Test 3 Thermal Applications - Amira Lucas and Kayla Davies

-Problem 1

TEST 3 - MET 350

PURPOSE- Determine quantity of air supplied to the space, states shown in drawing, processes in psychrometric chart, required capacity of the cooling & dehumidifying unit, amount of liquid water drained.

DIAGRAMS

ATTACHED BELOW

SOURCES

- CENGEL & Boles. Thermodynamics - An Engineering approach. 8th Edition. McGraw Hill 2015
- Psychrometric Chart & Canvas notes

DESIGN CONSIDERATIONS

- humidity ratio same for states 2 & 3
- air standard cycle - dry air
- maintained @ 75°F & 50% humidity

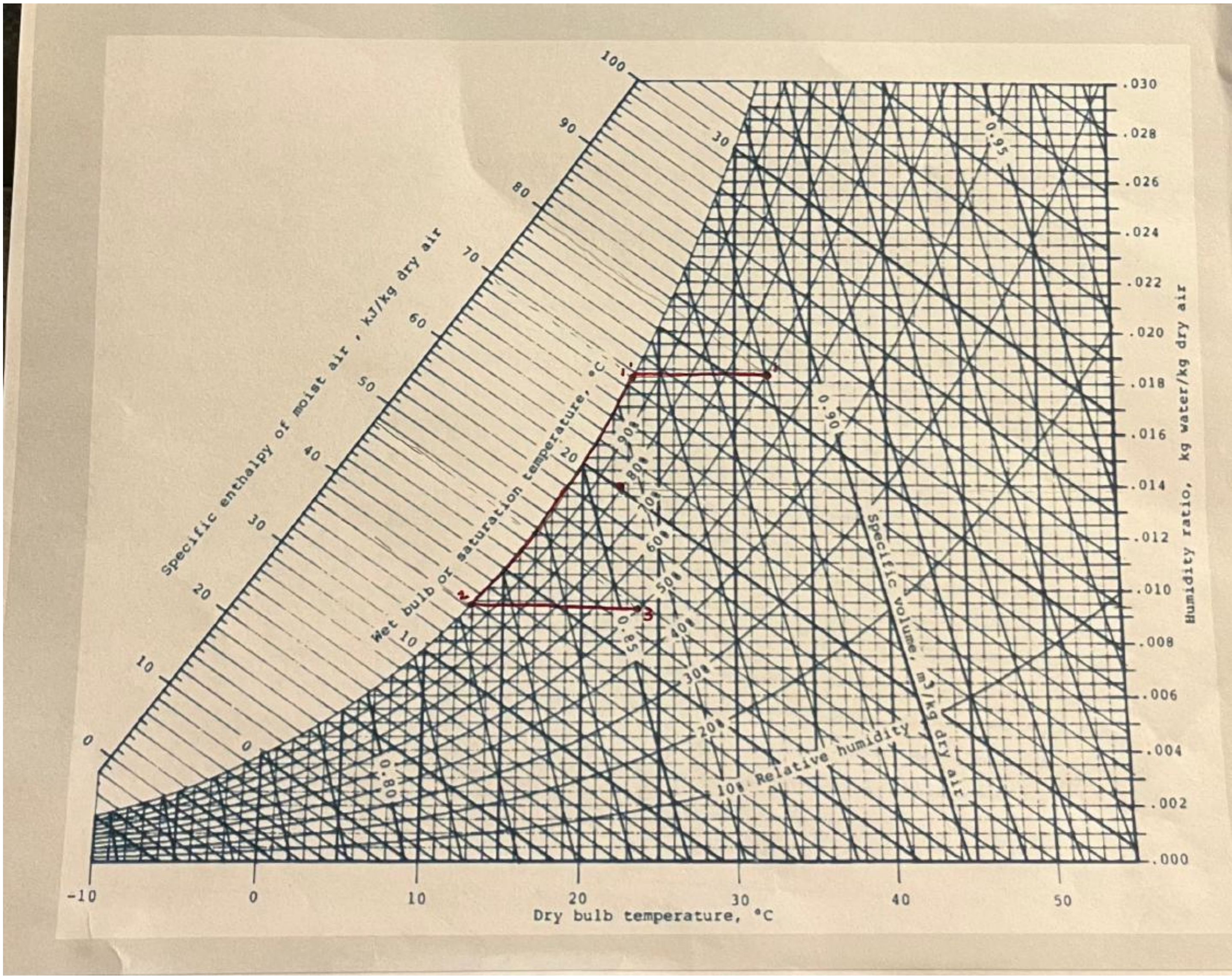
DATA & VARIABLES

$\dot{Q}_{room}$ = 72000 btu/hr $\quad T_{wb}$ = 75°F

$\dot{V}$ = 500 cfm $\quad \phi$ = 50%

MATERIALS:

- cooling & dehumidifying unit
- conditioned space
- mixing box

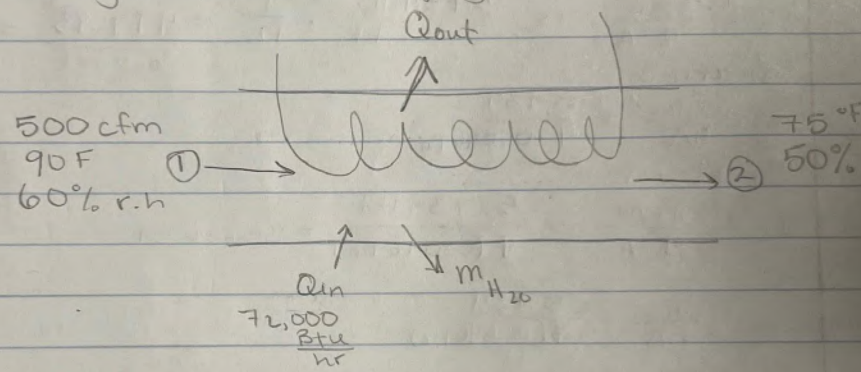

Specific enthalpy of moist air, kJ/kg dry air
Wet bulb or saturation temperature, °C
Specific volume, m³/kg dry air
Relative humidity
Humidity ratio, kg water/kg dry air
Dry bulb temperature, °C
1'
1
2
3

How to Calculate Sensible Heat Gain Infiltration

$$\text{infil. airflow} = \frac{(\text{volume space})(\text{air change rate})}{60} = \text{cfm}$$

$$Q_{sen} = 1.08\,(\text{airflow})(\Delta T)$$

Cooling w dehumidifying



$$-Q_{out} + m(h_1 - h_2) - \cancel{m_{H_2O} h_{H_2O}}^{\,0} = 0$$

$$Q_{out} = m_{air}(h_1 - h_2)$$

mass flow rate air

$$m = \frac{\dot{V}_1}{v_1} = \frac{500\ \text{cfm}}{0.89\ \frac{m^3}{kg}} \Rightarrow \frac{0.23597\ \frac{m^3}{s}}{0.89\ \frac{m^3}{kg}} = 0.265\ \frac{kg}{s}$$

capacity

$$Q_{out} = (0.265)(79 - 36) = \boxed{1,139.5\ \text{KW}}\ \times 100$$

$$m_1 h_1 - m_2 h_2 - m_{H_2O} = 0$$

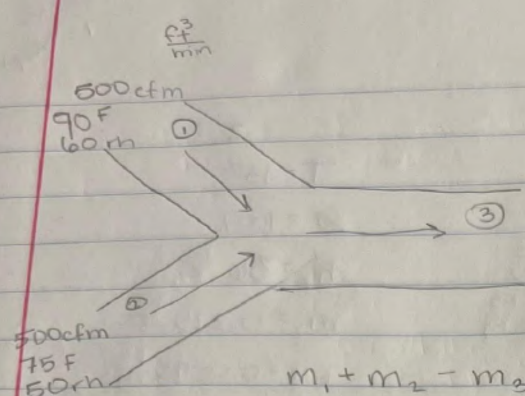
$$m'_1 - m'_2 - \cancel{m_{H_2O}}^{\,0} = 0$$

$$m_1 = m_2 = m'_{air}$$

$$m_{H_2O} = m'_{air}(\omega_1 - \omega_2)$$

$$\Rightarrow (0.265\ \tfrac{g}{kg})(0.0184\ \tfrac{g}{kg} - 0.0095)$$

$$m_{H_2O} = 0.0023585\ \frac{g}{s}$$



cons. mass

$$\dot m_1 + \dot m_2 - \dot m_3 = 0$$

cons. energy

$$\dot m_1 h_1 + \dot m_2 h_2 - \dot m_3 h_3 = 0$$

cons. mass H_2O

$$\dot m_1 \omega_1 + \dot m_2 \omega_2 - \dot m_3 \omega_3 = 0$$

$$\dot m_1 = \frac{\dot V}{v} = \frac{500 \frac{ft^3}{min}}{0.89 \frac{m^3}{kg\,dry}}$$

$$\frac{500\ \cancel{ft^3}}{\cancel{min}} \cdot \frac{kg\ dry}{0.89\ m^3} \cdot \frac{\cancel{min}}{1\ \cancel{ft^3}} \cdot \frac{0.000471947\ m^3}{s} = 0.265 \frac{kg}{s}$$

