ES201 - Examination I Fall 2009-2010 $5^{th}/6^{th}$ hours

NAME____ SECTION______________

BOX NUMBER__________

Problem 1 ______________ / 30

Problem 2 ______________ / 35

Problem 3 ______________ / 35

Total ______________ / 100

INSTRUCTIONS

- **Closed book/notes exam. (Unit conversion page provided)**
- **Help sheet allowed. (8-1/2 x 11" sheet of paper, one side)**
- **Laptops may be used; however, no pre-prepared worksheets or files may be used.**
- **After the exam, please find a nice restaurant and order yourself something nice.**

1) Show all work for complete credit.
   - Start all problems at the ANALYSIS stage, but clearly label any information you use for your solution.
   - **Problems involving conservation principles MUST CLEARLY IDENTIFY THE SYSTEM IN A SEPARATE DRAWING and show a clear, logical progression from the basic principle.**
   - Don't expect us to read your mind as to how or why you did something in the solution. Clearly indicate how your arrived at your answer.
   - **Always crunch numbers last on an exam**. The final numerical answer is worth the least amount of points. (Especially if all I would have to do is plug in the numbers into a well-documented solution.)
2) Useful Rule of Thumb (Heuristic): (100 point exam)/(50 min) = 2 points/minute. That means a 10 point problem is not worth more than 5 minutes of your time (at least the first time around).
3) Please remain seated until the end of class or everyone finishes. (Raise your hand and I'll pick up your exam if you have other work you need or want to do.)

USEFUL INFORMATION	SI	USCS	Molar Mass	
Ideal Gas Constant: R_u	= 8.314 kJ/(kmol-K)	= 1545 (ft-lbf)/(lbmol-°R)	Air	28.97
		= 1.986 Btu/(lbmol-°R)	O_2	32.00
Standard Acceleration of Gravity: g	= 9.810 m/s^2	= 32.174 ft/s^2	N_2	28.01
Density of liquid water	= 1000 kg/m^3	= 62.4 lbm/ft^3	H_2	2.016
		= 1.94 slug/ft^3	CO_2	44.01

Problem 1 (30 pts)

Answer each of the following unrelated questions.

a) (4 points) In the context of ES201, what does it mean for a property to be CONSERVED?

b) (4 points) Air is being compressed from $\forall_{initial}$ to $\forall_{final}$ in a closed piston-cylinder system. Since the overall mass in the system remains constant, it is clear that $\frac{d}{dt}\left(m_{sys}\right)=0$. Is the system at steady state? Explain why or why not.

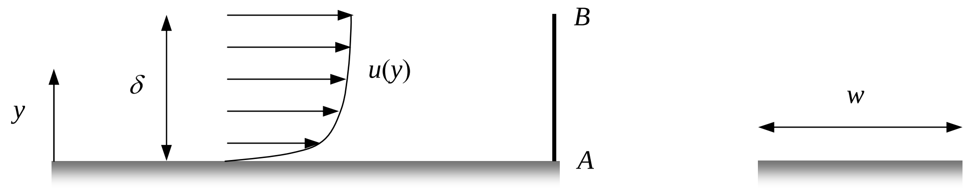
c) (2 points) Does 1 lb_f = 1 lb_m on the surface of the Earth where g = 32.2 ft/sec^2?

d) (2 points) How much does a 1 lb bag weigh on the surface of the moon? Assume that $g_{moon} = 0.16\ g_{earth}$.

e) (4 points) A liquid has a specific gravity of S.G. = 1.2. What is its specific volume?

f) (4 points) A 3 ft^3 tank of helium gas is at a pressure of 150 psi (absolute) and a temperature of 70 $^{\circ}$F. Assuming helium (R = 386.0 ft-lbf/lbm-^{o}R) to act as an ideal gas, what is the mass contained in the tank, in lbm?

g) (10 points) The thin region next to a solid wall ($y \le \delta$) is called the boundary layer (see figure).



Side view End view

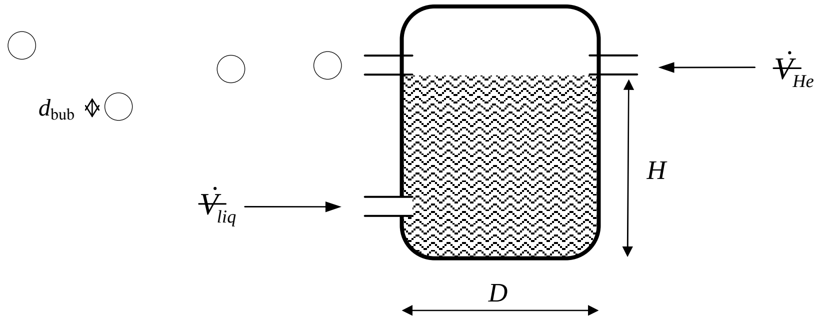
In this region, a fluid speed changes gradually from zero at the wall surface to freestream value ($u = U_o$) at $y = d$.
Assume the velocity profile within the boundary layer is given by

$$u(y) = \frac{1}{1-e^{-7}}\left[1 - \exp\left(-\frac{7y}{\delta}\right)\right] \qquad \text{over } y \le \delta$$

Assume a depth of w into the page, determine the total volume flow rate through the vertical plane AB of height δ.

Problem 2 (35 pts)

The Terre Haute Children Museum is designing a soap bubble machine (internal diameter = D) to be placed at the entrance to welcome kids. The machine works on a simple mechanism which mixes a liquid detergent (density = ρ_{liq}) with gaseous helium (density = ρ_{He}) as depicted below.



a) During the start-up process (no helium, no bubbles), the liquid detergent is allowed to fill the machine at a constant rate of $\dot{V}_{liq}$ up to the same level as the helium injection hole at height H. Apply conservation principle to determine the required filling time, τ_{fill}.

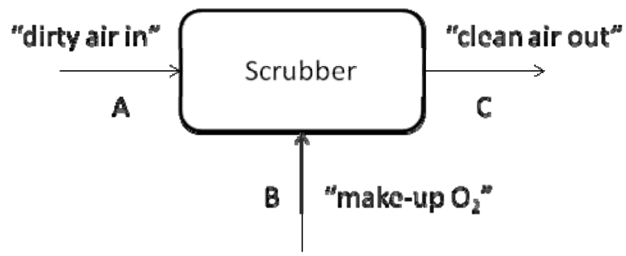
b) During the steady bubble generation process, it is required to inject gaseous helium at a fixed rate relative to that of the detergent given by

$$\frac{\dot{V}_{He}}{\dot{V}_{liq}} = \sigma$$

to maintain a continuous flow of soap bubble (density = ρ_{bub}) of diameter d_{bub} while the liquid detergent stays at the steady level H. Determine the number of soap bubble n_{bub} exiting the machine over any observable time interval τ_{obs}. (Hint: Volume of a sphere with radius $r = 4\ \pi r^3 / 3$)

Problem 3 (35 pts)

During space travel, CO_2 build-up in the air is something that must be dealt with so that astronauts do not experience a condition known as *hypercapnia*, which may result in death. A device called a "scrubber" is used to remove the excess CO_2 from the atmosphere. Over time, CO_2 accumulates in the scrubber, and it must be replaced. Neither N_2 nor O_2 accumulate in the scrubber, but extra "make-up O_2" is necessary to replace the oxygen used by the astronauts. Clean air (Stream C) must be provided to the cabin at the rate of 0.123 m^3/min. The apparent molar mass and density of the clean air are known to be $M = 28.97$ and $\rho = 1.18$ kg/m^3, respectively.



	Flow rate (m^3/min)	Mole Fractions		
		N_2	O_2	CO_2
A	?	0.790	?	0.007
B	?	--	1.000	--
C	0.123	0.790	0.210	--

a) Determine the <u>mass fraction</u> of N_2, O_2, CO_2 in Stream A.
b) Determine the <u>molar flow rate</u> of Stream C, in kmol/min to 3 significant figures.
c) Determine the unknown <u>molar flow rate</u> of Stream A and Stream B, in kmol/min to 3 significant figures.
d) What is the <u>molar accumulation of CO_2</u> in the scrubber, in kmol/min, to 3 significant figures.

Length

1 ft = 12 in = 0.3048 m = 1/3 yd

1 m = 100 cm = 1000 mm = 39.37 in = 3.2808 ft

1 mile = 5280 ft = 1609.3 m

Mass

1 kg = 1000 g = 2.2046 lbm

1 lbm = 16 oz = 0.45359 kg

1 slug = 32.174 lbm

Temperature Values

(T/K) = (T/ ^{o}R) / 1.8

(T/K) = (T/ ^{o}C) + 273.15

(T/^{o}C) = [(T/ ^{o}F) – 32]/1.8

(T/^{o}R) = 1.8(T/K)

(T/^{o}R) = (T/ ^{o}F) + 459.67

(T/ ^{o}F) = 1.8(T/ ^{o}C) + 32

Temperature Differences

(ΔT/^{o}R) = 1.8(ΔT / K)

(ΔT/^{o}R) = (ΔT/^{o}F)

(ΔT / K) = (ΔT/^{o}C)

Volume

1 m^3 = 1000 L = 10^6 cm^3 = 10^6 mL = 35.315 ft^3 = 264.17 gal

1 ft^3 = 1728 in^3 = 7.4805 gal = 0.028317 m^3

1 gal = 0.13368 ft^3 = 0.0037854 m^3

Volumetric Flow Rate

1 m^3/s = 35.315 ft^3/s = 264.17 gal/s

1 ft^3/s = 1.6990 m^3/min = 7.4805 gal/s = 448.83 gal/min

Force

1 N = 1 kg·m/s^2 = 0.22481 lbf

1 lbf = 1 slug·ft/s^2 = 32.174 lbm·ft/s^2 = 4.4482 N

Pressure

1 atm = 101.325 kPa = 1.01325 bar = 14.696 lbf/in^2

1 bar = 100 kPa = 10^5 Pa

1 Pa = 1 N/m^2 = 10^{-3} kPa

1 lbf/in^2 = 6.8947 kPa = 6894.7 N/m^2

[lbf/in^2 often abbreviated as "psi"]

Energy

1 J = 1 N·m

1 kJ = 1000 J = 737.56 ft·lbf = 0.94782 Btu

1 Btu = 1.0551 kJ = 778.17 ft·lbf

1 ft·lbf = 1.3558 J

Energy Transfer Rate

1 kW = 1 kJ/s = 737.56 ft·lbf/s = 1.3410 hp = 0.94782 Btu/s

1 Btu/s = 1.0551 kW = 1.4149 hp = 778.17 ft·lbf/s

1 hp = 550 ft·lbf/s = 0.74571 kW = 0.70679 Btu/s

Specific Energy

1 kJ/kg = 1000 m^2/s^2

1 Btu/lbm = 25037 ft^2/s^2

1 ft·lbf /lbm = 32.174 ft^2/s^2