GEORGIA INSTITUTE OF TECHNOLOGY
School of Civil & Environmental Engineering
CEE 2300 – Environmental Engineering Principles
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EXAM 1 – SOLUTIONS

1. **(25 points)** Briefly explain/answer the following:

1-a) The meaning of "the tragedy of the commons"; provide an example related to environmental degradation/pollution.
Meaning: The use of common resources leading to overexploitation/degradation.
Examples: CO_2 emissions to air; pollutant discharge in a river

1-b) What were/are the environmental and socio-economic impacts of the April 20, 2010 BP oil spill?
Marine pollution leading to:

- depletion of dissolved oxygen
- air toxics directly (e.g., methane) and indirectly due to burning (e.g., CO_2)
- direct toxicity and death of fish, wildlife, etc. due to the oil and toxicity indirectly due to dispersants used to disperse oil
- coastline and wetland contamination
- economic damage (e.g., fishing, tourism, etc.)

1-c) When was the US Environmental Protection Agency (US EPA) established, who was the US President at that time, and what was/were the purpose/reasons for the establishment of the US EPA?
When: December 2, 1970; Who: Richard Nixon
Purpose/reasons: to consolidate in one agency a variety of federal research, monitoring, standard-setting and enforcement activities to ensure environmental protection.

1-d) Globally speaking, what are the environmental and social consequences of large-scale biofuel production? List at least four (4) such impacts.

- land clearance and conversion (loss of natural habitats, soil erosion, etc.)
- introduction of potentially invasive species
- overuse of water and nutrients
- effects on the global food market, especially meat
- purchase or leasing of land by foreign investors, typically in developing and sometimes in semi-arid countries.

1-e) Explain why in the last two decades the CO_2 emissions due to consumption of goods and services in developed countries exceeded the CO_2 emissions due to production of goods and services.
It is the direct result of increased imports of goods and services from developing countries combined with the decrease in manufacturing in the developed countries. The opposite is true in the developing countries, i.e., CO_2 emissions due to production of goods and services exceeded the CO_2 emissions due to consumption of goods and services.

2. **(25 points)** Methane (CH_4) can be produced by microorganisms by the reduction of CO_2 by molecular hydrogen (H_2) as follows:

$$H_2 \quad + \quad CO_2 \quad \rightarrow \quad CH_4 \quad + \quad \text{product}$$

A. Balance the above equation and name the product on the right.

B. If H_2 and CO_2 are supplied in a gas mixture of N_2, H_2, and CO_2 at a total pressure of 1 atm and in which the partial pressure of N_2 (i.e., pN_2) is 0.5, calculate the partial pressures of H_2 and CO_2 according to the balanced stoichiometric equation you completed in part A, above.

<u>Solution:</u>

A-1) <u>Oxidation/reduction (i.e., electron) balance</u>:

oxidation state: 0 (H), +IV (C in CO_2), -IV (C in CH_4), +I (H in CH_4)

$$H_2 \quad + \quad CO_2 \quad \rightarrow \quad CH_4 \quad + \quad \text{product}$$

-8e-

+1e-/H x 8 = +8e-

Thus, there are 8 H or 4 H_2

$$4\ H_2 \quad + \quad CO_2 \quad \rightarrow \quad CH_4 \quad + \quad \text{product}$$

A-2) <u>Atom balance</u>:

$$4\ H_2 \quad + \quad CO_2 \quad \rightarrow \quad CH_4 \quad + \quad \text{product}$$

C:	1	1
H:	8	4 + 4
O:	2	0 + 2

$\left.\begin{array}{l} \\ \end{array}\right\}$ add 2 H_2O

Thus, complete equation: $4\ H_2 \quad + \quad CO_2 \quad \rightarrow \quad CH_4 \quad + \quad 2\ H_2O$ (eqn. 1)

