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MET 350 Thermal Applications
Dr. Orlando Ayala
Spring 2017
Test 2

Take home – Due Sunday April 30th 2017 before midnight.

READ FIRST

1. RELAX!!!! DO NOT OVERTHINK THE PROBLEMS!!!! There is nothing hidden. The test was designed for you to pass and get the maximum number of points, while learning at the same time. HINT: THINK BEFORE TRYING TO USE/FIND EQUATIONS (OR EVEN FIND SIMILAR PROBLEMS)

2. The total points on this test are one hundred (100). Ten (10) points are from your HW assignments. The other ninety (90) points will come from the problem solutions. I will not require technical writing for this test. You could still do it following the attached rubric, however (just for this test) you are under no obligation to do so it as I will not grade it.

3. There are 3 problems. Each worth the same amount of points.

4. What you turn in should be only your own work. You cannot discuss the exam with anyone, except me. Call me, skype me, text me, email me, come to my office, if you have any question.

5. I do not read minds. You should be explicit and organized in your answers. Use drawings/figures. If you make a mistake, do not erase it. Rather use that opportunity to explain why you think it is a mistake and show the way to correct the problem.

6. You have to turn in your test ON TIME and ONLY through BLACKBOARD. You must submit only one file and it has to be a pdf file. For the ePortfolio you are also supposed to upload this artifact to your Google drive. When you are done solving the test, please go ahead and upload it now before you forget.

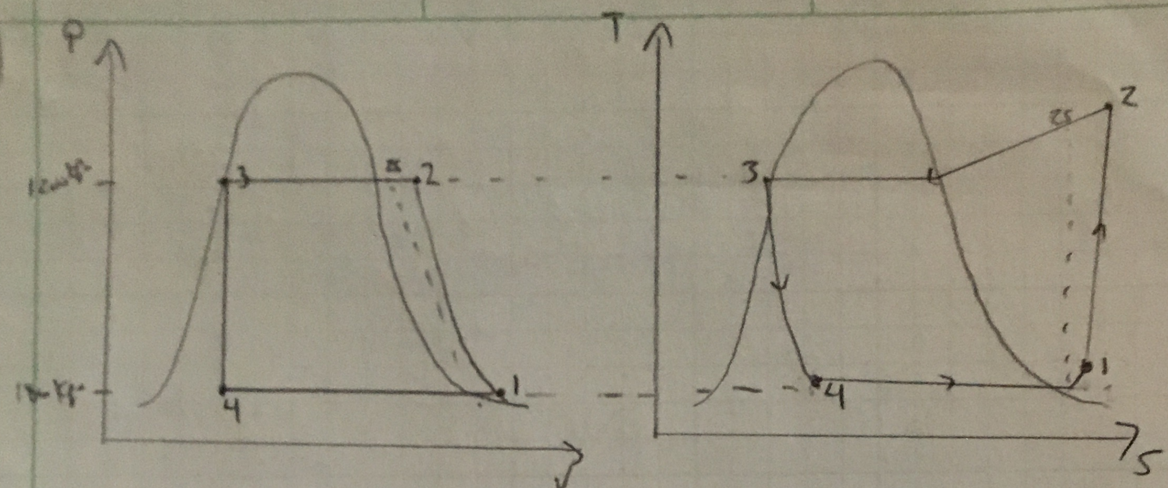
7. Do not start at the last minute so you can handle anything that could happen. Late tests will not be accepted. Test submitted through email will not be accepted either.

8. Cheating is completely wrong. The ODU Student Honor Pledge reads: "I pledge to support the honor system of Old Dominion University. I will refrain from any form of academic dishonesty or deception, such as cheating or plagiarism." By attending Old Dominion University you have accepted the responsibility to abide by this code. This is an institutional policy approved by the Board of Visitors. It is important to remind you the following part of the Honor Code:

> IX. PROHIBITED CONDUCT
> A. Academic Integrity violations, including:
> 1. *Cheating*: Using unauthorized assistance, materials, study aids, or other information in any academic exercise (Examples of cheating include, but are not limited to, the following: using unapproved resources or assistance to complete an assignment, paper, project, quiz or exam; collaborating in violation of a faculty member's instructions; and submitting the same, or substantially the same, paper to more than one course for academic credit without first obtaining the approval of faculty).

With that said, you are NOT authorized to use any online source of any type, unless is ODU related.

