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ESE – 40… ENERGY SYSTEMS LABORATORY - …
Air Conditioning Experiment Report

Student No :
Name-Surname :
Experiment Date :
Grade :

1. EXPERIMENT MANUALS

1.1 Air-conditioning Experiment

1.1.1 Objective

The purpose of this experiment is to introduce air-conditioning unit and to understand basic processes such as heating, cooling, humidification and dehumidification in this device. Also, it is aimed to determine the properties of atmospheric air using psychrometric chart.

1.1.2 Introduction

Human beings have an inherent weakness–they want to feel comfortable. They want to live in an environment that is neither hot nor cold, neither humid nor dry. However, comfort does not come easily since the desires of the human body and the weather usually are not quite compatible. Achieving comfort requires a constant struggle against the factors that cause discomfort, such as high or low temperatures and high or low humidity. Today, modern air-conditioning systems can heat, cool, humidify, dehumidify, clean, and even deodorize the air–in other words, condition the air to peoples' desires.

Air-conditioning systems can be classified according to their applications as comfort air-conditioning systems and process air-conditioning systems. Comfort air-conditioning systems provide occupants with a comfortable and healthy indoor environment in which to carry out their activities. Process air-conditioning systems provide needed indoor environmental control for manufacturing, product storage, or other research and development processes.

Air-conditioning processes include simple heating (raising the temperature), simple cooling (lowering the temperature), humidifying (adding moisture), and dehumidifying (removing moisture). Sometimes two or more of these processes are needed to bring the air to a desired temperature and humidity level.

1.1.3 Theory

1.1.3.1 Dry Air and Atmospheric Air

Air is a mixture of nitrogen, oxygen, and small amounts of some other gases. Air in the atmosphere normally contains some water vapor (or moisture) and is referred to as atmospheric air. By contrast, air that contains no water vapor is called dry air. It is often convenient to treat air as a mixture of water vapor and dry air since the composition of dry air remains relatively constant, but the amount of water vapor changes as a result of condensation and evaporation from oceans, lakes, rivers, showers, and even the human body. Although the amount of water vapor in the air is small, it plays a major role in human comfort. Therefore, it is an important consideration in air-conditioning applications.

For air-conditioning applications, dry air can be treated as an ideal gas with a constant c_p value of 1.005 kJ/kg·K. Taking 0°C as the reference point, the enthalpy and enthalpy change of dry air can be determined from

$$h_a = c_p T = 1.005T \qquad (2.1.1)$$

$$\Delta h_a = c_p \Delta T = 1.005 \Delta T \tag{2.1.2}$$

where T is in °C.

Since the partial pressure of water vapor is very low, it would be very convenient to also treat the water vapor in the air as an ideal gas with negligible error (under 0.2 percent), even when it is a saturated vapor. Therefore, water vapor in air behaves as if it existed alone and obeys the ideal-gas relation. Then, the atmospheric air can be treated as an ideal-gas mixture whose pressure is the sum of the partial pressure of dry air and that of water vapor;

$$P = P_a + P_v \tag{2.1.3}$$

Moreover, since water vapor is an ideal gas, the enthalpy of water vapor is a function of temperature only, that is, $h = h(T)$. Therefore, the enthalpy of water vapor in air can be taken to be equal to the enthalpy of saturated vapor at the same temperature. That is,

$$h_v(T, low\ P) \cong h_g(T) \tag{2.1.4}$$

The enthalpy of water vapor at 0°C is 2500.9 kJ/kg. The average c_p value of water vapor can be taken to be 1.82 kJ/kg·°C. Then the enthalpy of water vapor can be determined approximately from,

$$h_g(T) \cong 2500.9 + 1.82T \tag{2.1.5}$$

where T is in °C.

1.1.3.2 Specific and Relative Humidity of Air

The amount of water vapor in the air can be specified in various ways. One of the most logical way is to specify directly the mass of water vapor present in a unit mass of dry air. This is called *absolute* or *specific humidity* (also called humidity ratio) and is denoted by ω:

$$\omega = \frac{m_v}{m_a} \tag{2.1.6}$$

with the unit of: kg-water vapor/kg-dry air.

