Name: ____________________________ Last 4 Digits of Student I.D.#: _______________

CBE 140 Final Exam – Spring Sem. 2014 – Open-Book Section – 250 Points (out of 300 Total)

(Textbook, notes, other references, and calculators OK, but no "connected" devices)

1. (20 pts. – 5 pts. each) Convert the following quantities from / to the units specified:

    a. 1 Btu/lbY-R to kJ/kg-K

    b. 25,000 lb_f/ft^2 to mmHg

    c. 13,000 gallons/minute to m3/day

    d. An ideal-gas mixture of 20 volume % A and 80 volume % B to mole fractions

2. (30 pts.) "The Galaxy Song," written by Eric Idle and first performed in Monty Python's "The Meaning of Life" begins:

Just remember that you're standing on a planet that's evolving
Revolving at nine hundred miles an hour[1]*,*
Orbiting at nineteen miles a second[2]*, so it's reckoned,*
A sun that is the source of all our power.

[1] (i.e., rotating once per day) [2] (i.e., circling the sun once per year)

a. (10 pts.) Assuming that the Earth is a true sphere of radius 3,200 km, did he get the rotational velocity at the Earth's surface correct?

b. (10 pts) If the average distance between the Sun and the Earth is 150,000,000 km, and the Earth's orbit is perfectly circular, did he get the orbital velocity right?

c. (10 pts.) Is the sun, "the source of all our power?" Defend your answer, and list 5 types of power we derive from the sun (if your answer is **YES**), **OR** 3 types of power we derive from the sun and 2 types we do **not** derive from the sun (if your answer is **NO**).

List: _________________________ _________________________

_________________________ _________________________

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3. (50 pts.) Eicosane ($C_{20}H_{42}$) is a linear ("normal") alkane, solid at ambient conditions. Eicosane and molecules like it are too heavy and have too high a melting point to be much good for fuels, so they are often "cracked" into smaller molecules. Cracking takes place at high temperature (~1000 ˚F) and pressure (200 atm.) in the presence of hydrogen gas and a catalyst. You want to do experiments on cracking via the example reaction below, in which eicosane gets converted into 2 moles of decane (which is a liquid at ambient conditions and much more useful as a fuel):

$$C_{20}H_{42} + H_2 \rightarrow 2C_{10}H_{22}$$

You need to estimate the heat of reaction at 1000 ˚F and 200 atm, in order to design your experimental apparatus properly. List **all** of the steps in a calculational path that would allow you to do this.

Notes: (1) Heats of reaction / formation / etc. are **only** available at standard conditions

(2) Even if you can look up coefficients for an equation, you must list the experimental measurements that would be needed to determine those coefficients (e.g., you can look up coefficients for the Antoine Equation, but someone needed to make vapor pressure measurements in order to determine those coefficients).

(3) You don't need to write down equations exactly; just give the general functional form and say how they would be used.

(4) Suggestion: do not **number** the steps until the very end, in case you forget one and need to write it down later. Steps **do not** need to be **written down** in order, but they **do** need to be **numbered** in the correct order!

(5) Do **not** make any calculations – just write down the necessary steps

Step #	Equation / Method used to calculate H for this step	Physical Property Measurements Needed
_____	____	____________________
_____	____	____________________