B) According to the stoichiometric equation 1, above, and given that the pN_2 in the gas mixture is equal to 0.5, the following equations apply:

$$pN_2 + pH_2 + pCO_2 = 1 \quad \text{(eqn. 2)} \quad \text{or} \quad pH_2 + pCO_2 = 1 - pN_2 = 1 - 0.5$$

$$pH_2 + pCO_2 = 0.5 \quad \text{(eqn. 3)}$$

$$pH_2 = 4\ pCO_2 \quad \text{(eqn. 4)}$$

Substitute pH_2 from eqn. 4 into eqn. 3: $4\ pCO_2 + pCO_2 = 0.5 = 5\ pCO_2$

$pCO_2 = 0.5/5 = 0.1$

From eqn. 4: $pH_2 = 4\ pCO_2 = 4\ (0.1) = 0.4$

Thus: $\boxed{pCO_2 = 0.1 \text{ and } pH_2 = 0.4}$

<u>Check</u>: $pN_2 + pH_2 + pCO_2 = 0.5 + 0.4 + 0.1 = 1$

3. (25 points) A wastewater with nitrogen in the form of dissolved ammonia (NH_3) and ammonium (NH_4^+) has a total nitrogen (i.e., $[NH_4^+] + [NH_3]$) concentration of 7.1×10^{-4} mol/L. The Henry's constant (K_H) at 25°C is 57 mol/L • atm. The equilibrium equation is:

$$NH_4^+ \leftrightarrow H^+ + NH_3 \qquad K_a = 10^{-9.26}$$

The fraction of nitrogen in the ammonia form, which is strippable, as a function of pH is given by the following equation:

$$NH_3\ fraction = \frac{[NH_3]}{[NH_3]+[NH_4^+]} = \frac{1}{1+10^{(9.26-pH)}}$$

The wastewater pH is raised to 10 and the incoming air used for stripping of ammonia out of the wastewater has an ammonia partial pressure of 5×10^{-10}.

A. What would be the equilibrium concentration of total nitrogen (i.e., $[NH_4^+] + [NH_3]$) in the wastewater after air stripping? Assume equilibrium between air and wastewater and total gas pressure equal to 1 atm.

B. Under the above conditions, what percentage of the total wastewater nitrogen would be removed?

<u>Solution:</u>

A. Total nitrogen concentration after air stripping

In this case, going from dissolved NH_3 to gaseous NH_3 via stripping, the Henry's law is written as follows:

$$[NH_3]_{aq} = K_H \quad pNH_{3,g} \quad P_T \qquad \text{(eqn. 1)}$$

Thus, at equilibrium: $[NH_3]_{aq}$ = 57 mol/L • atm x 5×10^{-10} x 1 atm = 2.85×10^{-8} mol/L

At pH = 10, the NH_3 fraction is: $[NH_3]/([NH_4^+] + [NH_3]) = 1/[1 + 10^{(9.26-10)}] = 0.846$

Thus, $[NH_4^+] + [NH_3] = [NH_3]/0.846 = (2.85 \times 10^{-8}$ mol/L$)/0.846$ $\boxed{= 3.37 \times 10^{-8} \text{ mol/L}}$

B. Total nitrogen removal

Removal, % = [(Total N_{in} - Total N_{left})/Total N_{in}] x 100 = [1 - (Total N_{left}/Total N_{in})] x 100 =

= {1 - [(3.37×10^{-8} mol/L)/(7.1×10^{-4} mol/L)]} x 100 $\boxed{= 99.995\%}$

4. **(25 points)** Ozone (O_3) is a highly reactive oxidant used for the disinfection of drinking water. It is found that the ozone destruction in water follows fist-order kinetics with respect to the aqueous ozone concentration, such that its concentration decreases by 50% in 12 minutes (i.e., $t_{1/2}$ = 12 minutes). Estimate the initial ozone concentration in mg/L necessary to treat water for 40 minutes and result in a residual ozone concentration of 1 mg/L.

Solution:

For the ozone destruction, the first-order rate equation is: $dO_3/dt = - k\, O_3$ (eqn. 1)

and its solution is: $[O_3]_t = [O_3]_o \exp(-k\, t)$ (eqn. 2)

Based on the problem statement, calculate the value of the rate constant k at $t = t_{1/2}$ = 12 min:

$0.5\,[O_3]_0 = [O_3]_o \exp(-k\, t_{1/2})$ and then $t_{1/2} = -\ln 0.5/k = 0.693/k$

$k = 0.693/t_{1/2} = 0.693/12\ \text{min} = 0.0578\ \text{min}^{-1}$

Calculate the initial ozone concentration:

From eqn. 2, $[O_3]_o = [O_3]_t/\exp(-k\, t) = [O_3]_{40\ min}/\exp(-k\, t) =$

$$= (1\ \text{mg/L})/\exp(-0.0578\ \text{min}^{-1}\ 40\ \text{min}) \boxed{= 10\ \text{mg/L}}$$