It can also be expressed in terms of partial pressures:

$$\omega = 0.622\frac{P_v}{P_a} = 0.622\frac{P_v}{P - P_v} \tag{2.1.7}$$

In another definition, *relative humidity* which is the ratio of amount of moisture the air holds to the maximum amount of moisture the air can hold at the same temperature. That is,

$$\phi = \frac{m_v}{m_g} = \frac{P_v}{P_g} \tag{2.1.8}$$

where P_g is;

$$P_g = P_{sat.@T} \tag{2.1.9}$$

The relative humidity ranges from 0 for dry air to 1 for saturated air. Absolute humidity and relative humidity can be related with the following equations:

$$\phi = \frac{\omega P}{(0.622 + \omega)P_g} \tag{2.1.10}$$

$$\omega = 0.622 \frac{\phi P_g}{P - \phi P_g} \tag{2.1.11}$$

Atmospheric air is a mixture of dry air and water vapor, and thus the enthalpy of air is expressed in terms of the enthalpies of the dry air and the water vapor. In most practical applications, the amount of dry air in the air–water-vapor mixture remains constant, but the amount of water vapor changes. Therefore, the enthalpy of atmospheric air is expressed per unit mass of dry air instead of per unit mass of the air–water vapor mixture. The total enthalpy (an extensive property) of atmospheric air is the sum of the enthalpies of dry air and the water vapor:

$$H = H_a + H_v = m_a h_a + m_v h_v \tag{2.1.12}$$

Dividing by m_a;

$$h = h_a + \omega h_v \tag{2.1.13}$$

with the unit of kJ/kg-dry air.

1.1.3.3 Dry-bulb, Dew Point and Wet-bulb Temperatures

The ordinary temperature of atmospheric air is frequently referred to as the *dry-bulb temperature*.

The *dew-point temperature* is defined as the temperature at which condensation begins when the air is cooled at constant pressure. In other words, it is the saturation temperature of water corresponding to the vapor pressure:

$$T_{dp} = T_{sat.@P_v} \tag{2.1.14}$$

The process is given in Fig. 2.1.1. As the air cools at constant pressure, the vapor pressure P_v remains constant. Therefore, the vapor in the air (state 1) undergoes a constant-pressure cooling process until it strikes the saturated vapor line (state 2). The temperature at this point is T_{dp}, and if the temperature drops any further, some vapor condenses out. The air remains saturated during the condensation process and thus follows a path of 100 percent relative humidity (the saturated vapor line). The ordinary temperature and the dew-point temperature of saturated air are identical.

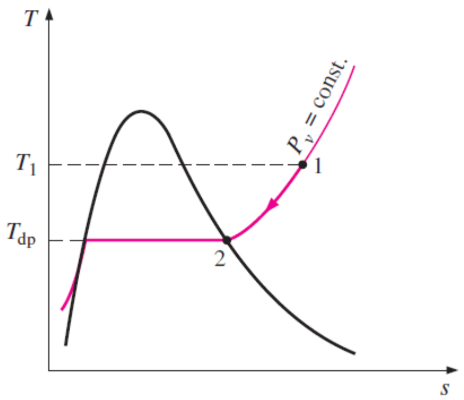


Figure 2.1.1. Constant-pressure cooling of moist air.

Relative humidity and specific humidity are frequently used in engineering and atmospheric sciences, and it is desirable to relate them to easily measurable quantities such as temperature and pressure. One way of determining the relative humidity is to determine the dew-point temperature of air which is discussed above.

A more practical approach is to use a thermometer whose bulb is covered with a cotton wick saturated with water and to blow air over the wick, as shown in Fig. 2.1.2. The temperature measured in this manner is called the *wet-bulb temperature*, and it is commonly used in air-conditioning applications.

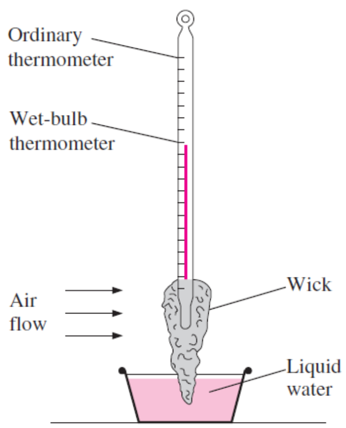


Figure 2.1.2. A simple arrangement to measure the wet-bulb temperature.