$$\dot m_2 = \frac{\dot V_2}{v_2} = \frac{500 ft^3/min}{0.8577 \frac{m^3}{kg}} = 0.275 \frac{kg}{s}$$

$$\dot m_3 = 0.265 + 0.275 = 0.54$$

$$h_3 = \frac{\dot m_1 h_1 + \dot m_2 h_2}{\dot m_3} = \frac{(0.265 \frac{kg}{s})(79 \frac{kJ}{kg}) + (0.275)(36)}{0.54}$$

$$h_3 = 57.10 \frac{kJ}{kg}$$

$$\omega_3 = \frac{\dot m_1 \omega_1 + \dot m_2 \omega_2}{\dot m_3} \Rightarrow \frac{(0.265)(0.0184) + (0.275)(0.0095)}{0.54}$$

$$0.01387 \frac{kg}{kg}$$

1.387

b)

1	1'	2
$T = 90^F = 32.2^C$	$T = 23^{\circ C}$	$T = 13^{\circ C}$
$\phi = 60\%$	$\phi = 100\%$	$\phi = 100\%$
$h_1 = 79 \frac{kJ}{kg}$	$h_1' = 69.5 \frac{kJ}{kg}$	$h_2 = 36 \frac{kJ}{kg}$
$m_1 = 0.265 \frac{kg}{s}$	$\omega_1' = 0.0184 \frac{kg}{kg}$	$m_2 = 0.275 \frac{kg}{s}$
$\omega_1 = 0.0184 \frac{kg}{kg}$		$\omega_2 = 0.0095 \frac{kg}{kg}$

3

$T = 75^F = 23.89^C$

$\phi = 50\%$

$h_3 = 47.5 \frac{kJ}{kg}$

$\omega_3 = 0.0095 \frac{kg}{kg}$

$m_3 = 0.54 \frac{kJ}{s}$

a) heat index (quality)

$T = 22.5^{\circ C}$ } $T_q = 23^{\circ C}$

$\phi = 80\%$

$\boxed{@\ 500\ \text{cfm}}$

d) Cooling:

$Q_{in} = m_1(h_1 - h_2)$

$(0.265)(79 - 36) = 11.395\ \text{KW}$

e) $m_1 h_1 + m_2 h_2 - m_{H_2O} = 0$

$m_1' + m_2' - \cancel{m_{H_2O}}^{\,0} = 0$

$m_1 = m_2 = m_{air}'$

$m_{H_2O} = m_{air}(\omega_1 - \omega_2)$

$= (0.265)(18.4 \frac{g}{kg} - 9.5 \frac{g}{kg})$

$\boxed{m_{H_2O} = 2.3585 \frac{g}{s}}$

Problem 1

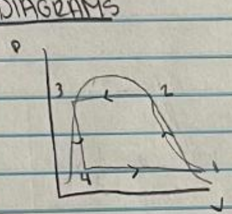
Summary: For problem 1, we were given a space and AC cycle to analyze. We were asked to find a) quality of the air being supplied to the space b) each state defined from the chart. c) drawings using the psychrometric chart. d) required capacity of cooling and dehumidyfing unit. and e) amount of liquid that's drained from said units.

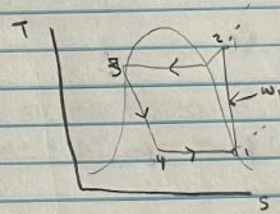
Analysis: After calculations and analysis with the psychrometric chart, we identified each state fully finding: temp (T), relative humidity (Ø), specific enthalpy (h), and the humidity ratio (ω). The quality of the air was found from the mixed airstreams came to be 500 cfm at 28°C and 80% r.h. The capacity was found by $\dot{Q}_{out} = 1139.5$ kW. Lastly, the amount of water drained was found by finding mass flow rate of water - $\dot{m}_{H_2O} = 2.3585 \frac{g}{s}$.

Problem 2 and 3

(2+3) PURPOSE: Design refrigerant equipment & provide the operating pressure of the evaporator & condenser, states, pv & ts diagrams, COP of cycle, mass flow rate, power required in HP, waste heat rate. Then, revise the cycle design & provide volume & mass flow rate.

