# Web-based Air Conditioning Experiment - Sample Solution
ME113 – Spring 2003 – Professor Rhee
Name
Date

Objectives: The objectives of this assignment include gaining familiarity with the implementation and analysis of the vapor-compression refrigeration cycle, and practicing the analysis of air-water vapor mixtures as applicable to air conditioning.

Apparatus: The apparatus is shown in the schematic in Figure 1. It consists of a duct with an air-water vapor mixture flowing through it and a vapor-compression refrigeration cycle used to remove heat from the duct. The temperature and relative humidity are measured at Locations 2 and 3 in the experiment. The evaporator in the refrigerator is used to remove heat between these two measurements. The temperature of the refrigerant, R12, is measured prior to the evaporator (Location 6). Temperature and pressure of the refrigerant is measured before the expansion valve (Location 5) and after the evaporator (Location 7).
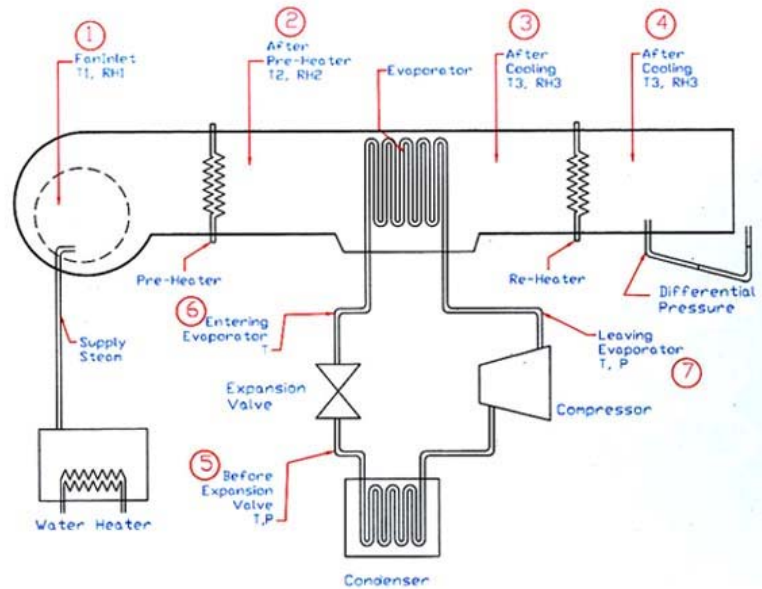
Approach: There was only one case run in this experiment. Humid air modeled as an air-water vapor mixture was forced through the duct. Energy balances using the acquired data were performed on the humid air and the refrigerant in the refrigeration cycle. The theoretical and actual condensate rates were compared. Sources of experimental errors and discrepancies were theorized.

Data: Two sets of data were taken for this experiment and averaged. The data are shown in Table 1.

Variable	units	Data set 1	Data set 2	Average
T2	deg C	31	27	29
RH2	%	52	48	50
T3	deg C	16	12	14
RH3	%	102	98	100
C vol	mL	3	1	2
C time	min	30	20	25
mdot r12	g/s	19.5	15.5	17.5
T5	deg C	45.5	43.5	44.5
P5	kPa	1020	980	1000
T6	deg C	8.1	6.1	7.1
T7	deg C	12.8	10.8	11.8
P7	kPa	310	290	300

Table 1. Data for Web-based Air Conditioning Experiment

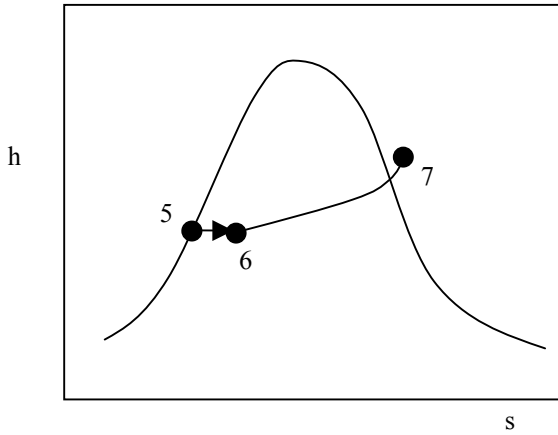**Results and Discussion:**
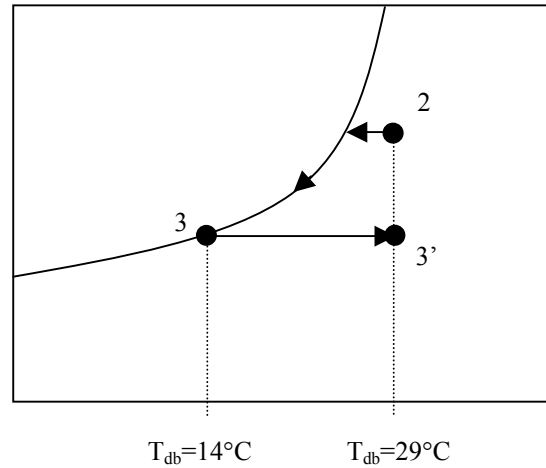

Figure 2. h-s diagram of R12

Figure 3. Air-water vapor states on psychrometric chart.