(1)



(1)

$P_1 = 180 kPa$

$T_1 = -12.7°C + 2.7°C$

$T_1 = -10°C$

Interpolate

T_{sat} at 180kPa $= -14 + (180 - 171)\left(\frac{-12-(-14)}{185-171}\right)$

Table A-13 superheated

$h_1 = 245.15 kJ/kg$

$s_1 = .9484 kJ/kg \cdot K$

(2) (2s)

$P_2 = 1200 kPa$

$T_2 = 60°C$

$s_1 = s_2$

$T_{sat} = 46.3$ at 1200kPa

$h_2 = 289.66 kJ/kg$

$s_2 = .9615 kJ/kg \cdot K$

Interpolate

$$h_{2s} = h_{sat\,50°C} + (h_{60°C\,sat} - h_{sat})\left(\frac{s_2 - s_{sat\,50°C}}{s_{sat} - s_{50°C}}\right)$$

$$h_{2s} = 278.20 + (289.66 - 278.20)\left(\frac{.9485 - .9268}{.9615 - .9268}\right)$$

$h_{2s} = 285.40 kJ/kg$

(3)

$P_3 = P_2 = 1200 kPa$

$T_3 = T_{sat}$ at 1200kPa $- 6.3$

$T_3 = 46.3 - 6.3°C$

$T_3 = 40°C$

Table A-11

$h_3 = 108.27$

$s_3 = .3949 kJ/kg \cdot K$

(4)

$P_1 = P_4 = 180 kPa$

$h_4 = h_3 = 108.27 kJ/kg$

$s_4 = x_4 s_g + (1 - x_4) s_f$ ← Table A-11

$$x_4 = \frac{h_4 - h_f}{h_{fg}} = \frac{108.28 - 34.94}{207.95}$$

Table A-11 sat

$x_4 = .3526$

$s_4 = .3526(.93974 kJ/kg \cdot K) + (1 - .3526)(.1435 kJ/kg \cdot K)$

$s_4 = .4229 kJ/kg \cdot K$

a) Rate of cooling: $\dot{Q}_L = \dot{m} q_L$

$\dot{Q}_L = \dot{m}(h_1 - h_4)$

$\dot{Q}_L = .06 kg/s (245.15 kJ/kg - 108.27 kJ/kg)$

$\dot{Q}_L = 8.214 kW \left| \frac{3412 Btu/h}{1 kW} \right.$

$\dot{Q}_L = 28,026 Btu/h$

$COP = \frac{\dot{Q}_L}{\dot{W}_{in}}$ ✓

$\dot{W}_{in} = \dot{m} w_{in} = \dot{m}(h_2 - h_1)$

$= .06\ kg/s (289.66\ kJ/kg - 245.2\ kJ/kg)$

$\dot{W}_{in} = 2.664\ kW$

$COP = \frac{8.214\ kW}{2.664\ kW}$

$COP = 3.083$

b) isentropic efficiency of compressor, η_C

$\eta_c = \frac{W_{in\ isnt}}{W_{in\ actual}} = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{285.4\ kJ/kg - 245.15\ kJ/kg}{289.66\ kJ/kg - 245.15\ kJ/kg} = \frac{40.25\ kJ/kg}{44.51\ kJ/kg}$

$\eta_c = .9043 \approx 90.4\%$

c) ratio of volume flow rate of air entering the air handler (m^3/min) to the mass flow rate of refrigerant (kg/s) through air handler in ($m^3 air/min$) / (kg_{R134}/s)

$\frac{\dot{V}_{air}}{\dot{m}_R} = \frac{m_{air}}{kg_{R134}/s}$

$\dot{Q}_L = \dot{m}_a c_p \Delta T$

$8.22\ kW = \dot{m}_a (1.005\ kJ/kg \cdot K)(20°C)$

$\dot{m}_a = .4089\ kg/s \left| \frac{1\ m^3_{air}/s}{1.2\ kg/s} \right. = \dot{V}_{air}$

$\dot{V}_{air} = .341\ m^3_{air}/s \left| \frac{60\ sec}{1\ min} \right.$

$\dot{V}_{air} = 20.5\ m^3_{air}/min$

$\frac{\dot{V}_{air}}{\dot{m}_R} = \frac{20.5\ m^3_{air}/min}{.06\ kg_{R134}/s}$

$\frac{\dot{V}_{air}}{\dot{m}_R} = 341.7\ (m^3_{air}/min)/(kg_{R134}/s)$

d) the power input = $\dot{W}_{in}$ = ?

