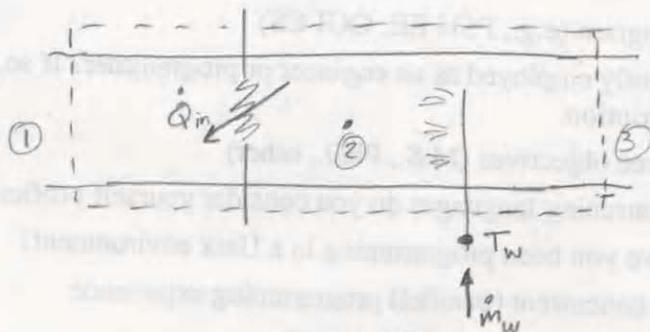
Two basic types of humidification

(1) Steam injection: adds sensible energy and moisture to the air

(2) water spray: Energy required to evaporate the water will remove some sensible heat from the moist air mixture. If the water is preheated the sensible heat loss of the moist air can be minimized or overcome. Think about how a hot shower can heat up a small bathroom.

Heating with Humidification (continued)

Apparatus:



Analysis: Use alternative analysis from Cengel and Boles
 - combine heating and humidification in one step

Assume that $T_1, \omega_1, T_3, \omega_3, \dot{m}_a$ and T_w are known

mass conservation: $\dot{m}_{a1} = \dot{m}_{a3} = \dot{m}_a$

$$\dot{m}_a \omega_1 + \dot{m}_w = \dot{m}_a \omega_3$$

$$\Rightarrow \dot{m}_w = \dot{m}_a (\omega_3 - \omega_1)$$

Conclusion: if we know ω_1 and \dot{m}_a , the \dot{m}_w can be computed with preceding equation

Energy conservation

$$\dot{Q}_{in} - \dot{W}_{out} = \sum \dot{m}_{out} h_{out} - \sum \dot{m}_m h_{in}$$

$$\dot{Q}_{in} = \dot{m}_a h_3 - \dot{m}_a h_1 - \dot{m}_w h_w$$

$$= \dot{m}_a [h_3 - h_1 - (\omega_3 - \omega_1) h_w]$$

Heating with Humidification (continued)

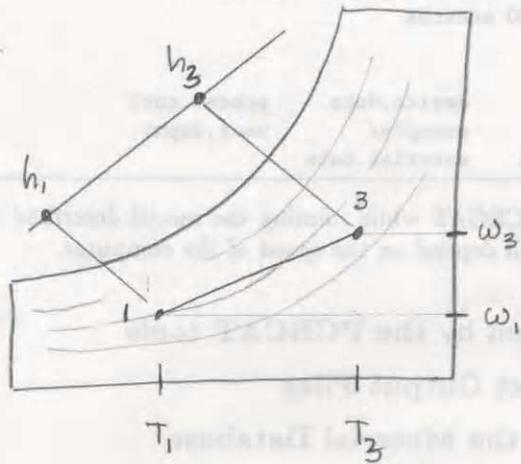


Figure 2 is shown below from the psychrometric chart. The process line is a straight line connecting point 1 to point 3. The process is heating and humidification. The initial state is 1 and the final state is 3. The humidity ratio increases from ω_1 to ω_3 and the temperature increases from T_1 to T_3 .

3.2 Cooling and Dehumidification

The process involves cooling and dehumidification. The process line is a straight line connecting point 1 to point 2. The humidity ratio decreases from ω_1 to ω_2 and the temperature decreases from T_1 to T_2 .

- The process line is a straight line connecting point 1 to point 2.
- The humidity ratio decreases from ω_1 to ω_2 .
- The temperature decreases from T_1 to T_2 .
- The process is cooling and dehumidification.

3.3 A Simple RHP

The process involves heating and humidification. The process line is a straight line connecting point 1 to point 3. The humidity ratio increases from ω_1 to ω_3 and the temperature increases from T_1 to T_3 .

- The process line is a straight line connecting point 1 to point 3.
- The humidity ratio increases from ω_1 to ω_3 .
- The temperature increases from T_1 to T_3 .
- The process is heating and humidification.