1. To dehumidify an air-water vapor mixture, you must cool it below its dew point temperature and then add heat. You will not get the same result if you add the heat first and then cool, as the dew point temperature will not be reached.
2. If you start with a dry bulb temperature of 25°C and a relative humidity of 20%, you cannot dehumidify the air without going below 0°C. If you start with a dry bulb temperature of 30°C and a relative humidity of 90%, you can reduce the absolute humidity from 0.0245 kg water/kg air to 0.0038 kg water/kg air. The lowest absolute humidity achievable is 0.0038 kg water/kg air.
3. Measurement fluctuations in the air-water vapor mixture and the R12 could occur from turbulence and non-uniform mixing across the flow passageways. Sensor fluctuations and offsets could also contribute to measurement fluctuations.

Appendix A. Calculations

The calculations outlined below follow the steps suggested in the on-line experiment.

1. See Figure 1 in **Apparatus** section.
2. See Table 1 in **Data** section.
3. State 5 exists before the expansion valve in the refrigeration cycle. It is likely to be a saturated liquid (ideal cycle) or a slightly subcooled liquid (real cycle). Its temperature (T5 = 44.5°C +273 = 317.5 K) and pressure (P5 = 1000 kPa) indicate that it is close enough to saturated conditions to be within the measurement uncertainty. For both a saturated or subcooled liquid, the enthalpy can be estimated to be h_f at T5, or:

    h_5 = 107.4 kJ/kg

4. Energy balance around the throttle indicates that:

    $$0 = \dot{m}\left(h_6 - h_5\right) \text{ or } h_6 = h_5 = 107.4 \text{ kJ/kg}$$

    At 280 K, h_f = 71.26 kJ/kg and h_{fg} = 148.01 kJ/kg. We can solve for x_6:

    $x_6 = (h_6 - h_f)/h_{fg} = 0.244$

5. At State 7, the temperature is greater than T_{sat} at P7. Therefore, it is slightly superheated. Using linear interpolation:

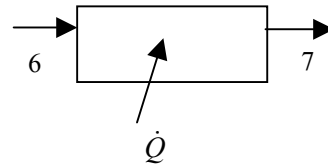 $$\frac{284.8 - 280}{290 - 280} = \frac{h_7 - 220.98}{227.44 - 220.98}$$

    h_7 = 224.08 kJ/kg

6. An energy balance around the evaporator gives us the heat absorbed by the evaporator.

    $$0 = \dot{m}_{R12}\left(h_7 - h_6\right) - \dot{Q}$$
    $$\dot{m}_{R12} = 17.5g/s = 0.017kg/s$$
    $$\dot{Q} = 0.017\left(224.08 - 107.3\right) = 2.04kW$$

7. From the psychrometric chart we can look up the enthalpy and absolute humidity of States 2 and 3 based on their temperatures and relative humidity.
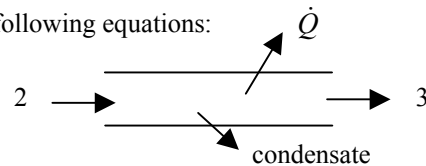
    h_2 = 62 kJ/kg air, ω_2 = 0.0128 kg water/kg air
    h_3 = 40 kJ/kg air, ω_3 = 0.0100 kg water/kg air

8. Mass and energy balances from State 2 to 3 yield the following equations:

    COM: $0 = \dot{m}_a\left(\omega_3 - \omega_2\right) + \dot{m}_w$

    COE: $0 = \dot{m}_a\left(h_3 - h_2\right) + \dot{m}_w h_w + \dot{Q}$

    The only unknowns are the mass flow rates of water and the mass flow rates of air. We have two equations and two unknowns, which yields the following solution for mass flow rate of air:

$$0 = \dot{m}_a \left(h_3 - h_2 \right) + \dot{m}_a \left(\omega_2 - \omega_3 \right) h_w + \dot{Q}$$

$$\dot{m}_a = \frac{-\dot{Q}}{\left(h_3 - h_2 \right) + \left(\omega_2 - \omega_3 \right) h_w} = \frac{-2.04}{\left(40 - 62 \right) + \left(0.0128 - 0.01 \right) 62.99}$$

$$\dot{m}_a = 0.093 kg / s$$

9. The theoretical condensate rate can be calculated from the Conservation of Mass equation in Step 8 above.

$$\dot{m}_w = \dot{m}_a \left(\omega_2 - \omega_3 \right) = 0.093 \left(0.0128 - 0.010 \right) = 2.6 x 10^{-4} kg / s$$

The measured condensate rate is determined from the condensate volume and the time required to collect it, as shown in Table 1:

$$measured \ \dot{m}_w = \frac{\left(cond.vol. \right) \left(cond.density \right)}{time} = \frac{\left(2mL \right) \left(997 kg / m^3 \right)}{25 \min} \times \frac{\min}{60 s} \times \frac{m^3}{10^6 mL}$$
$$= 1.33 \ x \ 10^{-6} \ kg/s$$

The measured condensate rate is less than the theoretical condensate rate. Reasons for the discrepancy may include: Non-steady state conditions during measurement, condensate sticking to evaporator coils or duct walls, and human and instrument errors.

10. To bring State 3 back up to T2 (29°C), we need to add heat. We will be achieving simple heating with this process, with $\omega_{3'} = \omega_3 = 0.0100$ kg water/kg air. With T3' and $\omega_{3'}$ we can look up enthalpy and relative humidity on the psychrometric chart:

    h = 55 kJ/kg air, ϕ = 40%

Conservation of energy gives us heat input:

$$\dot{Q}_{heat} = \dot{m}_a \left(h - h_3 \right) = 0.093 \left(55 - 40 \right) = 1.395 kW$$

The reduction in relative humidity from State 2 is about 10%.