$\dot{W}_{in} = \dot{m}\,(h_2 - h_1)$

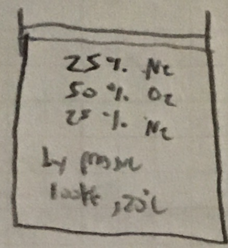
$\dot{W}_{in} = .06\,kg/s\,(289.6\,kJ/kg - 245.2\,kJ/kg)$

$\dot{W}_{in} = 2.664\,kW$

(2) **Purpose:** To determine the work, in kJ/kg, required to compress this mixture isentropically from 100kPa and 20°C to 1000kPa. Evaluate the properties of fluids at 300K.

- Mixture of ideal gases whose pressure fractions are 25 % Ne, 50% O_2, 25 % N_2 in a closed system.

Drawings and Diagrams:



Sources: Cengel and Boles, Thermodynamics, an engineering Approach. 8th edition. McGraw Hill 2015

Procedure and Calculations:

Pressure

$P_{Ne} = Y_{Ne} P_m = (.25)(100\,kPa) = 25\,kPa$

$P_{O_2} = Y_{O_2} P_m = (.50)(100\,kPa) = 50\,kPa$

$P_{N_2} = Y_{N_2} P_m = (.25)(100\,kPa) = 25\,kPa$

Ne, 25 kPa
O_2, 50 kPa
N_2, 25 kPa

Volume fraction:

$Y_{Ne} = \frac{P_{Ne}}{P_{total}} = \frac{25\,kPa}{100\,kPa} = .25$

$Y_{O_2} = \frac{P_{O_2}}{P_{total}} = \frac{50}{100} = .50$

$Y_{N_2} = \frac{P_{N_2}}{P_{total}} = \frac{25}{100} = .25$

Table A-1 ✓

Mass

$m_{Ne} = N_{Ne} M_{Ne} = (25\,kmol)(20.183\,kg/kmol) = 504.6\,kg$

$m_{O_2} = N_{O_2} M_{O_2} = (50\,kmol)(31.9\,kg/kmol) = 1600\,kg$

$m_{N_2} = N_{N_2} M_{N_2} = (25\,kmol)(28.013\,kg/kmol) = 700.3\,kg$

total mass

$m_m = m_{Ne} + m_{O_2} + m_{N_2}$

$m_m = 2804.9\,kg$

$N_m = N_{Ne} + N_{O_2} + N_{N_2}$

$N_m = 100\,kmol$

Molecular weight of mixture

$$M_m = \frac{m_m}{N_m} = \frac{2804.9 kg}{100 \text{ k-mol}}$$

$$M_m = 28.04 \text{ Kg/K-mol}$$

mass fraction

$$mf_{Ne} = \frac{m_{Ne}}{\Sigma m_m} = \frac{504.66 \text{ kg}}{2804.9 \text{ kg}} = .1799$$

$$mf_{O_2} = \frac{m_{O2}}{m_m} = \frac{1600 \text{ kg}}{2804.9 \text{ kg}} = .5704$$

$$mf_{N_2} = \frac{m_{m}}{m_m} = \frac{700.3 \text{ kg}}{2804.9 \text{ kg}} = .2497$$

Constant-volume specific heat of mixture

Table A-2 (a)