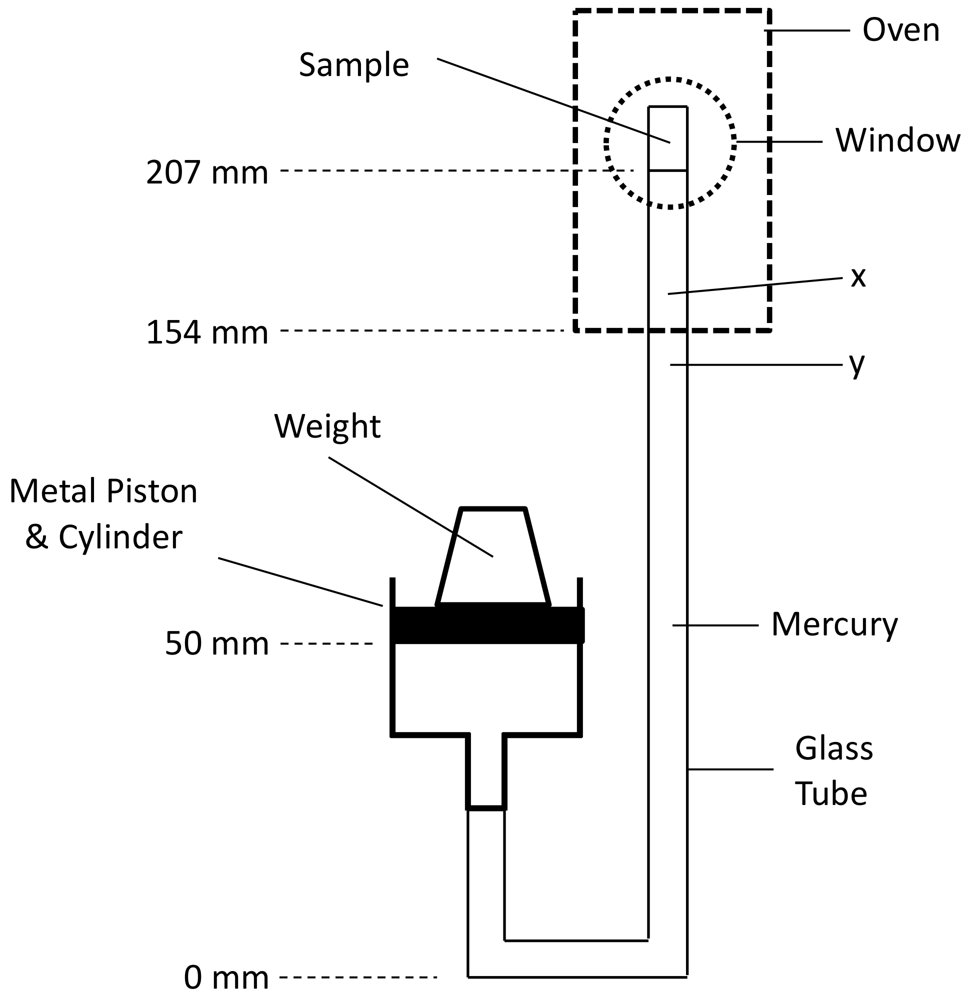
(Note: additional space on next page)

(Note: additional space on next page)

(Note: Don't Panic! Extra spaces are provided in case you need to cross out errors, etc. – the number of spaces provided is greater than the necessary number of steps!)

4. (40 pts.) The setup shown on the next page is one I used many years ago to determine the critical points of hydrocarbon mixtures by observing them directly, and noting the temperature and pressure where they occurred. The pressure was controlled by a piston upon which weights could be placed, attached to a glass U-tube completely filled with mercury except for a small amount of sample at the top of the (sealed) end of the glass tube. The upper part of the tube, including the sample, was enclosed in an oven so the temperature could be controlled. In the case shown below, the barometric pressure was 748 mmHg, the piston had an area of 0.1 in^2, and the piston plus the weight had a total mass of 38 lb_m. Although the entire system below the sample was filled with mercury, the mercury **inside** the oven was much hotter than the ambient temperature in the lab. For this run, the mercury **outside** the oven could be assumed to have a density of 13.6 g/cm^3, but the mercury **inside** the oven had a density of only 12.4 g/cm^3.

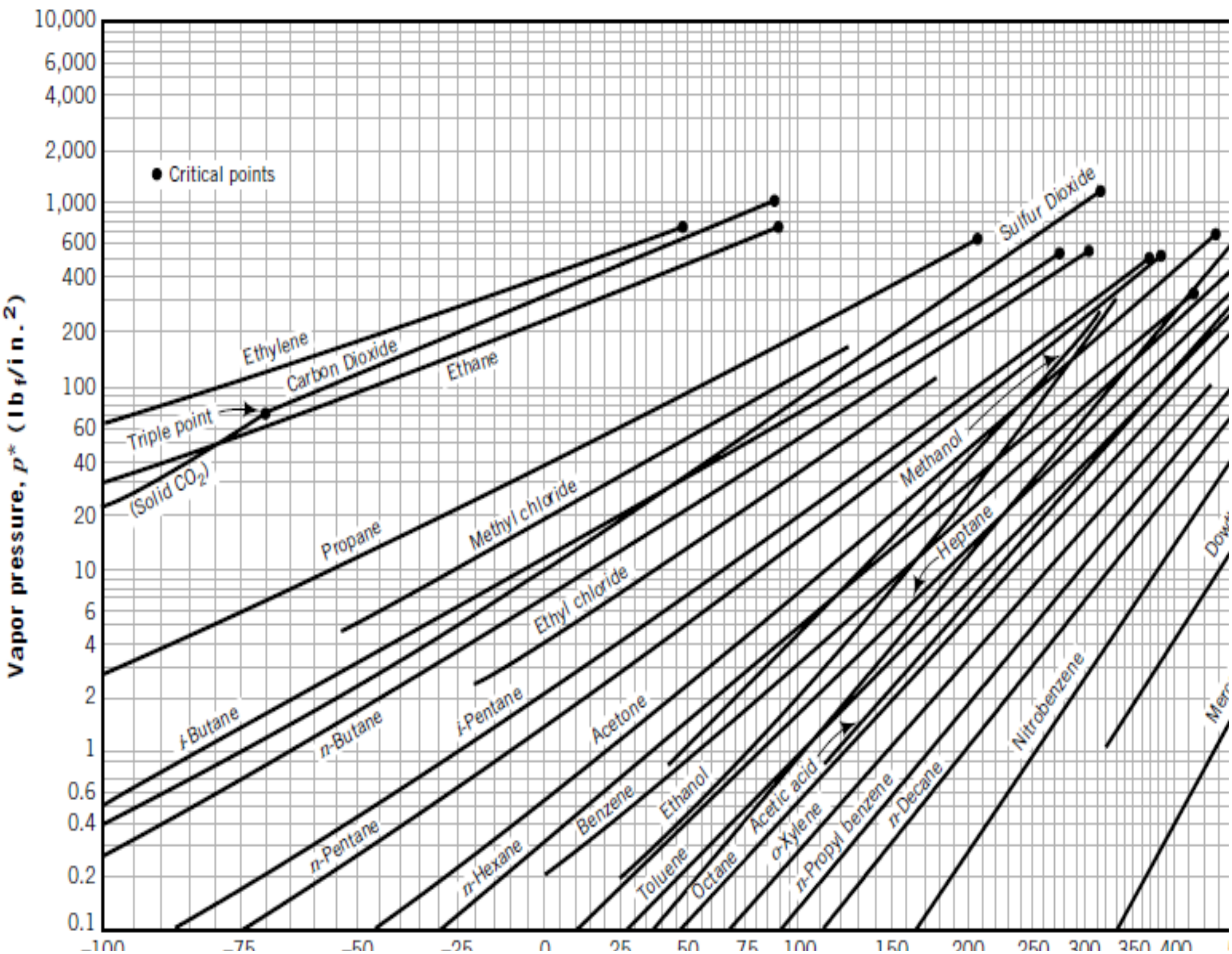
    a. (25 pts.) Compute the pressure on the sample in the case described above.



