Chapter 9

Drying of Process Materials

The drying processes discussed in this chapter relate to the removal of water or other organic liquids from solids or fluid substances. The following examples explain different situations where drying and humidity concepts affect the performance of a fuel cell.

9.3-1 Humidity from Vapor – Pressure Data
9.3-2 Use of Humidity Chart
9.3-3 Adiabatic Saturation of Feed Air for Proton – Exchange Membrane Fuel Cells.
9.3-4 Wet Bulb Temperature and Humidity

Example 9.3-1: Humidity from Vapor – Pressure Data

The air in the cathode chamber of a proton – exchange membrane fuel cell is at a temperature of 80°C and a pressure of 1 atm. Determine the partial pressure of water, humidity, saturation humidity, percentage humidity if the air has a relative humidity of 8.55 %.

Strategy

The definitions of the required parameters can be used to solve this problem.

Solution

The following definitions can be used to obtain the solution to this problem:

$$H_R = 100\frac{P_{H_2O}}{\_\_\_\_\_\_}\qquad H_P = 100\frac{H}{H_S}$$

$$H_S = \frac{M_{H_2O}}{M_{Air}}\frac{P^s_{H_2O}}{P - P^s_{H_2O}}\qquad H = \frac{M_{H_2O}}{M_{Air}}\frac{P_{H_2O}}{\_\_\_\_\_\_\_\_\_\_}$$

First we can solve for the partial pressure of water from the equation of relative humidity, as this value is given in the problem statement. Thus,

$$P_{H_2O} = \frac{\_\_\_\_\_\_}{100} = \frac{(8.55)(\_\_\_\_\_\_\ \text{atm})}{100}$$

$$\boxed{P_{H_2O} = 0.04\ \text{atm}}$$

The saturation pressure of water at the temperature of 80°C was obtained from Appendix A.2 of Geankoplis.

The partial pressure of water can now be substituted into the Equation for the absolute humidity H to yield:

$$H = \frac{\dfrac{\_\_\_\_\_\_\ \text{kg } H_2O}{1\ \text{kgmol}}}{\dfrac{\_\_\_\_\_\_\ \text{kg Air}}{1\ \text{kgmol}}}\frac{(0.04\ \text{atm})}{1\ \text{atm} - 0.04\ \text{atm}}$$

$$\boxed{H = \_\_\_\_\_\_\_\ \frac{\text{kg } H_2O}{\text{kg Air}}}$$

In a similar way, we can use the saturation pressure of 0.468 atm obtained from Appendix A.2 to determine the saturation humidity of the air in the fuel cell, as shown in the following steps:

$$H_S = \frac{\dfrac{\_\_\_\_\_\_\_ \text{ kg H}_2\text{O}}{1 \text{ kgmol}}}{\dfrac{\_\_\_\_\_\_\_ \text{ kg Air}}{1 \text{ kgmol}}} \frac{(0.468 \text{ atm})}{1 \text{ atm} - \_\_\_\_\_\_\_ \text{ atm}}$$

$$\boxed{H_S = \_\_\_\_\_\_\_ \frac{\text{kg H}_2\text{O}}{\text{kg Air}}}$$

The only remaining value to be calculated is the percentage humidity H_P from the ratio of the absolute humidity to the saturation humidity. Therefore,

$$H_P = 100 \left(\frac{0.026 \dfrac{\text{kg H}_2\text{O}}{\text{kg Air}}}{\_\_\_\_\_\_\_ \dfrac{\text{kg H}_2\text{O}}{\text{kg Air}}} \right)$$

$$\boxed{H_P = \_\_\_\_\_\_\_ \%}$$

Example 9.3-2: Use of Humidity Chart

The air in a fuel cell has a dry – bulb temperature of 80°C and a humidity of $0.035\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$. Use the humidity chart to determine the percentage humidity H_P, humid volume υ_H, humid heat C_S, and dew point of this air/steam mixture.

Strategy

We can locate the given information in the humidity chart to determine the values required to solve this problem.

Solution

First we locate the point that corresponds to a humidity of $H = 0.035\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$ at a temperature of 80°C. From this point we can move horizontally to the left until reaching the saturation line (H_P = 100%). The temperature in this point corresponds to the dew point, found to be:

$$\boxed{T_{sat} = \underline{\qquad\qquad}\ ^{\circ}\text{C}}$$

At the point we located initially for the dry bulb temperature and absolute humidity, we can read directly the percentage humidity. For the air in the fuel cell, we find that:

$$\boxed{H_P = \underline{\qquad\qquad}\ \%}$$

In section 9.3B of Geankoplis, we are given the following equations for the humid heat and volume as a function of the absolute humidity:

$$\upsilon_H = \left[\left(2.83\times10^{-3}\right) + \left(4.56\times10^{-3}H\right)\right]T$$

$$C_S = \underline{\qquad\qquad\qquad\qquad\qquad\qquad}$$

In these equations, υ_H is in $\frac{\text{m}^3}{\text{kg dry air}}$, H is in $\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$, T is in K, and C_S is in $\frac{\text{kJ}}{\text{kg dry air}\cdot\text{K}}$. Entering the humidity and the temperature into these equations, we get:

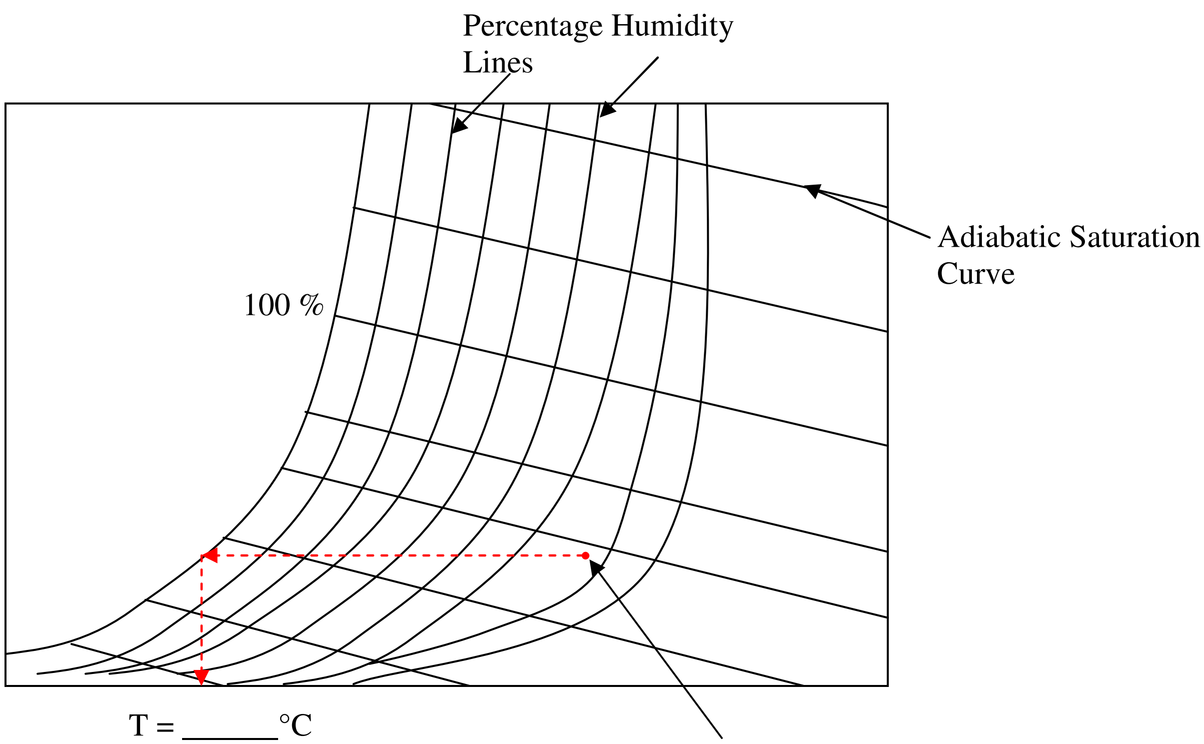
$$\upsilon_H = \left\{\left(2.83\times10^{-3}\right) + \left[4.56\times10^{-3}\left(0.035\frac{\text{kg H}_2\text{O}}{\text{kg Air}}\right)\right]\right\}\left(\underline{\qquad\qquad}\ \text{K}\right)$$

$$\boxed{\upsilon_H = \underline{\qquad\qquad\qquad}\ \frac{\text{m}^3}{\text{kg dry air}}}$$

$$C_S = 1.005 + 1.88\left(0.035\frac{\text{kg H}_2\text{O}}{\text{kg Air}}\right)$$

$$\boxed{C_S = \_\_\_\_\_\_\_\_ \frac{\text{kJ}}{\text{kg dry air}\cdot\text{K}}}$$

The following figure illustrates how to determine the saturation temperature and percentage humidity from the chart:



Initial point corresponding to $T = 80°\text{C}$ and $H = 0.035\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$

This point is also located approximately at a percentage humidity of 6.25%

Example 9.3-3: Adiabatic Saturation of Feed Air for Proton – Exchange Membrane Fuel Cells.

Air to be used as reactant in a PEMFC with an initial humidity of $0.057\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$ enters an adiabatic saturator before being fed to the cathode side of the fuel cell. The air enters the saturator at a dry bulb temperature of 60 °C and must enter the fuel cell with a humidity of $0.063\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$. Determine the final temperature and percent humidity of the air.

Strategy

Both H_P and the temperature of the air entering the fuel cell can be obtained using the humidity chart.