$$Cv = (mf_{Ne})(Cv_{Ne}) + (mf_{O_2})(Cv_{O2}) + (mf_{N_2})(Cv_{N_2})$$

$$Cv = (.1799)(.6179 \text{ KJ/Kg·K}) + (.5704)(.658) + (.2497)(.743)$$

$$Cv = .1112 + .3753 + .1855$$

$$Cv = .672 \text{ KJ/Kg·K}$$

Apparent Gas Constant of mixture

$$R = \frac{R_u}{M_m} = \frac{8.314 \text{ KJ/Kmol K}}{28.04 \text{ Kg/K-mol}}$$

$$R = .2965 \text{ KJ/Kg·K}$$

Constant-pressure Specific heat of mixture

$$Cp = C_v + R = .672 \text{ KJ/Kg·K} + .2965 \text{ KJ/Kg·K}$$

$$Cp = .9685 \text{ KJ/Kg·K}$$

$$k = \frac{Cp}{Cv} = \frac{.9685 \text{ KJ/Kg·K}}{.672 \text{ KJ/Kg·K}}$$

$$K = 1.441$$

Isentropic

$$W_{out} = \int_1^2 P\,dV = ?\ kJ/kg$$

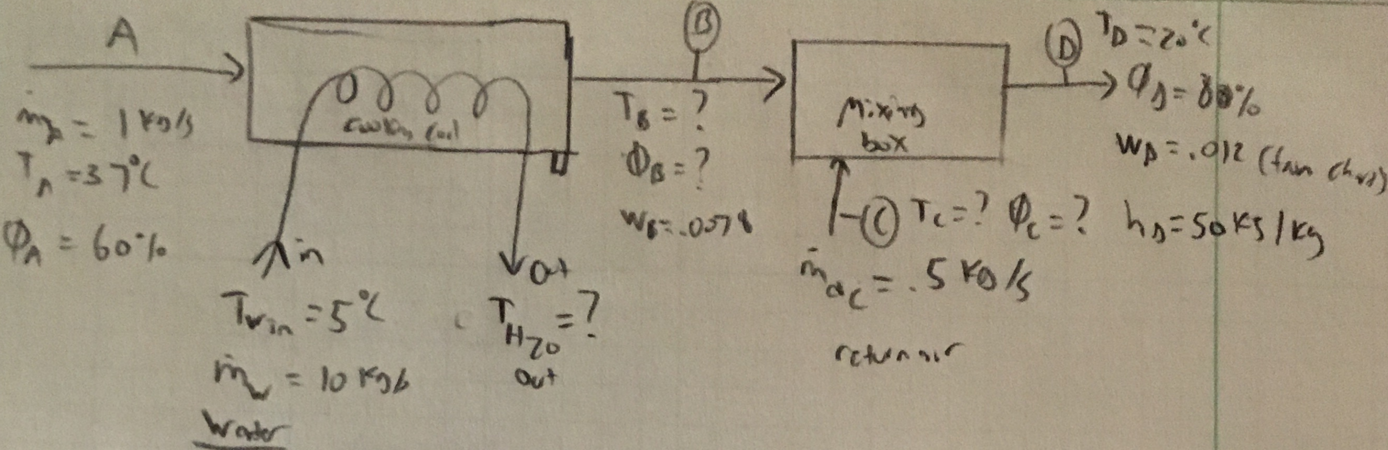
$$W_{out} = \frac{RT}{M(1-k)}\left[\left(\frac{P_2}{P_1}\right)^{k-1/k} - 1\right]$$

$$W_{out} = \frac{(8.314\ kJ/kmol\cdot K)(293.15K)}{(28.04\ kJ/kmol)(1-1.441)}\left[\left(\frac{1000\ kPa}{100\ kPa}\right)^{1.441-1/1.441} - 1\right]$$

$$W_{out} = \frac{2437.2}{-12.365}(1.023)$$

$$W_{out} = 201.6\ kJ/kg$$

(3)



$\dot{m}_A = 1$ kg/s
$T_A = 37°C$
$\phi_A = 60\%$

$W_A = .025$ (from chart)
$h_A = 102$ kJ/kg

a) $T_B = 10°C$ (from chart)
b) $\phi_B = 100\%$ (Because water is condensing from atmospheric air)
$W_B = .0078$
$h_B = 29$ kJ/kg
$\dot{m}_{a_B} = \dot{m}_{a_A}$

$$\dot{Q} = \dot{m}_{a_A}(h_A - h_B) = \dot{m}_w C p_{water}(T_{H_2O\,out} - T_{w_{in}})$$

$$1 \text{ kg/s}(102 \text{ kJ/kg} - 29 \text{ kJ/kg}) = 10 \text{ kg/s}(4.18 \text{ kJ/kg·K})(T_{H_2O} - 5°C)$$

$$73 = 41.8(T_{H_2O} - 5)$$

$$73 = 41.8 T_{H_2O} - 209$$
$$+209 \qquad\qquad +209$$

$$\frac{282}{41.8} = \frac{41.8 T_{H_2O}}{41.8}$$

e) $T_{H_2O\,out} = 6.74°C$

1st law to mixing box

$$\dot{m}_{a_D} W_D = \dot{m}_{a_B} W_B + \dot{m}_{a_C} W_C$$

$$(1.5 \text{ kg/s})(.012) = 1(.0078) + (.5 \text{ kg/s})(W_C)$$

$$.018 = .0078 + .5 W_C$$
$$-.0078 \qquad -.0078$$

$$\frac{.0102}{.5} = \frac{.5 W_C}{.5}$$

$$W_C = .0204$$

$\dot{m}_{a_D} = \dot{m}_{a_A} + \dot{m}_{a_C}$
$\dot{m}_{a_D} = 1$ kg/s $+ .5$ kg/s
$\dot{m}_{a_D} = 1.5$ kg/s