Air at 1 atm is to be heated and humidified from 10°C and 30% relative humidity to 25°C and 60% relative humidity. The volumetric flow rate leaving the heater/humidifier is $45 \text{ m}^3/\text{min}$. Compare the difference in sensible heat input for two humidification strategies.

a.) saturated steam injection

b.) spray of liquid water at 50°C

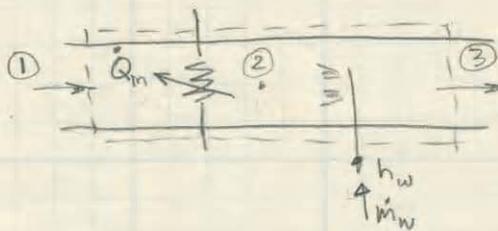
Schematic:

Analysis:

(1) Write down governing equations and simplify to obtain an equation for \dot{Q}_m , the sensible heat input

(2) Write down values of thermodynamic properties needed to compute \dot{Q}_m from the preceding equations

(3) Evaluate \dot{Q}_m for the two cases

SWR's solutionSchematic:Analysis:

mass conservation: $\dot{m}_{a1} = \dot{m}_{a3}$ $\dot{m}_{a1}\omega_1 + \dot{m}_w = \dot{m}_{a3}\omega_3$

$$\Rightarrow \dot{m}_w = \dot{m}_a(\omega_3 - \omega_1)$$

also $\dot{m}_a = \rho_3 \dot{V}_3$ $\dot{V} = 45 \text{ m}^3/\text{min} = \text{volumetric flow rate at 3}$

energy conservation: $\dot{Q}_m = \dot{m}_{a3}h_3 - \dot{m}_wh_w - \dot{m}_{a1}h_1$

$$= \dot{m}_a [h_3 - h_1 - (\omega_3 - \omega_1)h_w]$$

Thermodynamic Properties: read from psychrometric chart and saturation tables

state 1: $T_1 = 10^\circ\text{C}$, $\phi_1 = 30\%$

$$\Rightarrow \omega_1 = 0.0024 \frac{\text{kg H}_2\text{O}}{\text{kg dry air}} \quad h_1 = 15.5 \frac{\text{kJ}}{\text{kg dry air}}$$

state 3: $T_3 = 25^\circ\text{C}$, $\phi = 60\%$

$$\Rightarrow \omega_3 = 0.012 \frac{\text{kg H}_2\text{O}}{\text{kg dry air}} \quad h_3 = 55.7 \frac{\text{kJ}}{\text{kg dry air}}$$

$$v_3 = 0.861 \text{ m}^3/\text{kg}$$

Saturated steam;

at $T = 100^\circ\text{C}$, $p = 1 \text{ atm}$

$$h_g = 2676.1 \frac{\text{kJ}}{\text{kg}}$$

liquid water:

at $T = 50^\circ\text{C}$

$$h_w \approx h_{f,\text{sat}} = 209.33 \frac{\text{kJ}}{\text{kg}}$$

} Cengel and
Boles
Table A-4
p. 904

GWR's Solution, continued

Evaluate \dot{Q}_m

$$\dot{m}_a = \frac{(45 \frac{\text{m}^3}{\text{min}}) (\frac{1 \text{ min}}{60 \text{ s}})}{(0.861 \frac{\text{m}^3}{\text{kg}})} = 0.871 \frac{\text{kg}}{\text{s}}$$

Steam injection:

$$\dot{Q}_m = (0.871 \frac{\text{kg}}{\text{s}}) \left[55.7 \frac{\text{kJ}}{\text{kg}} - 15.5 \frac{\text{kJ}}{\text{kg}} - (0.012 - 0.0024) 2676.1 \frac{\text{kJ}}{\text{kg}} \right]$$

$$\dot{Q}_m = 12.6 \text{ kW} \quad \underbrace{\hspace{10em}}_{14.5 \frac{\text{kJ}}{\text{kg}}}$$

water spray:

$$\dot{Q}_m = (0.871 \frac{\text{kg}}{\text{s}}) \left[55.7 \frac{\text{kJ}}{\text{kg}} - 15.5 \frac{\text{kJ}}{\text{kg}} - (0.012 - 0.0024) 209.33 \frac{\text{kJ}}{\text{kg}} \right]$$

