I. ENVH 557 Exposure Controls
M. Yost, Winter 2008 KEY- Problem set I (due Thurs. Feb 7, 2006)

1. Standard conditions in ventilation are: T = 70ºF, P = 29.9in Hg, air density = 0.075 lbm/ft3. Express the temperature in degrees C, R and K. Express the pressure in the following units: mm Hg, inches of water, atm and psi. What change in temperature or pressure is needed to make a change in the air density of at least 5%?

ANS: 70ºF + 459.7 = 529.7ºR; (70ºF-32) *5/9 = 21.1ºC; (70ºF-32) *5/9+273 = 294.1ºK
29.9 "Hg = 760 mmHg = 1 Atm = 407"$H_2$0
Air density changes proportionally to absolute pressure and inversely with absolute temperature. This is expressed by the density factor = d= (P/407)* 529.7/(459.7+T) where P is pressure in "$H_2$0 and T is temperature in ºF. To get a 5% change in the density factor, temperature and pressure would be above or below the range below:

Problem 1b	High	Low
Temp5%	98	44
Press5%	428	386

2. Air is flowing at a velocity of 3500ft/min (FPM) through a circular duct section 15 inches in diameter and 12 ft long. Assume standard conditions. What is the volume flow rate? What is the mass flow rate?

ANS: the volume flow rate in CFM = Q = (duct area) * velocity; mass flow rate is = m_dot = Q*density. At standard conditions the air density is 0.0.75 lbm/cuft. Therefore:

Problem 2		
FPM	Duct_vel	3500
lb/cuft	Air_density	0.075
Inches	Duct_diam	15
Sqft	Duct_area	1.23
CFM	**Q**	**4295.15**
Lbm/min	**m_dot**	**322.14**

3. At the end of the 15-inch section above, the duct diameter reduces to 9 inches and after 18 feet at this diameter, changes to a 9" x 12" rectangular duct section 12 feet long. Draw a sketch of this duct network and label each section (a,b,c, etc.). What is the new velocity, volume flow rate and Re number in each section of duct? (HINT: to calculate Re for a non-circular duct, you need to find the equivalent hydraulic diameter of the duct section.)

ANS: The volume flow rate is the velocity times the area or Q= VA = 3500*1.227= 4295 CFM. The mass flow 0.075lbs/cuft*4295 CFM = 322 lbs/min. These terms remain constant in a serial flow duct section. Since density is constant, we can use Q above to compute the velocity into each section. The table below gives the calculations for each duct section. (Note the diameter in yellow is the hydraulic diameter which is = 4* area/ perimeter. Also, the area of duct section 3 is just the geometric area (length * width), it is

NOT computed from the hydraulic diameter). We see that section 2 has the highest Reynolds number, therefore making that section laminar will make all others laminar. Note that Reynolds number scales linearly with velocity, so we can use a simple proportion to find the velocity that gives Re= 2000. Setting the velocity to 26 FPM in section 2 gives Re~2000 (the maximum velocity condition for laminar flow).

Kinematic Viscosity of air	
Cm^2/s	Ft2/s
0.15083	1.6235E-04

Duct Section #3		
width	length	D_hydro
9	12	10.2857143

Problem 3							
section	Dia(in)	SqFt	Dia (ft)	Velocity	CFM	lb/min	Re
1	15	1.22718463	1.250	3500	4295	322	449133
2	9	0.44178647	0.750	9722	4295	322	748554
3	10.29	0.75	0.857	5727	4295	322	503926
For laminar flow, we choose section 2 as limiting case; assume a maximum Re of 5000							
2	9	0.44178647	0.750	64	28	2	4928

4. Air is moving through a pipe at a volume flow rate of 2000 CFM and a temperature of 70ºF. If the temperature increases to 95ºF, what is the new volume flow rate, assuming the barometric pressure (1 atm) remains constant? What is the new mass flow rate?

ANS: The problem is solved directly if we remember the mass flow stays constant while the volume flow rate changes with changes in density, so (Rho1) Q1 = (Rho2) Q2

Problem 4	Temp_1	Temp_2	Temp_1R	Temp_2R
	70	95	529.67	554.67
Q1 (CFM)	Density_1	m1 lbs/min	Density_2	Q_2 (CFM)
2000	0.075	150	**0.07162**	**2094.4**

5. The velocity pressure of air in a duct is 1.5 in w.g. What is the velocity?

ANS: Assume standard conditions, so V = 4005*√(Pv)

Problem 5	Pv	Velocity
	1.5	4905.10

6. The static pressure in a 5-inch diameter duct is measured as -2.5 in w.g. The total pressure (or stagnation pressure) is -1.3 in w.g. What is the velocity of the air in the duct? What is the volume flow rate?

ANS: Use the relationship Pt=Ps+Pv to find the velocity pressure Pv, then compute the velocity from the relationship in problem #5. The volume flow rate Q is then computed in the same manner as in problem 3.

Problem 6

Pt	Ps	Pv	Dia(in)	SqFt	Velocity	CFM
-1.3	-2.5	1.2	5	0.1364	4387.3	598

7. Assume a ventilation system is operating with a 4-inch diameter duct. At what volume flow rate (cfm) will the upper limit of laminar flow be reached?

ANS: This problem is similar to problem 3, assume Re of ~2000 for laminar flow.

Problem 7	Dia(in)	SqFt	Dia (ft)	Velocity	CFM	Re
	4	0.08726646	0.333	58.45	5	2000