Air Pollution Control
FINAL EXAM

Note 1: Consult your books, notes, annotated reports, etc., but be sure to use your time effectively (i.e., rely as much as possible on information in handouts and solved problems). Rather than leaving some of the problems unanswered, while solving others in detail, make sure you at least outline the solutions to each one of them. If some information is missing in problem statements (and is not available in the handouts or annotated reports), make reasonable assumptions and justify them.
Note 2: Solve only four problems. Problem #1 is compulsory for everyone. From problems #2-#6, select *three;* exclude the problem which deals with the pollutant(s) that your group studied during the semester, except for the bonus part of the problem.
Note 3: Each problem is worth 25%.

1. (a) Discuss (briefly) the principal sources of each one of the air pollutants covered in the course.
(b) Summarize the most important methods used for their control.

2. Control of SOx.
(a) Calculate the annual uncontrolled SO_2 emissions from a 1000 MW(e) power plant that burns coal (12000 BTU/lb; 2 wt. % sulfur; 15 wt. % ash) at 33% efficiency. Determine the efficiency of the sulfur capture process that is required to comply with NSPS.
(b) At what temperature does the conversion of SO_2 to SO_3 become thermodynamically favorable? Above this temperature, does the conversion become more or less favorable?
(c) Calculate the time needed for 98% thermal decomposition of $NaHCO_3$ at 500 K. Assume 1st-order Arrhenius behavior with a pre-exponential factor of 2.65×10^{12} s^{-1} and an activation energy of 111.5 kJ/mol.

3. Control of NOx.

(a) Estimate the uncontrolled emissions of nitrogen oxides from the same plant as in #2, using a typical emission factor rating. Does this plant need to install NOx control equipment to meet the NSPS?

(b) Aviation kerosene ($CH_{1.88}$) is burned at 2250 K and 10 atm, with a residence time of 5 milliseconds. If the equivalence ratio is 1.0, calculate the mole fraction of NO in the gaseous product. Compare your result with the solutions to E6.2 and P6.3 in Benítez (op. cit.) and comment on the trends observed.

4. Control of COx.

(a) Estimate the uncontrolled emissions of carbon oxides (both CO and CO_2) from the same plant as in #2, using a typical emission factor rating for CO.

(b) When 50% of blood hemoglobin is converted to HbCO, a person is very close to death. If a person breathes 4 liters of air per minute and air contains ten times more CO than permitted by 1-h NAAQS, how much time is needed to reach this HbCO level? Use the assumptions in P1.7, Benítez (op. cit.).

(c) Australia's 1990 emissions of CO_2 (equiv.) were 385 million tons. If one of the projections for the year 2010, 540 million tons, is indeed realized, by how much will Australia need to reduce these emissions to meet the requirements of the Kyoto Protocol?

5. Control of PM.

(a) Estimate the uncontrolled emissions of particulate matter from the same plant as in #2, using a typical emission factor rating. Does this plant need to install PM control equipment to meet the NSPS?

(b) A group of particles is described by the log-normal distribution with a mass-mean diameter of 10 μm and a standard deviation of 1.5. Calculate the mass fraction of the particles having diameter less than 1 μm. An air stream containing these particles goes through a collector that is 100% efficient for particles with $D \geq 40\mu$m, 50% efficient for particles 10-40 μm and 10% efficient for particles smaller than 10 μm. Calculate the mass fraction of particles removed by this collector.

6. Control of VOCs.

(a) Explain in as much detail as possible, and with relevant quantitative examples, Figure D.1 in de Nevers (op. cit.) which shows how ozone concentration in polluted air varies with changes in NOx and VOC concentrations.

(b) The gaseous effluent from a chemical process (20 m^3/s; 300 K, 1 atm) contains 3000 ppm toluene, 20% O_2 and 79.7% N_2. Calculate the temperature needed to reduce toluene concentration to 20 ppm in a thermal incinerator with a residence time of 0.6 seconds.

(c) Toluene concentration in the vicinity of the plant was reported to be ~1 $\mu g/m^3$. Show whether this is within the range given in Figure D.1.