DIAGRAMS





SOURCES

- Cengel & Boles. Thermodynamics- An engineering approach. 8th edition McGraw Hill 2015
- canvas notes

DESIGN CONSIDERATIONS

- waste heat is rejected to the outside air
- evaporator superheated by 2.7°C & subcooled by 6.3°C
- isentropic efficiency of compressor 80%.
- operates on vapor-compression refrideration cycle

DATA & VARIABLES

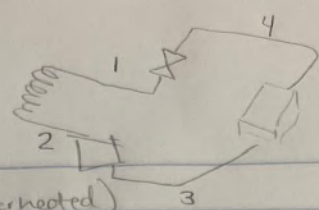
$T_1 = 7°C$ $T_3 = 45°C$

$\eta_{T4} = 80\%$ relative humidity: 90%.

MATERIALS

refrigerant 134a

water tower



Evap

2) leaves $7^{\circ C}$ ($2.7^{\circ C}$ superheated)

$T_{sat} = 4.3^{\circ C}$

$P_{ev} = 4.3^{\circ C} \approx 2.6$ bar

Condensor

$T = 45^{\circ C}$ (subcooled by $6.3^{\circ C}$) $\Rightarrow 51.3^{\circ C}$

$P_{con} = 51.3^{\circ C} \approx 11.5$ bar

$\underline{1} \xrightarrow{\text{evap outlet}} \underline{2} \xrightarrow{\text{compl outlet}} \underline{3} \xrightarrow{\text{cond outlet}} \underline{4} \xrightarrow{\text{expand valve}}$

1	2	3	4
$T = 7^{C}$	$\eta^{th} = 80\%$	$P = 11.5$ bar $= 1.15$ MPa	$P = 2.6$ bar $= 0.26$ MPa
$P = 0.26$ MPa	$S_1 = S_{2s} =$	$T = 45^{\circ C}$	$x_4 =$
R-134a	$P = 11.5$ bar $= 1.15$ MPa	subcool water	
$h_1 = 61.315$ interpolate		$h_3 =$	$h_4 = h_3$
	$h_2 = h_1 + \dfrac{(h_{2s} - h_1)}{\eta^{th}}$		$T = > 4.3^{\circ C}$

$$h_2 = 61.315 + \frac{(254.291 - 61.315)}{0.8} = 302.535$$

	S_2
0.24	0.97384
0.28	0.93503

avg $S_1 = 0.9544$

	h_2
0.24	258.056
0.28	250.526

avg. $h_1 = 254.291$

?

T_4 : neg?

bonus → mixture of questions

↳ how get w_1, w_2, m_3

evap outlet

compressor outlet

1

$T = 7\,°C$ (2.7 °C above sat)

$P = 0.26$ MPa

R-134a table

$h_g = h_1 = 254.525\ \frac{kJ}{kg}$

$x_1 = 100\%$ vapor

2

$T_2 = 44.56\,°C$

$P_2 = 1.15$ MPa $= 1{,}150$ kPa

$\eta_{in} = 80\%$ $\qquad h_2 = 277.87\ \frac{kJ}{kg}$

$x = 100\%$ vapor

$h_{2s} = 273.2$ ← interp

condensor outlet

expand valve

3

$T_3 = 45\,°C$

$P_3 = 1.15$ MPa

$h_3 = 115.82\ \frac{kJ}{kg}$

$x_3 = 0\%$ liquid

4

$P = 0.26$ MPa

$h_3 = h_4$

$T_4 = -3.315\,°C$

$x_4 = 0\%$ vapor

$$h_2 = h_1 + \frac{(h_{2s} - h_1)}{\text{efficency}} \Rightarrow h_2 = (254.525) + \frac{(273.2 - 254.525)}{0.80}$$

$h_2 = 277.87\ \frac{kJ}{kg}$

$Q_{out} = m(h_2 - h_1) = 16.88$ kW

$72{,}000 = m(277.87 - 254.525)$

$21.10\text{ kW} = m(23.34375\ \frac{kJ}{kg})$

$m = 0.904\ \frac{kg}{s}$

$$x = \frac{S_1 - S_{sat}}{S_{fg}}$$

$$x = \frac{0.933515 - 0.18804}{0.745475}$$

$Q_L = h_1 - h_4 \Rightarrow 254.525 - 115.82 = 138.705$

$W_{in} = h_2 - h_1 \Rightarrow 277.87 - 254.525 = 23.345$

$COP = \boxed{5.94}$

$P = (8.215)(277.87 - 254.525)$

$P = 191.78\text{ kW} \cdot \frac{1.341\text{ HP}}{1\text{ kW}} = 257.18$ HP

$$e)\ \dot{m} = \frac{Q_{in}}{(h_1 - h_4)} \Rightarrow \frac{1139.5\text{ kW}}{(254.525 - 115.82)} = \boxed{8.215\ \frac{kg}{s}}$$