b. (15 pts.) Unfortunately, mercury is a pretty good conductor of heat, so Point “x” in the diagram above will actually be colder than the oven temperature, and Point “y” will actually be warmer than the ambient temperature, making the density correction for the mercury somewhat uncertain. Suggest a simple equipment modification to minimize the impact of the mercury temperature difference. You may not add any new instruments or devices.

5. (50 pts.) 100 moles of a 50/50 (mol/mol) gaseous mixture of i-Pentane and Heptane at 1 atm pressure is cooled to 130 ˚F. Assuming that the vapors behave as ideal gases and that Raoult's Law can be used for the liquid, and that pure-component vapor pressures can be obtained from the attached Cox Chart:

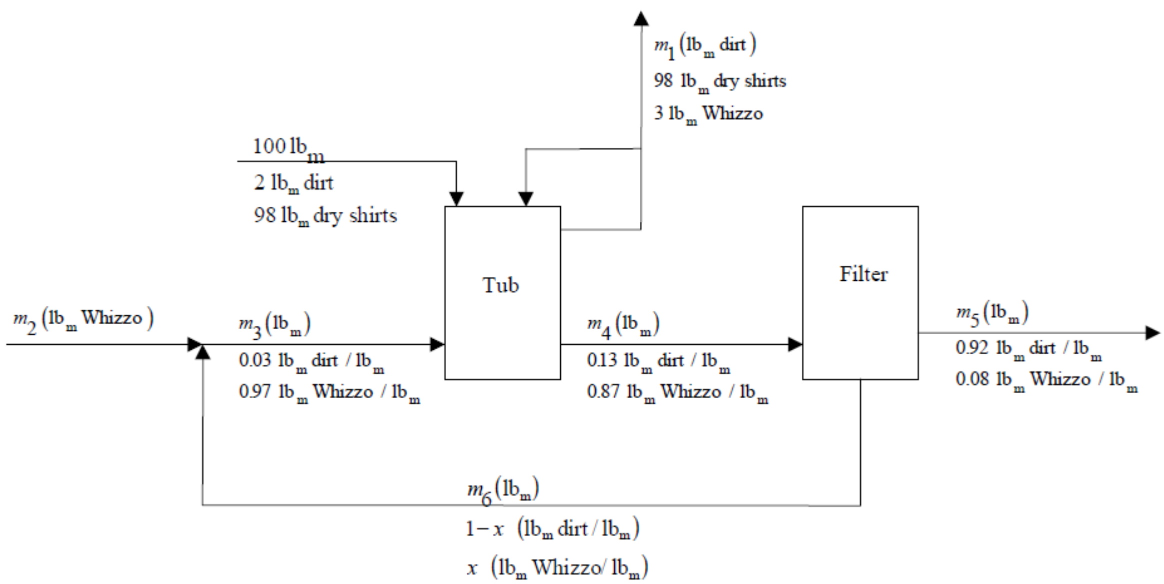
    a. (25 Pts.) Compute the resulting liquid and vapor compositions at equilibrium
    b. (15 pts.) Compute amount of liquid and vapor present at equilibrium
    c. (10 pts.) How high would you need to raise the temperature to leave a liquid phase **completely** free of i-Pentane? Explain your answer