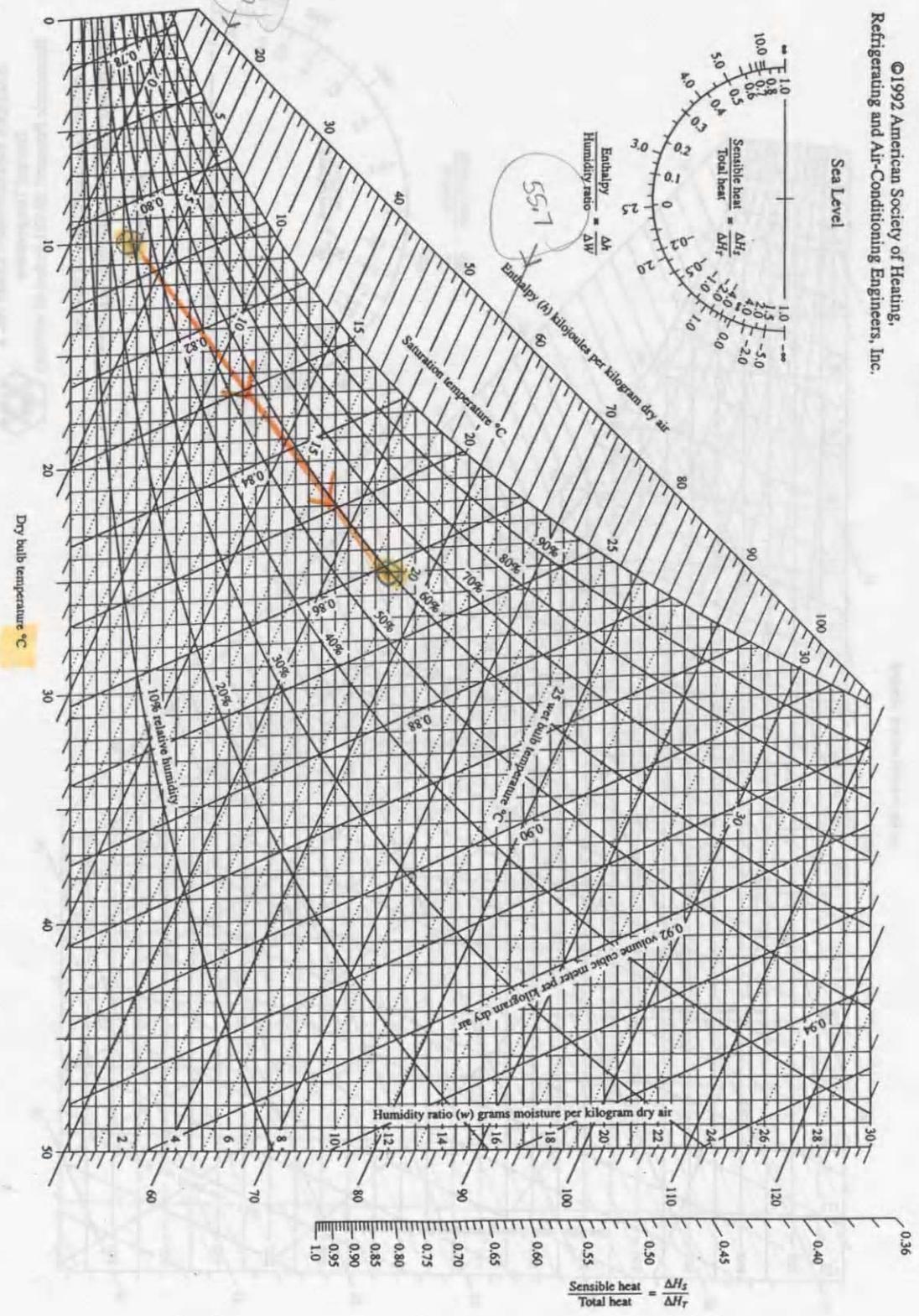
$$\dot{Q}_m = 33.3 \text{ kW} \quad \underbrace{\hspace{10em}}_{38.2 \frac{\text{kJ}}{\text{kg}}}$$

Psychrometric chart at 1 atm total pressure. (Reprinted by permission of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., Atlanta, GA; used with permission.)

ASHRAE Psychrometric Chart No. 1
 Normal Temperature
 Barometric Pressure: 101.325 kPa



©1992 American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.



Prepared by Center for Applied Thermodynamic Studies, University of Idaho.