The wet-bulb temperature can also be measured by placing the wet-wicked thermometer in a holder attached to a handle and rotating the holder rapidly, that is, by moving the thermometer instead of the air. A device that works on this principle is called a sling psychrometer.

1.1.3.4 The Psychrometric Chart

The state of the atmospheric air at a specified pressure is completely specified by two independent intensive properties. The rest of the properties can be calculated easily from the previous relations. The sizing of a typical air-conditioning system involves numerous such calculations, therefore, there is clear motivation to computerize calculations or to do these calculations once and to present the data in the form of easily readable charts. Such charts are called psychrometric charts, and they are used extensively in air-conditioning applications.

The basic features of the psychrometric chart are illustrated in Fig. 2.1.3. The dry-bulb temperatures are shown on the horizontal axis, and the specific humidity is shown on the vertical axis. On the left end of the chart, there is a curve (called the saturation line) instead of a straight line. All the saturated air states are located on this curve. Therefore, it is also the curve of 100 percent relative humidity. Other constant relative-humidity curves have the same general shape.

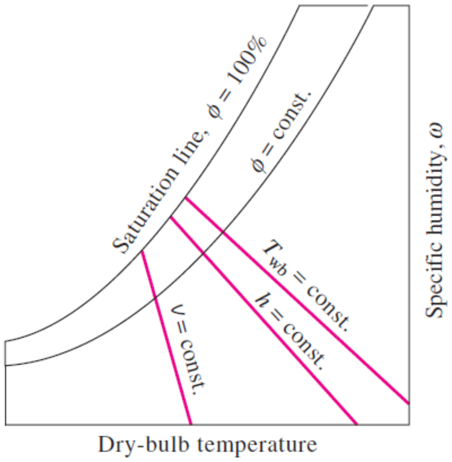


Figure 2.1.3. Schematics for a psychrometric chart.

Psychrometric chart for a pressure of 1 atm (101.325 kPa) is given at the end of the document. Psychrometric charts at other pressures (for use at considerably higher elevations than sea level) are also available in the literature.

1.1.3.5 Air-conditioning Processes

There are four main air-conditioning processes.

- Heating
- Cooling
- Humidification
- Dehumidification

Combinations of these four are frequently applied during the air-conditioning processes. Various air-conditioning processes are illustrated on the psychrometric chart in Fig. 2.1.4. Notice that simple heating and cooling processes appear as horizontal lines on this chart since the moisture content of the air remains constant (ω=constant) during these processes. Air is commonly heated and humidified in winter and cooled and dehumidified in summer. Notice how these processes appear on the psychrometric chart.

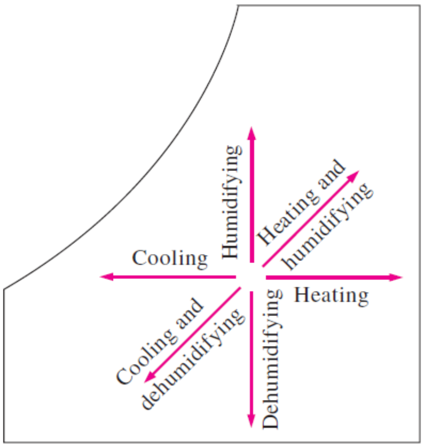


Figure 2.1.4. Various processes shown on a psychrometric chart.

1.1.4 Experimental Set-up

The experimental setup is essentially composed of an air duct and air-conditioning sections are installed along the channel. The schematic view of the device is given in Fig. 2.1.5. The air that will be conditioned in the duct is withdrawn from the medium via a radial fan and directed toward the duct. The channel has heating, cooling, and humidification units in serial. The sensors placed on various locations measure the dry-bulb temperature and relative humidity. Those points are also shown on the figure. Having read the dry-bulb temperature and relative humidity data, the remaining properties of the air are obtained using the psychrometric chart.