Vapor pressure, p^* ($lb_f/in.^2$)
10,000
6,000
4,000
2,000
1,000
600
400
200
100
60
40
20
10
6
4
2
1
0.6
0.4
0.2
0.1
● Critical points
Ethylene
Carbon Dioxide
Ethane
Triple point
(Solid CO_2)
Propane
Methyl chloride
Ethyl chloride
Sulfur Dioxide
Methanol
Heptane
i-Butane
n-Butane
i-Pentane
Acetone
n-Pentane
n-Hexane
Benzene
Ethanol
Toluene
Octane
Acetic acid
o-Xylene
n-Propyl benzene
n-Decane
Nitrobenzene
0
25
50
75
100
150
200
250
300

6. (30 pts.) In a simple shirt-cleaning process, the shirts are soaked in an agitated tub containing a detergent, W, and are then removed and wrung out and sent to a rinse process. The dirty W is sent to a filter in which most of the dirt is removed, and the cleaned detergent is recycled back to join a stream of pure W, with the resulting combined stream serving as the net feed to the tub. Each 100 lb_m of dirty shirts contains 2 lb_m of dirt. The washing removes 95% of the dirt in the dirty shirts. For each 100 lb_m of dirty shirts, 25 lb_m W leaves with the clean shirts, of which 22 lb_m is wrung out and immediately recycled to the tub. The detergent that enters the tub contains 97% W, and that which enters the filter contains 87% W. The wet dirt that leaves the filter contains 8.0% W

   a. (20 pts.) How much pure W must be supplied per 100 lb_m of dirty shirts?
   b. (10 pts.) What is the composition of the recycled stream?



<u>Strategy</u>

95% dirt removal $\Rightarrow m_1$ $(= 5\%$ of the dirt entering)

Overall balances: 2 allowed (we have implicitly used a clean shirt balance in labeling the chart) $\Rightarrow m_2, m_5$ (solves Part (a))

Balances around the mixing point involve 3 unknowns (m_3, m_6, x), as do balances around the filter (m_4, m_6, x), but the tub only involves $2(m_3, m_4)$ and 2 balances are allowed for each subsystem. Balances around tub $\Rightarrow m_3, m_4$

Balances around mixing point $\Rightarrow m_6, x$ (solves Part (b))

a. <u>95% dirt removal</u>: $m_1 = (0.05)(2.0) = 0.10 \text{ lb}_m \text{ dirt}$

<u>Overall dirt balance</u>: $2.0 = 0.10 + (0.92)m_5 \Rightarrow m_5 = 2.065 \text{ lb}_m \text{ dirt}$

<u>Overall Whizzo balance</u>: $m_2 = [3 + (0.08)(2.065)](\text{lb}_m \text{ Whizzo}) = \underline{\underline{3.17 \text{ lb}_m \text{ Whizzo}}}$

b. <u>Tub dirt balance</u>: $2 + 0.03m_3 = 0.10 + 0.13m_4$ (1)

<u>Tub Whizzo balance</u>: $0.97m_3 = 3 + 0.87m_4$ (2)

Solve (1) & (2) simultaneously $\Rightarrow m_3 = 20.4 \text{ lb}_m, m_4 = 19.3 \text{ lb}_m$

<u>Mixing pt. mass balance</u>: $3.17 + m_6 = 20.4 \text{ lb}_m \Rightarrow m_6 = 17.3 \text{ lb}_m$

<u>Mixing pt. Whizzo balance</u>:

$3.17 + x(17.3) = (0.97)(20.4) \Rightarrow x = 0.961 \text{ lb}_m \text{ Whizzo/lb}_m \Rightarrow \underline{\underline{96\% \text{ Whizzo, } 4\% \text{ dirt}}}$

Note: “W” from Problem Statement = “Whizzo” in Solution

7. (30 pts.) For each situation described below, define a system, write the general open-system form of the First Law of Thermodynamics, and simplify it as much as possible. Explain which terms can be dropped, and why

   a. (10 pts.) A liquid stream flows through a 1-inch-diamter pipe within a horizontal heat exchanger, where it is heated from 25 – 80 ˚C.

   b. (10 pts.) Water from a reservoir behind a dam passes over the dam and falls onto a turbine rotor, causing it to turn and thereby generate electricity. The water then flows gently into a large river. The water does not undergo a significant change in temperature as a result of this process.

   c. (10 pts.) Crude oil is pumped through an uninsulated, 36-inch diameter cross-country pipeline. The pipe begins in the Sierra-Nevada Mountains and ends on the shore of San Francisco Bay. A booster pump is located near the mid-point of the pipeline to make up for frictional losses