**ES201** - Examination I Fall 2003-2004

NAME______________________________________________BOX NUMBER______________

Problem 1 ( 16 ) ________________

Problem 2 ( 24 ) ________________

Problem 3 ( 28 ) ________________

Problem 4 ( 32 ) ________________

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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.**

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 and show a clear, logical progression from the basic principle(s).**
   - **Don't expect us to read your mind** as to how or why you did something in the solution. Clearly indicate how you arrived at your answer and how you used the given information in the process.
   - **Always crunch numbers last on an exam**. The final numerical answer is worth the least amount of points. (Especially if all we would have to do is plug in the numbers into a well-documented solution.)
2) Useful Rule of Thumb (Heuristic): (100 point exam)/(90 min) ≈ 1 point/minute. That means a 10 point problem is not worth more than 10 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 [kg/kmol; lbm/lbmol] | |
|---|---|---|---|---|
| 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 |

## 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

$(T/K) = (T/{}^oR) / 1.8$

$(T/K) = (T/{}^oC) + 273.15$

$(T/{}^oC) = [ (T/{}^oF) - 32 ]/1.8$

$(T/{}^oR) = 1.8(T/K)$

$(T/{}^oR) = (T/{}^oF) + 459.67$

$(T/{}^oF) = 1.8(T/{}^oC) + 32$

## Temperature Differences

$(\Delta T/{}^oR) = 1.8(\Delta T / K)$

$(\Delta T/{}^oR) = (\Delta T/{}^oF)$

$(\Delta T / K) = (\Delta T/{}^oC)$

## 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 $ft^2/s^2$

**Problem 1** (16 points)

(a) (2 pts) Explain the difference between an *extensive* property and an *intensive* property.

(b) (3 pts) Terms in the general accounting equation can be classified as *accumulation* terms, *transport* terms, or *production/consumption* terms.

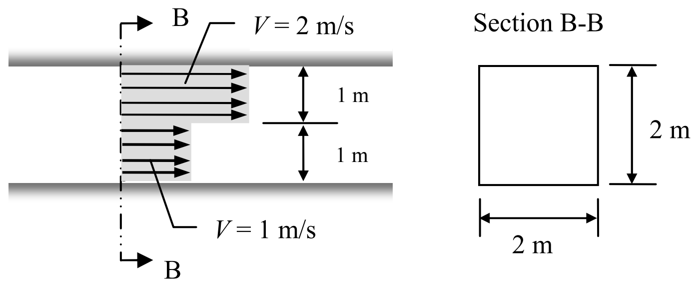
| **Question** | **Circle the correct answer** | | |
|---|---|---|---|
| Where does a *transport* term physically occur? | At a system boundary | OR | Inside the system |
| Where does a *consumption* term physically occur? | At a system boundary | OR | Inside the system |
| Where does an *accumulation* term physically occur? | At a system boundary | OR | Inside the system |

(c) (2 pts) A moon rock has a mass of 1 lbm. What is its mass on Earth? ($g_{moon}$ = 5.4 ft/s$^2$, $g_{earth}$ = 32.2 ft/s$^2$)

**Problem 1 (continued)**

(d) (4 pts) Water flows through a duct with a square cross section as shown in the figure.

Calculate the mass flow rate crossing the boundary labeled "B-B".




(e) (2 pts) A friend has looked up the molar mass (molecular weight) of methane in a handbook and found the following statement: "The molar mass of methane ($CH_4$) is $M = 16.0$."

Using this information, determine the mass (in kg) of 2 kmol of $CH_4$.

(f) (3 pts) A closed container has a constant volume and contains 15 kg of an ideal gas initially at 400 K and 100 kPa. If the temperature of the gas is decreased to 300 K, determine the final pressure of the gas in the tank.

**Problem 2** (24 points)

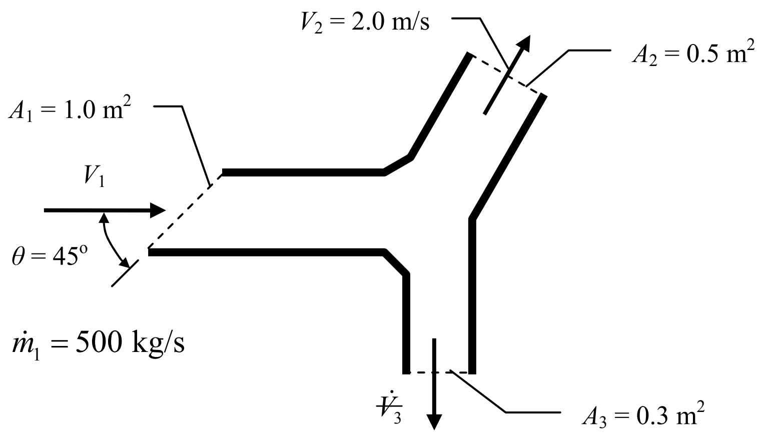
Water enters the steady-state system (shown in the figure) at inlet 1 with a mass flow rate of 500 kg/s and exits the system at outlets 2 and 3.

All known areas are shown as dashed lines on the figure. The velocity $V_1$ makes an angle of 45° with the known area $A_1$. Velocities $V_2$ and $V_3$ are normal to the known areas $A_2$ and $A_3$, respectively.

(a) Calculate the volumetric flow rate at outlet 3.

(b) Calculate the value of velocity $V_1$ at inlet 1.

Note: For full credit show *all* steps in your solution.

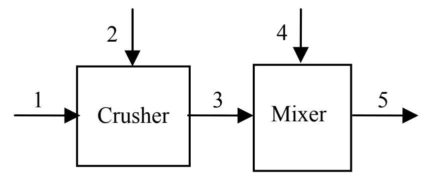


**Problem 3** (28 points)

The ItsaVegetable Co. makes ketchup for school lunchrooms using a two-stage process.

Raw tomatoes and tomato concentrate are fed into the crusher to make tomato slurry. The tomato slurry then flows into the mixer where spices are added to produce the ketchup. Additional flow rate and composition data is shown in the table.

Develop a sufficient set of independent equations that could be used to determine the unknown information. DO NOT SOLVE THE EQUATIONS.

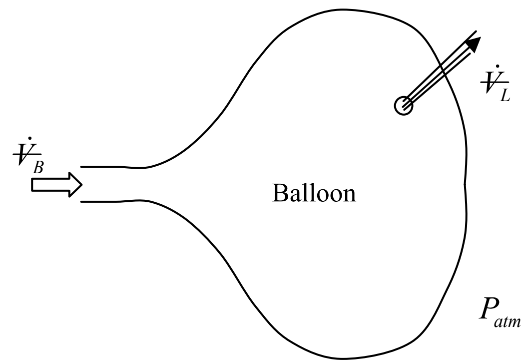



For full credit, you *must* clearly identify *both* the equations you would use and the unknowns that can be determined by solving your set of equations.

| Stream | | Mass Flow Rate | Composition (Mass Fraction) | | |
|---|---|---|---|---|---|
| | | lbm/h | Tomato Solids | Water | Spice |
| 1 | Raw Tomato Feed | 1000 | 0.500 | 0.500 | 0.000 |
| 2 | Tomato Concentrate Feed | | 0.900 | 0.100 | 0.000 |
| 3 | Tomato Slurry | | | | |
| 4 | Spice Feed | | 0.000 | 0.000 | 1.000 |
| 5 | Wet Ketchup Slurry | | 0.714 | | 0.036 |

**Problem 4** (32 points)

You are given a leaky balloon (see figure) and asked to inflate it. Initially, the balloon is deflated with a volume $V = V_o$ and a pressure inside $P = P_{atm}$, the atmospheric pressure.




At time $t = 0$, you begin to inflate the balloon by blowing at a constant volumetric flow rate $\dot{V}_B$.

The following information is also known:

- The balloon volume $V$ is related to the balloon pressure $P$ by the equation:

  $$V = V_o + C(P - P_{atm})$$

  where $C$ is a dimensional constant and $P_{atm}$ is the atmospheric pressure.

- The leakage volumetric flow rate, $\dot{V}_L$, is proportional to the square root of the pressure difference across the wall:

  $$\dot{V}_L = K\sqrt{P - P_{atm}}$$

  where $K$ is a dimensional constant and $P_{atm}$ is the atmospheric pressure.

- As an approximation, assume the air to be incompressible.
- The following parameters are assumed to be given (i.e. have constant, known values):

  $$P_{atm.}, \dot{V}_B, V_o, C, \text{ and } K.$$

(a) Develop an equation for the *time rate of change* of the balloon volume, $dV/dt$. (Do not solve the equation.)

(b) Assuming that the balloon doesn't break and that you don't run out of air, what is the steady-state volume of the balloon? Give your answer in terms of the given parameters listed above.

Note: For full credit show *all* steps in your solution.