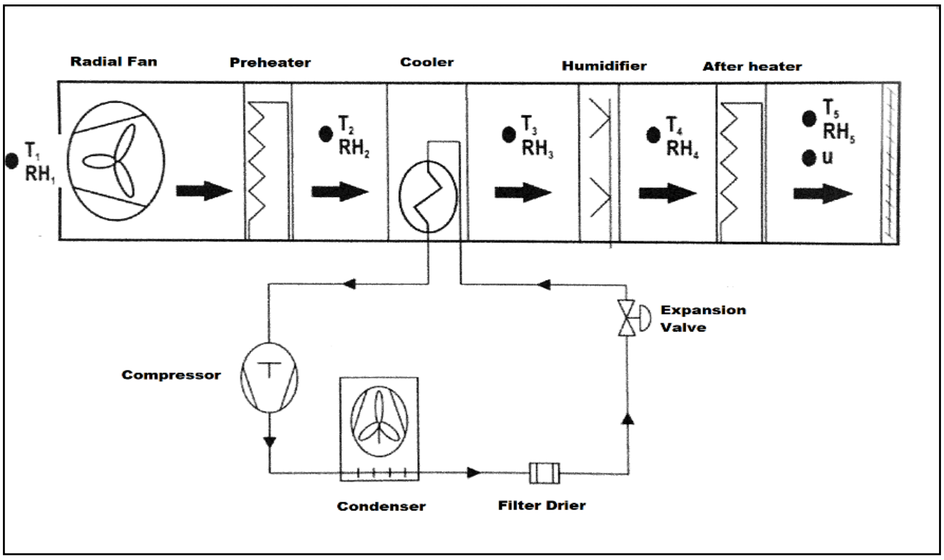


Figure 2.1.5. Schematic view of the experimental set-up.

1.1.4.1 Measurements

For winter session air-conditioning:

Table 2.1.1.

Reading:	**1**	**2**	**3**
T_1 [°C]			
RH_1 [%]			
T_2 [°C]			
RH_2 [%]			
T_4 [°C]			
RH_4 [%]			
T_5 [°C]			
RH_5 [%]			
$P_{preheater}$ $[W]$			
$P_{afterheater}$ $[W]$			
u $[m/s]$			

For summer session air-conditioning:

Table 2.1.2.

Reading:	**1**	**2**	**3**
T_1 [°C]			
RH_1 [%]			
T_3 [°C]			
RH_3 [%]			
T_5 [°C]			
RH_5 [%]			
$P_{afterheater}$ $[W]$			
P_{cooler} $[W]$			
u $[m/s]$			

1.1.4.2 Calculations

Under steady-state conditions, mass and energy balances in psychrometry is given by the following relations.

Continuity equation for dry air:

$$\dot{m}_{a1} = \dot{m}_{a2} = \dot{m}_a \tag{2.1.15}$$

and for water vapor,

$$\dot{m}_{a1}\omega_1 + \dot{m}_w = \dot{m}_{a2}\omega_2 \tag{2.1.16}$$

where $\dot{m}_w$ is zero for simple heating and simple cooling processes.

Energy balance equation:

$$\dot{m}_{a1}h_1 + \dot{m}_w h_w + \dot{Q} = \dot{m}_{a2}h_2 \tag{2.1.17}$$

where $\dot{Q}$ is zero for humidification and dehumidification processes.

In order to calculate mass flow rate of dry air:

