ME 433
Spring Semester, 2020
Homework Set # 3
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1. (15 pts) Some Penn State researchers recently published an article comparing the health effects of air pollution to smoking cigarettes. See https://tinyurl.com/wqa2qqk. Read the article and look up some things on the Internet to answer the following questions:
   
   (a) According to the article, if a person is continuously exposed (24/7) to the NAAQS level for particulate matter (PM) air pollution for one full year, how many packs of cigarettes would need to be smoked in a one year period to have equivalent health effects?
   
   (b) The article does not distinguish between PM2.5 and PM10 particulate matter. Let’s assume the air pollution being compared is of the PM2.5 variety. Look up the current NAAQS mass concentration level for primary PM2.5 particle air pollution in units of $\mu g/m^3$.
   
   (c) Estimate the mass concentration of PM2.5 air pollution (in $\mu g/m^3$) equivalent to smoking one pack of cigarettes per day, every day. Show all your calculations, including all units.
   
   (d) This part is opinion. If you are working in a group, everyone in the group needs to answer this part separately. If you live in an area of the country where the PM2.5 air pollution is at or near the NAAQS level, would you be concerned about health effects? Why or why not?

2. (20 pts) In Week 2 of the Lectures/HW link on the main ME 433 website, I provide links to eight articles about how to capture/sequester/convert/reduce carbon dioxide from the atmosphere.
   
   (a) Read these articles and write your opinion: Which of these, if any, show the most promise of reducing CO$_2$ in the atmosphere at “reasonable” expense and practicality? Why?
   
   (b) Look up a few more other articles about fake trees, carbon sequestration, carbon conversion, etc. (the topic is your choice – must be something related to global warming and carbon dioxide reduction). Cite one or two of them that show real promise and explain why.

3. (15 pts) There are many layers of earth’s atmosphere such as the troposphere, stratosphere, etc., which we discussed very briefly in class.
   
   (a) Do some Internet searching, and briefly define the five main atmospheric layers. List the approximate altitude ranges or extents (lowest to highest in km) for each of the five layers.
   
   (b) Some atmospheric scientists and meteorologists label a sixth layer called the chemosphere, which does not seem to be as popular in the literature as the other layers. Define the chemosphere and its approximate altitude range.

4. (15 pts) A flux chamber is constructed to measure the rate at which carbon monoxide (CO) is produced by a process that involves some non-ideal combustion, producing soot and CO. The flux chamber is built around (encloses) the process in the usual fashion, and the following parameters are measured: flux chamber volume = 1.35 m$^3$, mass concentration of CO in the ambient air = 2.7 mg/m$^3$, and volume flow rate of bulk air entering the flux chamber = 1.33 m$^3$/s. After sufficient time, the system reaches steady-state conditions, and the mass concentration of CO in the bulk air leaving the flux chamber levels off at 1.28 g/m$^3$. As always, be careful with units and show all units and unit conversions.
   
   (a) Calculate the source strength (mass generation rate) of CO from the process in units of grams of CO per minute.
   
   (b) Re-calculate for the case in which the volume of the flux chamber is doubled, everything else being equal.
   
   (c) Sketch (can be a hand sketch, not a computer-generated plot, although you are welcome to generate a computer plot if desired) the measured $c_f$ at the flux chamber outlet vs. time for the two cases and explain what happens when the volume is doubled, and why.

Note: There is another page. →
5. (20 pts) A combustion chamber contains octane (C₈H₁₈) and air. Prior to combustion, the molar oxygen-fuel ratio is 18:1, which means that there is one mol of octane molecules for every 18 mols of oxygen molecules (O₂). The air contains 3.76 mols of N₂ for every mol of O₂, but the nitrogen does not react — it just “goes along for the ride.” The air contains only trace amounts of argon, CO₂, etc. The mixture is burned. We assume complete combustion, so that the burning process produces only the following:

- carbon dioxide (CO₂)
- water vapor (H₂O)
- oxygen (O₂)
- nitrogen (N₂)

(a) Find constants $a$, $b$, $c$, $d$, and $e$ if we write the chemical equation for this combustion process in the following form:

$$\text{C}_8\text{H}_{18} + a\text{(O}_2 + 3.76\text{N}_2) = b\text{(CO}_2 + c\text{(H}_2\text{O)} + d\text{(O}_2 + e\text{(N}_2)$$

(b) Note that the oxygen-fuel ratio given in the problem statement is an oxygen-fuel ratio, not an air-fuel ratio. Keeping in mind that the air contains 3.76 mols of N₂ for every mol of O₂, calculate the molar air-fuel ratio in the combustion chamber prior to combustion.

(c) Calculate the mass air-fuel ratio (AF), assuming $M_{\text{air}} = 28.97 \text{ g/mol}$.

6. (15 pts) Here are a few quick problems using emission factors. (Note: For consistency in your answers, use Appendices A-2 through A-7 of the Heinsohn & Cimbala textbook for emission factors — these appendices are posted on the course website for your convenience. Some of these emission factors may have changed since publication of that book, but use the values in the posted appendices for consistency.) Give your final answers to two significant digits, which is the best we can typically expect from emission factor calculations.

(a) Shari recently painted nearly the entire outside of her house. She used 12.5 gallons of hydrocarbon-based paint. The paint weighs 4.05 kg per gallon. How many kilograms of volatile hydrocarbons were emitted into the atmosphere by this painting activity?

(b) A half-empty container of carbon tetrachloride (CCl₄) is left open to the atmosphere in a building. The evaporation rate is estimated to be 3.6 grams per hour. An identical container of perchloroethylene (PERC), also half empty, is also left open to the atmosphere in the same building. Estimate the evaporation rate of the perchloroethylene in grams per hour. Hint: Emission factors for evaporation rates of VOCs are expressed in the appendices for each VOC as a ratio of evaporation rate of the VOC to that of carbon tetrachloride, which the EPA decided to use as a kind of “base case.”

(c) Lime particles are emitted by a rotary kiln in a plant that uses 3000 kg of raw material (lime) per hour. Lime dust particles escape from the kiln, but an air cleaner is used to keep most of the lime dust from escaping to the atmosphere. If the air cleaner is 92% efficient, estimate the rate of mass of lime dust discharged into the atmosphere in units of kg/hour.

(d) A plastics manufacturing company produces polyvinyl chloride at a rate of 4.5 metric tons per day. They have an air pollution control system (APCS) to remove some of the air pollutants, and air samples of their stack exhaust reveal that approximately 2.3 kg of polyvinyl chloride particles are emitted into the atmosphere per day. Estimate the removal efficiency of the APCS as a percentage.