Heat Rejected $= m(h_2 - h_3)$

$(8.215)(277.87 - 115.82)$

$\boxed{= 1331.24 \text{ KW}}$

$Heat_{out} = m_w C_p \Delta t$

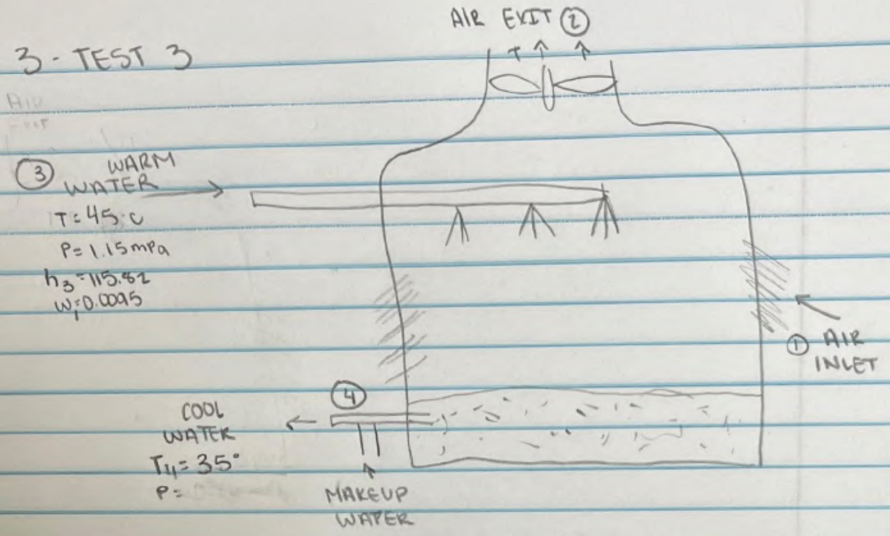
cond water flow

mass flow

$m_{mu} = m_a (\omega_2 - \omega_1)$

$\frac{m_{mu}}{m_w} \Rightarrow \%$

PROB. 3 - TEST 3



$\dot{m}_{H2O} = 2.36$ kg/s $\quad T_{H2O} = 45°C \quad T_{H2O_2} = 35°$

air enters: $T_{DB} = 24°C \quad T_{wb} = 13°C \qquad$ air leaving: $\omega = 0.184 \quad T_{DB} = 32°C \quad \phi = 60\%$

a) $\dot{m}_w h_w + \dot{m}_a h_1 + \dot{m}_{H2O} h_{2O} = m_a h_2 + \dot{m}_{H2O} h_{H2O_2}$

$\dot{m}_a (h_2 - h_1) = \dot{m}_{H2O} Cp_{H2O} (T_{H2O_1} - T_{H2O_2}) + \dot{m}_w h_w$

$$\dot{m}_a = \frac{\dot{m}_{H2O} Cp_{H2O} (T_{H2O_1} - T_{H2O})}{(h_2 - h_1) - (\omega_2 - \omega_1) h_w}$$

$$= \frac{8.215 \times 4.18 (45 - 35)}{(79 - 47.5) - (0.184 - 0.0095) 146.64}$$

$$\boxed{\dot{m}_a = 58.089 \ \frac{\text{kg dry air}}{s}}$$

$h_w \rightarrow h_f\ T = 35° \quad h_w = 146.64$ kJ/kg

Cp_{H2O} @ T = 40 → 4.18 $\frac{kJ}{kg \cdot k}$

h_1 & ω_1 → psychrometric chart

$h_1 = 47.5 \quad \omega_1 = 0.0095$

h_2 & ω_2 → chart

$h_2 = 79 \quad \omega_2 = 0.184$

b) $\dot{m}_w = \dot{m}_a (\omega_2 - \omega_1)$

$= 58.089 (0.184 - 0.0095)$

$$\boxed{\dot{m}_w = 10.14 \ \frac{\text{kg water}}{s}}$$

PROBLEM 2&3

SUMMARY

The cooling & dehumidifying unit in problem 1 was a part of a ac unit. We were required to design the equipment operating on a refrigeration cycle. We then revised our cycle design in problem three to absorb the waste heat. In order to prove this was a feasible design, we provided the volume flow rate & mass flow rate.

ANALYSIS

Following the rule of thumb provided in class, we found the P_1 and P_3 and identified each state. The COP was 5.94, within normal limits, and the mass flow rate was 8.215 kg/s. In our cooling tower design, we used the psychometric chart to find the volume flow rate and mass flow rate, which were 58.089 kg dry air/s and 10.14 kg H_2O/s.