

PHYS/ENVS 3070

Homework Assignment #9:

Problem #1. In the year 2020, it is conceivable that 20 GigaWatts of electricity could be continuously generated in a single western state by coal burning power plants.

(5 points total)

Part I: At 38% efficiency for generating electric power, how many tons of coal would be burned per year?

If we want 20 GigaWatts = 20×10^9 Watts or Joules/second for one year (or 3×10^7 seconds), we need $(20 \times 10^9 \text{ Joules/second}) \times (3 \times 10^7 \text{ seconds}) = 6 \times 10^{17}$ Joules of electrical energy. If our generating power plant is only 38% efficiency, then we need much more input fuel energy of $6 \times 10^{17} / 0.38 = 1.6 \times 10^{18}$ Joules.

One ton of coal has an energy of 2.81×10^{10} Joules (according to the textbook front cover inset). Therefore we can calculate the number of tons of coal needed.

$$\text{TonsCoal} = \frac{\text{EnergyNeeded}}{\text{Energy/TonCoal}} = \frac{1.6 \times 10^{18} \text{ J}}{2.81 \times 10^{10} \text{ J/ton}} = 5.6 \times 10^7 \text{ tons}$$

Thus, we need 56 million tons of coal each year for this power plant.

Part II: If the sulfur content of the coal averages 1%, how many tons of SO₂ would be released per year?

If sulfur is 1%, then 5.6×10^5 tons of sulfur is contained in the coal. However, given the atomic weight of sulfur (32) and oxygen (16), the mass of SO₂ is half sulfur and half oxygen (two atoms in each molecule). Thus the 5.6×10^5 tons of sulfur will turn into 1.2×10^6 or 1.2 million tons of SO₂.

Part III: If a standard of 0.1 pounds of particulates per million BTU is adhered to, how many tons of particulates would be released per year?

Since this limit on particulates is given in terms of BTU, we need to convert the coal energy of 1.6×10^{18} Joules into BTU. Using the conversion in the front cover of the book, we get 1.5×10^{15} BTU. The wording of this problem could imply it is per BTU of electrical energy instead of fuel energy, and so either number is fine.

If we take $1.5 \times 10^{15} \text{ BTU} / 1 \times 10^6 \text{ BTU} = 1.5 \times 10^9$ million BTU. So there is 1.5 billion million BTU of energy. If for every million BTU there is 0.1 pounds of

particulates, then there are 0.15 billion pounds of particulates that can be emitted each year. A ton is 2000 pounds, and so this is 75,000 tons of particulates.

Part IV: How many tons of CO₂ would be released per year, assuming that the coal is 100% carbon?

This problem is the same as a previous homework problem. Since we have 56 million tons of coal and CO₂ is made of carbon (mass 12) and two oxygen (mass 16), for every ton of carbon or coal, there is about three times as much CO₂ produced. This is thus 168 million tons of CO₂.

Problem #2. In the above problem, assume that the amount of SO₂ released per year is 1.18×10^6 tons. If a thermal inversion persists for a 24-hour period over the whole state and the released SO₂ can rise no higher than 1000 meters, what concentrations of SO₂ (in units of micrograms per cubic meter) will be present in the air?

Assume that the state is 500 km x 500 km in area.

(5 points total)

We are keeping all the 1.18 million tons of SO₂ in a very large box. The box with dimensions 500,000 meters x 500,000 meters x 1000 meters (note converting all distances to meters), has a volume = 2.5×10^{14} m³ or cubic meters. Thus, we can just divide the mass by the volume to get the answer. However, we want to convert tons in units of micrograms or 10^{-6} grams.

One ton = 2000 pounds and 1 pound = 454 grams and 1 gram = 1×10^6 micrograms.

$$\frac{SO_2(\text{micrograms})}{\text{meter}^3} = \left(\frac{1.18 \times 10^6 \text{ tons}}{2.5 \times 10^{14} \text{ m}^3} \right) \times \left(\frac{2000 \text{ pounds}}{1 \text{ ton}} \right) \times \left(\frac{454 \text{ grams}}{1 \text{ pound}} \right) \times \left(\frac{1 \times 10^6 \text{ micrograms}}{1 \text{ gram}} \right)$$
$$\frac{SO_2(\text{micrograms})}{\text{meter}^3} = 4.2 \times 10^3 \text{ micrograms / cubicmeter}$$

In the above problem, the wording is somewhat ambiguous. It makes more sense to say you only have the emissions from the 24-hour period in the box, not from the whole year. This would then result in a SO₂ density that is a factor of 1/365 smaller.

How does this level compare to standards set from the clean air legislation?

In the textbook in Table 9.3 are listed the National Ambient Air Quality Standards which for SO₂ is 365 micrograms per cubic meter for a 24 hour period or 1300 micrograms per cubic meter for a three hour period. In either case the above

calculated number is above these limits. You can also find more information on clean air legislation from other resources.

Problem #3. The pH of normal rain is _____ and it contains _____.

- a) 4.5 H₂SO₄
- b) 7.0 no acid at all
- c) 5.6 carbonic acid
- d) 7.0 carbonic acid
- e) 6.5 HNO₃
- f) 7.5 H₂SO₄

(1 point) C is the correct answer. As detailed in Section 9.10 of the textbook "pure rainwater has a pH of around 5.6, somewhat lower than the pH of 7 for a neutral solution. This slight acidity comes about mainly from the formation of carbonic acid (H₂CO₃)."

Problem #4. Pick the set of answers which best characterize the major fuel, time of occurrence, principle constituents, and principle effect of photochemical smog (e.g. in Los Angeles):

- a) petroleum, early morning, (CO, SO₂), bronchial irritation
- b) petroleum, midday, (O₃, NO, NO₂, CO), eye irritation
- c) coal, midday, (O₃, NO, NO₂, CO), eye irritation
- d) petroleum, early morning, (O₃, NO, NO₂, CO), eye irritation

(1 point) B is the best answer. See details in Section 9.6 of the textbook. Many emissions start early in the morning, but the photochemical smog takes some time to develop.

Problem #5. The most environmentally harmful emissions from automobiles are _____.

- a) CO, SO₂, and particulates
- b) hydrocarbons, CO₂, and SO₂
- c) hydrocarbons, CO, and NO_x
- d) CO, particulates, and NO_x
- e) CO₂, SO₂ and NO_x
- f) CO, SO₂, and NO_x
- g) SO₂ and NO_x
- h) radioactivity and SO₂

(1 point) C is the best answer. See details in Section 9.7 of the textbook. In particular, Table 9.4 is quite useful in considering the various sources of pollutants including transportation.