Solution

First we need to locate the point that corresponds to the temperature of 60°C and humidity of $0.057\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$. Once we located this point in the humidity chart, we move parallel to the adiabatic saturation curves, until reaching a point where the absolute humidity is $0.063\frac{\text{kg H}_2\text{O}}{\text{kg Air}}$.

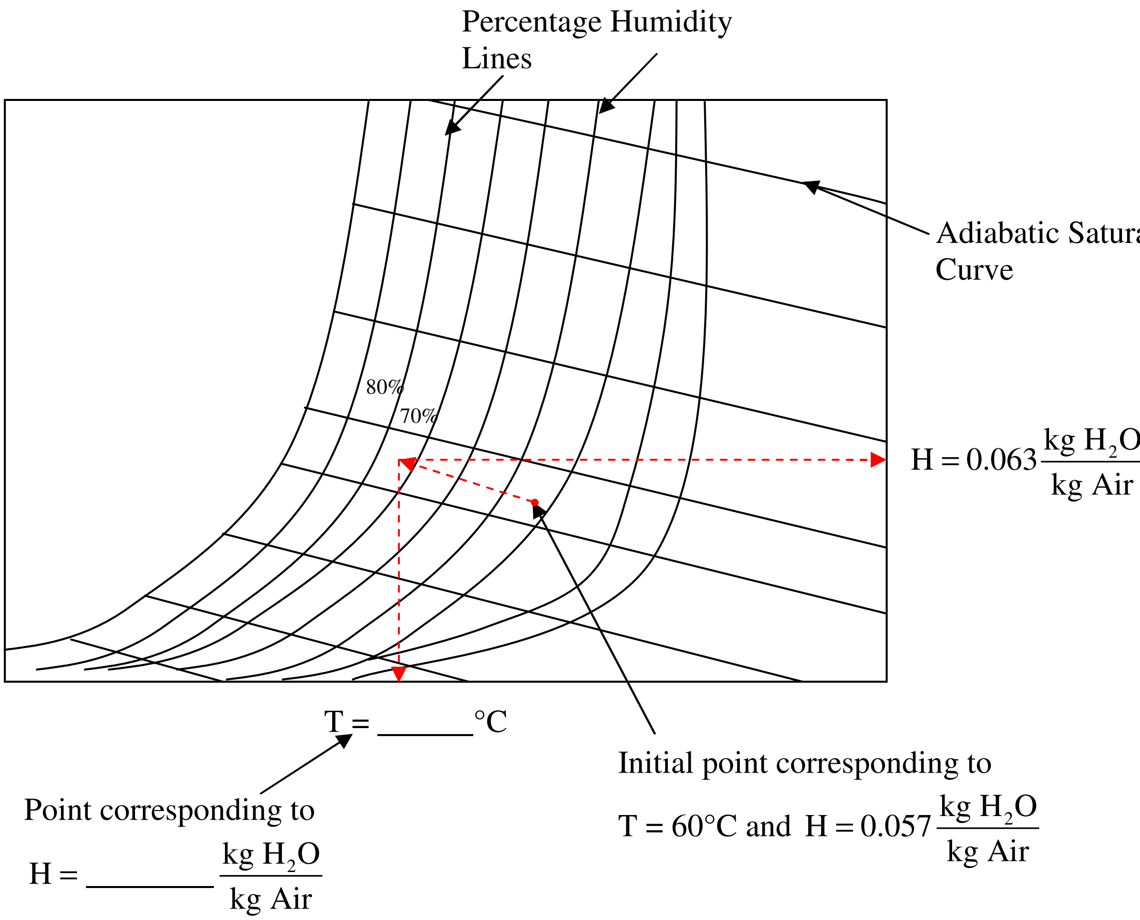
Now we are at the point where the air has the conditions required for entering the fuel cell and therefore we can read the temperature and percentage humidity to be:

$T \approx$ ______ °C

$H_P \approx$ ______ %

In the following page we can see a chart indicating the method to determine these values.

The next chart indicates the procedure followed to determine the temperature and percentage humidity:



Also we can read the percent humidity to be approximately ___ %

Example 9.3-4: Wet Bulb Temperature and Humidity

Estimate the humidity of the reactant air in a proton – exchange membrane fuel cell if it has a dry and wet bulb temperature of 80 °C and 42.5 °C, respectively.

Strategy

The humidity of the air can be determined from the humidity chart using the temperature data given in the problem statement.

Solution

The wet bulb temperature corresponds to the temperature of the air when it has 100 % humidity. Hence, we need to move vertically from the temperature axis in the chart until reaching the curve corresponding to 100 % humidity. From this point we move downwards to the right, parallel to the adiabatic saturation curves until we reach the vertical line for T = 80°C. Now we can read the humidity of the air in the fuel cell to be:

$$H = \_\_\_\_\_\_ \frac{\text{kg } H_2O}{\text{kg Air}}$$

The method to determine the previous humidity value was obtained as follows: