**UNIVERSITY OF TORONTO**
**FACULTY OF APPLIED SCIENCE AND ENGINEERING**
**MIE 514S**
**Atmospheric pollution: Environmental effects & consequences**

**FINAL EXAM**
**April 16, 2001**
**1400 hrs. to 1630 hrs.**
**Examiner: J. F. Keffer**

**This is a closed book exam of two an one-half hour duration.**
**All questions are of equal value**

1. Answer the following questions briefly but clearly. Use diagrams if you wish, to help explain your points.
   a) Describe the Walker Circulation Model as it applies to the Pacific Ocean and discuss how it is changed when the ENSO (el Niño) phenomenon occurs.
   b) Describe and discuss the significance of the End Permian Mass Extinction.
   c) The mass of carbon on the planet is virtually constant and the way in which it appears through storage and transfer processes is termed the Carbon Cycle. Discuss these processes and their importance.
   d) Describe how emphysema occurs and its consequences.

2. The basic equations of motion for a fluid (the so-called Navier Stokes equations) are:

$$\frac{dq}{dt} = \frac{\partial q}{\partial t} + (q \cdot \nabla)q = g - \frac{1}{\rho}\nabla p + \nu \nabla^2 q$$

where **q** is the velocity vector with components, **u**, **v** and **w** in the three co-ordinate directions. The pressure and temperature variation with altitude in the atmosphere are governed by the aerostatic simplification of the above equations and the equation of state for a perfect gas.

Using the aerostatic simplification and the equation of state where necessary, determine the pressure and temperature variation with altitude for the following cases:
   a) a constant density atmosphere
   b) an isothermal atmosphere
   c) an atmosphere with a linear decrease of temperature with altitude, such as $T = T_o - \lambda(z - z_o)$, where $\lambda$ is the (constant) lapse rate.

Which of these would be the most realistic assumption for the troposphere, which could you use for the tropopause and what would you do to try to model the stratosphere?

3. Certain atmospheric stability conditions will produce a chimney stack plume which is characterized as "looping". Sketch such a plume.

a) For what type of atmospheric stability would this occur? Sketch the appropriate lapse rate with respect to the standard reference lapse rate.
b) Referring to the diagram of the looping plume, sketch the following:
   i. the streakline for the plume
   ii. typical particle paths
   iii. typical streamlines

4. An industrial complex is located near a local international airport. Its single stack is 300 m high and under full operation, discharges 5,000 g/s of $SO_2$. The flight path of the main runway of the airport is perpendicular to the plume under prevailing wind conditions and crosses the plume 5 km downwind. The airport safety officer has deemed it unsafe for aircraft to fly through any part of the plume where the concentration of $SO_2$ is greater than 500 $\mu g/m^3$. As a precaution he has recommended that all aircraft fly at an altitude of at least 900 m. Show whether or not this is reasonable.

Assume that the average velocity of the prevailing wind is 3 m/s and constant up to the geostrophic height. The plume rise due to buoyancy and momentum is 100 m. Choose a stability criterion that is consistent with daytime flights only and significant cloud cover.

5. A burning dump emits 3 g/s of $NO_x$.

a. determine the maximum concentration of the contaminant 1 km downwind for an overcast night with a mean wind speed of 7 m/s.
b. The owner suggests that things would be much better if a 20 m stack were erected on the dump site. Check this out. Ignore the plume rise in both cases and assume that the wind speed does not change significantly from the reference value.

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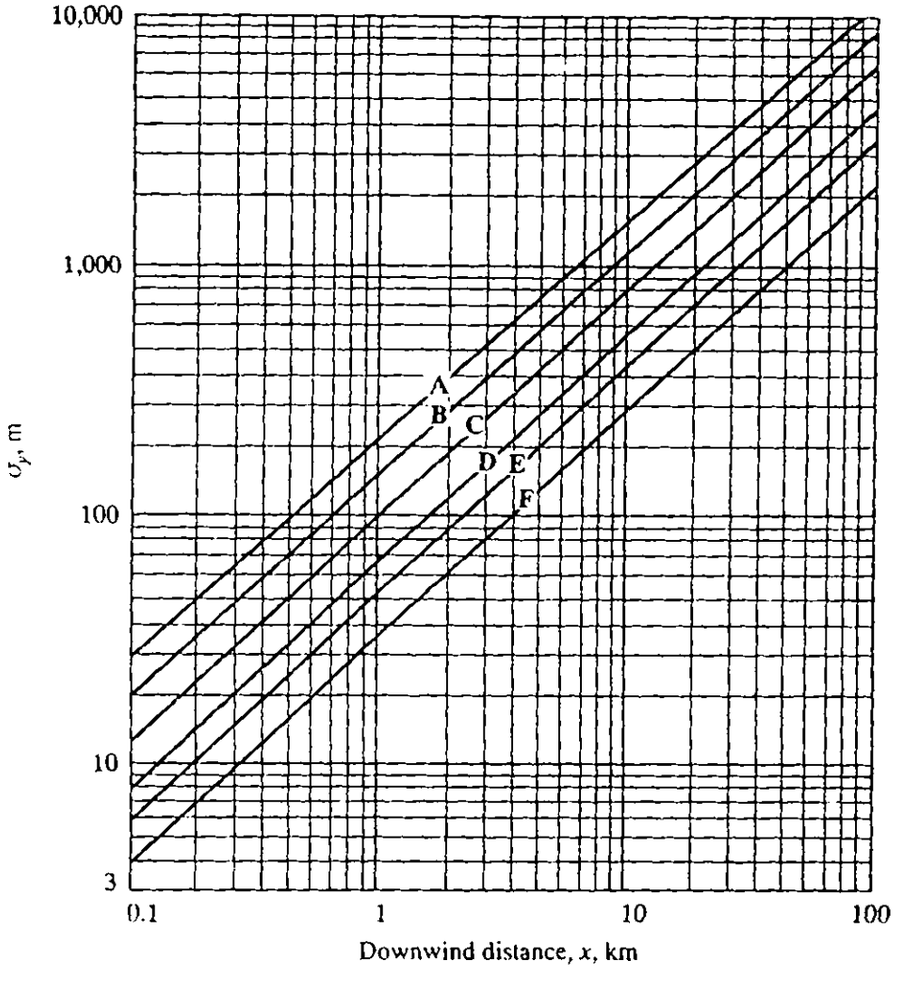
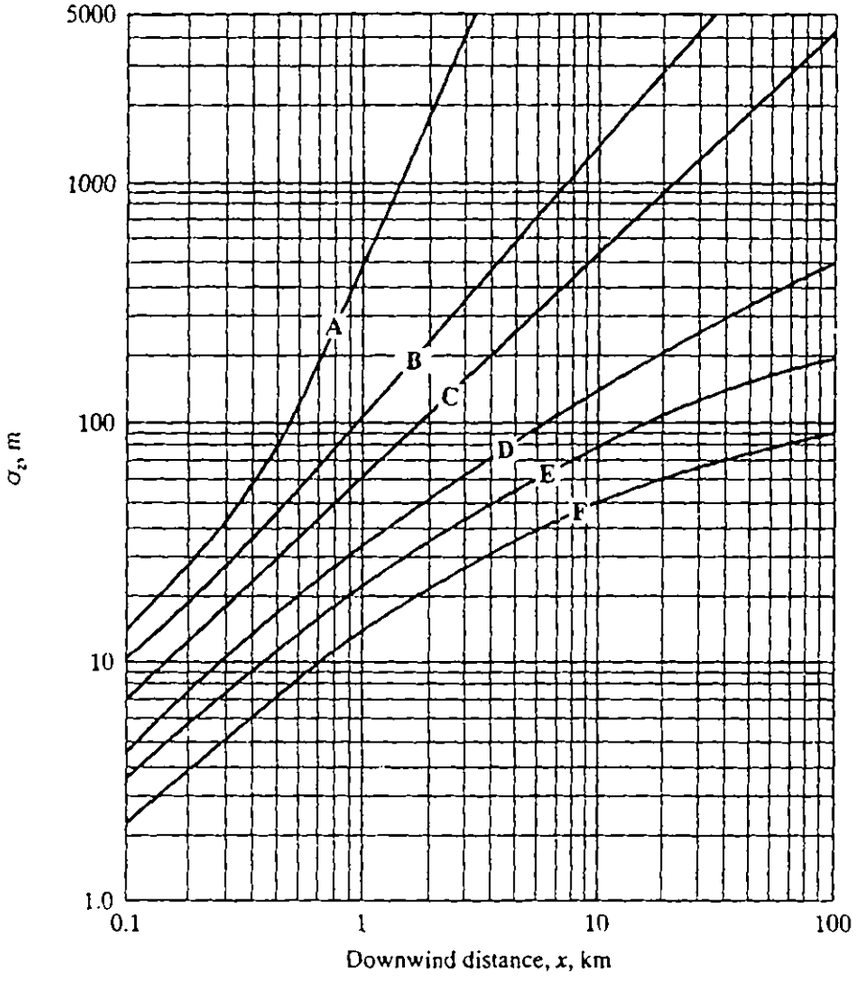
The general thin plume diffusion equation from a point source is:

$$\chi(x,y,z:H)=\frac{Q}{2\pi\sigma_y\sigma_z U}\exp\left[-\frac{1}{2}\left(\frac{y}{\sigma_y}\right)^2\right]\left\{\exp\left[-\frac{1}{2}\left(\frac{z-H}{\sigma_z}\right)^2\right]\pm\exp\left[-\frac{1}{2}\left(\frac{z+H}{\sigma_z}\right)^2\right]\right\}$$

Use the appropriate form of this equation in Questions 4. and 5. to give a conservative answer, i.e. a reflected plume.


10,000
1,000
100
10
3
$\sigma_y$, m
A
B
C
D
E
F
0.1
1
10
100
Downwind distance, $x$, km




## Key to stability categories

| Surface wind speed (at 10 m), m/s | Day | | | Night | |
|---|---|---|---|---|---|
| | Incoming solar radiation | | | | |
| | Strong | Moderate | Slight | Thinly overcast or ≥ $\frac{4}{8}$ cloud | Clear or ≤ $\frac{3}{8}$ cloud |
| 0–2 | A | A–B | B | — | — |
| 2–3 | A–B | B | C | E | F |
| 3–5 | B | B–C | C | D | E |
| 5–6 | C | C–D | D | D | D |
| ≥ 6 | C | D | D | D | D |