Energy balance

$\dot{m}_{a_B} h_B + \dot{m}_{a_C} h_C = \dot{m}_D h_D$

$(1\ kg/s)(29\ kJ/kg) + (.5\ kg/s)(h_C) = (1.5\ kg/s)(50\ kJ/kg)$

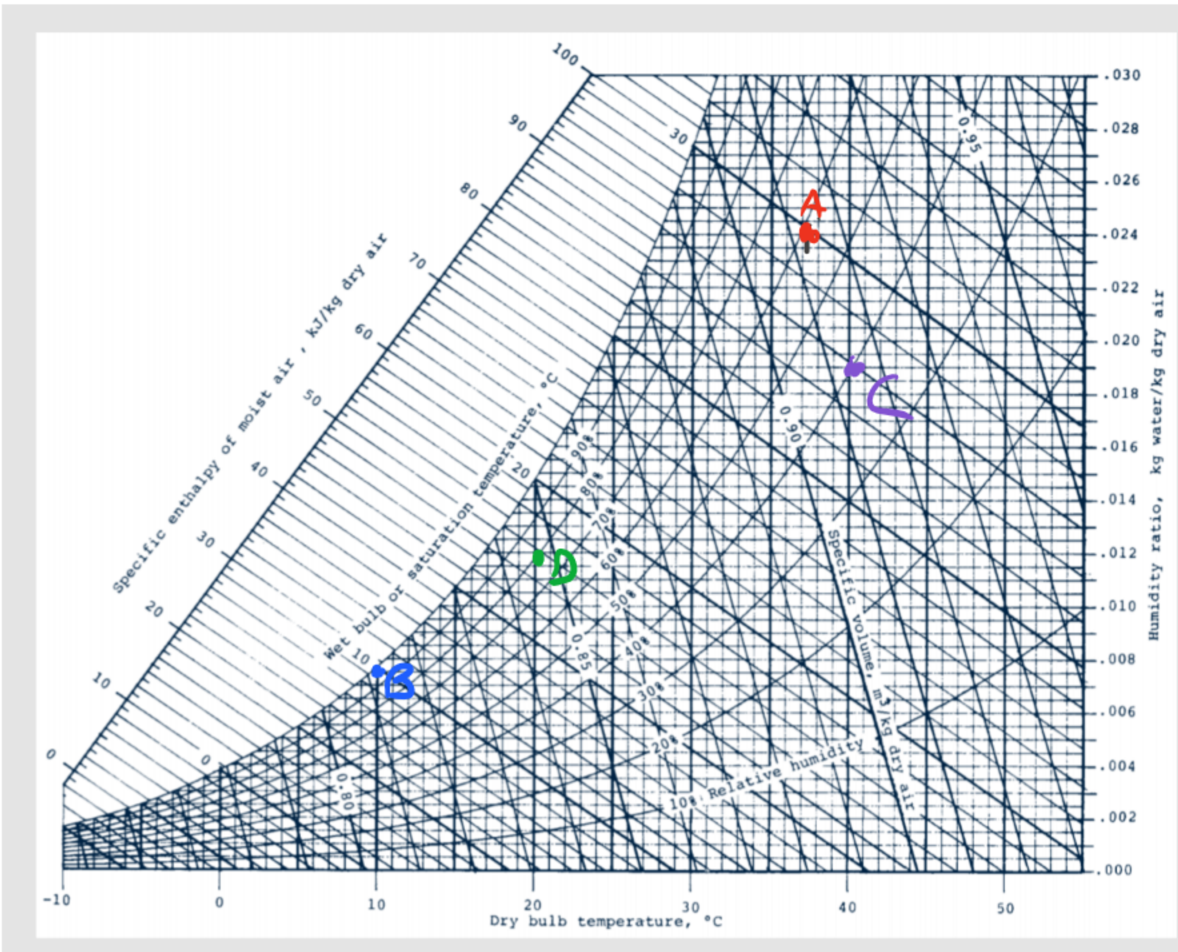
$29 + .5 h_C = 75$

$$\frac{.5 h_C}{.5} = \frac{46}{.5}$$

$h_C = 92\ kJ/kg$

c) $T_C = 40°C$ (from chart)

d) $\phi = 40\%$



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
A
B
C
D