$$\dot{m}_a = \frac{\dot{V}}{v} \tag{2.1.18}$$

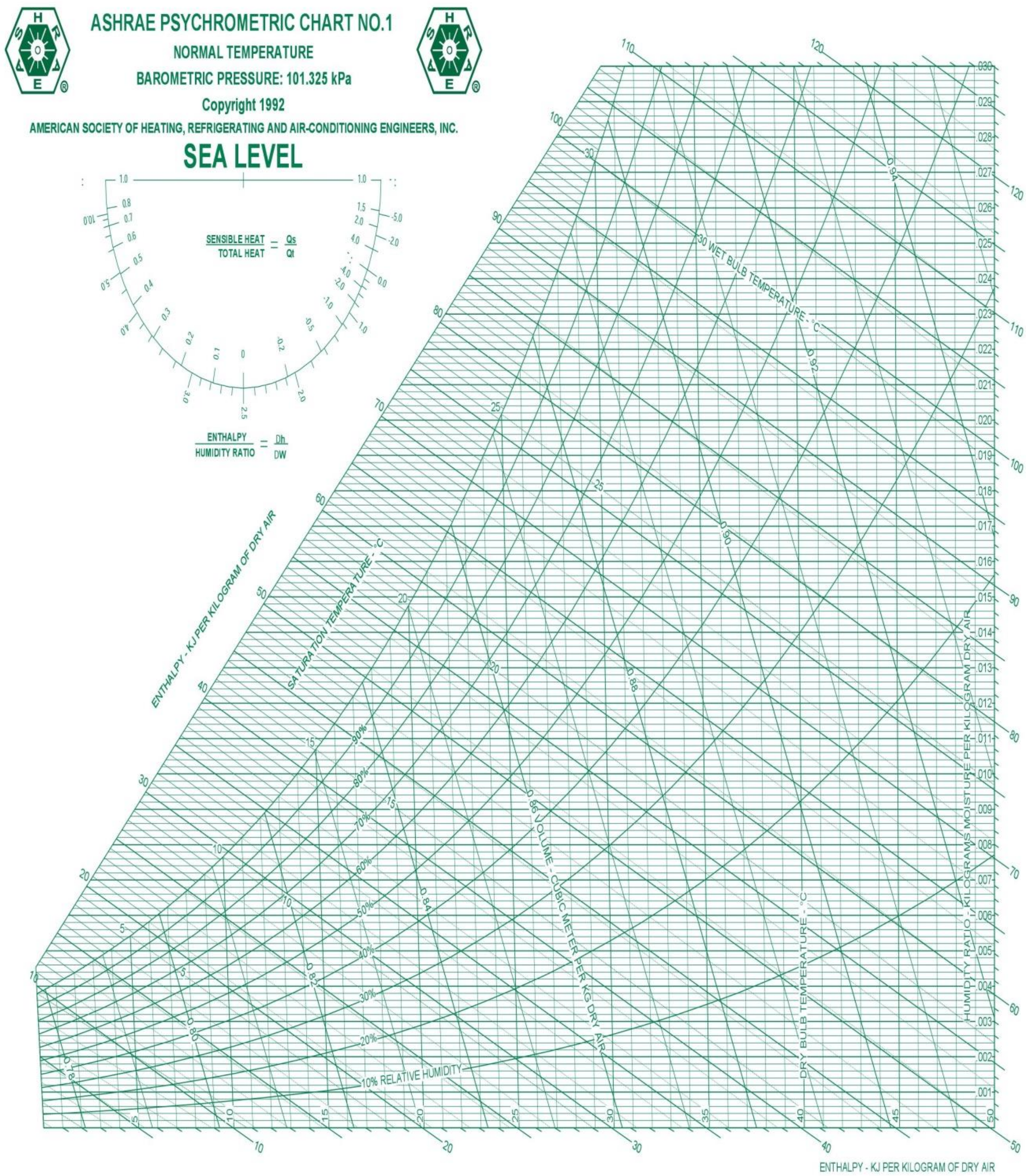
where v is the specific volume of dry air and $\dot{V}$ is the volume flow rate given by:

$$\dot{V} = uA_c \tag{2.1.19}$$

where u is the air velocity and A_c is the cross-sectional area of the duct which is 0.108 m^2.

2.1.5 Report

1) Show the processes on the psychrometric chart.
2) Find the specific humidity and enthalpy values for each point using measured data.
3) Determine the heating, cooling and humidification loads.
4) Determine the efficiencies of heaters, and COP of the refrigeration cycle.


ASHRAE PSYCHROMETRIC CHART NO.1
NORMAL TEMPERATURE
BAROMETRIC PRESSURE: 101.325 kPa
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AMERICAN SOCIETY OF HEATING, REFRIGERATING AND AIR-CONDITIONING ENGINEERS, INC.
SEA LEVEL
SENSIBLE HEAT / TOTAL HEAT = Qs / Qt
ENTHALPY / HUMIDITY RATIO = Dh / DW
ENTHALPY - KJ PER KILOGRAM OF DRY AIR
SATURATION TEMPERATURE - °C
30 WET BULB TEMPERATURE - °C
VOLUME - CUBIC METER PER KG DRY AIR
DRY BULB TEMPERATURE - °C
HUMIDITY RATIO - KILOGRAMS MOISTURE PER KILOGRAM DRY AIR
10% RELATIVE HUMIDITY
20%
30%
40%
50%
60%
70%
80%
90%
ENTHALPY - KJ PER KILOGRAM OF DRY AIR