UNIVERSITY OF TORONTO
FACULTY OF APPLIED SCIENCE AND ENGINEERING
FINAL EXAMINATION, DECEMBER 2001

MIE 512F: AIR POLLUTION: ITS FORMATION AND CONTROL

Examiner: M.J. Thomson

Attempt all questions.
You are allowed one sheet of notes.
The value of the questions given in parentheses.
Show your work.
Circle your answers.

1) (20%) An engineer is asked to design a particle filtration system. The particle is in air at 27C and 1 atm. The fiber solids fraction is 0.10. The particle density is 1000 kg/m^3. The fiber diameter is 5 microns. The air velocity is 4cm/s.
   a) In order to remove 99% of the 0.1-micron particles, what filter thickness is needed?

2) (10%) A water heater produces 100 liters of hot water per day using methane. The methane is burnt at an equivalence ratio of 0.9. While retaining a methane fired hot water heater, suggest the best strategy for reducing CO_2 emissions

3) (20%) An electrostatic precipitator must treat 225 m^3/s with 99% efficiency. Assuming an effective drift velocity of 0.1 m/s,
   a) calculate the required plate area in m^2, and the number of plates if each is 3m tall and 10m long
   b) after the ESP is built, the gas flow increases to 300 m^3/s. Calculate the new efficiency.
   c) How could we increase the drift velocity.

4) (30%) A 100 m^3/s air stream (27°C and 1 atm) contains 1 micron particles. The particle density is 1000 kg/m^3.
   a) What diameter high efficiency cyclone will give you 90% removal of the particles? See table below for dimensions of a high efficiency cyclone.
   b) What is the inlet air velocity? Is this reasonable?

5) (20%)
   a) Name two advantages and one disadvantage of electrostatic precipitators.
   b) What pollutants does a car's catalytic converter remove? When does it operate at its lowest removal efficiency?
   c) Name a "Zero emission vehicle" and discuss its advantages and disadvantages.
   d) Describe the impaction mechanism of filtration.

Data

Henry's Law Constants of pollutants in air and water at 30C:

SO_2 H' = 4.3E6 Pa
HCl H' = 3.6E4 Pa
NO H' = 3.1E9 Pa

Chemical kinetic data for hydrocarbons

$$C_nH_m + (n+m/4)\ O_2 \rightarrow n\ CO_2 + (m/2)\ H_2O$$

$$d[C_nH_m]/dt = -Rf$$

$$R_f = A\ \exp(-(Ea/R)/T)\ C_{CnHm}^{\ a}\ C_{O2}^{\ b}$$

Note: Units of m, s, mol, K
C_{CnHm}, and C_{O2} are in mol m^{-3}; T in K; R_f = mol m^{-3} s^{-1}

Hydrocarbon		A	Ea/R	a	b
Methane	CH_4	130,000,000	24,400	-0.3	1.3
Propane	C_3H_8	27,000,000	15,000	0.1	1.65
Methanol	CH_3OH	101,000,000	15,000	0.25	1.5
Ethanol	C_2H_5OH	47,000,000	15,000	0.15	1.6

Molecular Weights

MW of water = 18g/mol
MW of N_2 = 28g/mol
MW of O_2 = 32g/mol

Constants:

Ideal gas law constant: R = 8.314 J/mol K

Boltzmann's constant: k = 1.38 E-23 J/K

1 atm = 1.01E5 Pa

Effective Migration (Drift) Velocities

Application	Migration (Drift) velocity
	cm/s
Grinding	8
Utility boiler	10
Cement (Dry Process)	6
Blast furnace	10

Standard Cyclone Dimensions

	Cyclone Type		
	High Efficiency	Conventional	High Throughput
D/D	1	1	1
H/D	0.44	0.5	0.8
W/D	0.21	0.25	0.35
L_b/D	1.4	1.75	1.7
L_c/D	2.5	2	2

Table A.4 Thermophysical properties of gases at atmospheric pressure[a]

T (K)	ρ (kg/m³)	c_p (kJ/kg · K)	$\mu \cdot 10^7$ (N · s/m²)	$\nu \cdot 10^6$ (m²/s)	$k \cdot 10^3$ (W/m · K)	$\alpha \cdot 10^6$ (m²/s)	Pr
Air							
100	3.5562	1.032	71.1	2.00	9.34	2.54	0.786
150	2.3364	1.012	103.4	4.426	13.8	5.84	0.758
200	1.7458	1.007	132.5	7.590	18.1	10.3	0.737
250	1.3947	1.006	159.6	11.44	22.3	15.9	0.720
300	1.1614	1.007	184.6	15.89	26.3	22.5	0.707
350	0.9950	1.009	208.2	20.92	30.0	29.9	0.700
400	0.8711	1.014	230.1	26.41	33.8	38.3	0.690
450	0.7740	1.021	250.7	32.39	37.3	47.2	0.686
500	0.6964	1.030	270.1	38.79	40.7	56.7	0.684
550	0.6329	1.040	288.4	45.57	43.9	66.7	0.683
600	0.5804	1.051	305.8	52.69	46.9	76.9	0.685
650	0.5356	1.063	322.5	60.21	49.7	87.3	0.690
700	0.4975	1.075	338.8	68.10	52.4	98.0	0.695
750	0.4643	1.087	354.6	76.37	54.9	109	0.702
800	0.4354	1.099	369.8	84.93	57.3	120	0.709
850	0.4097	1.110	384.3	93.80	59.6	131	0.716
900	0.3868	1.121	398.1	102.9	62.0	143	0.720
950	0.3666	1.131	411.3	112.2	64.3	155	0.723
1000	0.3482	1.141	424.4	121.9	66.7	168	0.726
1100	0.3166	1.159	449.0	141.8	71.5	195	0.728
1200	0.2902	1.175	473.0	162.9	76.3	224	0.728
1300	0.2679	1.189	496.0	185.1	82	238	0.719
1400	0.2488	1.207	530	213	91	303	0.703
1500	0.2322	1.230	557	240	100	350	0.685
1600	0.2177	1.248	584	268	106	390	0.688
1700	0.2049	1.267	611	298	113	435	0.685
1800	0.1935	1.286	637	329	120	482	0.683
1900	0.1833	1.307	663	362	128	534	0.677
2000	0.1741	1.337	689	396	137	589	0.672
2100	0.1658	1.372	715	431	147	646	0.667
2200	0.1582	1.417	740	468	160	714	0.655
2300	0.1513	1.478	766	506	175	783	0.647
2400	0.1448	1.558	792	547	196	869	0.630
2500	0.1389	1.665	818	589	222	960	0.613
3000	0.1135	2.726	955	841	486	1570	0.536
Ammonia (NH_3)							
300	0.6894	2.158	101.5	14.7	24.7	16.6	0.887
320	0.6448	2.170	109	16.9	27.2	19.4	0.870
340	0.6059	2.192	116.5	19.2	29.3	22.1	0.872
360	0.5716	2.221	124	21.7	31.6	24.9	0.872
380	0.5410	2.254	131	24.2	34.0	27.9	0.869
400	0.5136	2.287	138	26.9	37.0	31.5	0.853
420	0.4888	2.322	145	29.7	40.4	35.6	0.833
440	0.4664	2.357	152.5	32.7	43.5	39.6	0.826