GEORGIA INSTITUTE OF TECHNOLOGY
School of Civil & Environmental Engineering
CEE 2300 – Environmental Engineering Principles
Instructor: S. G. Pavlostathis **Spring 2014**

EXAM 2 – SOLUTIONS

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

1-a (5 pts) Law of conservation of matter

Matter can neither be created nor destroyed (with the exception of nuclear reaction)(D+M. p. 144).

1-b (5 pts) Plot (sketch) the concentration of a pollutant (C_t on the y-axis) versus time (t on the x-axis) for a batch reactor achieving 80% pollutant destruction in 5 hours assuming that pollutant destruction follows zero-order kinetics. Write an equation for the pollutant destruction rate constant (k).

Zero-order:

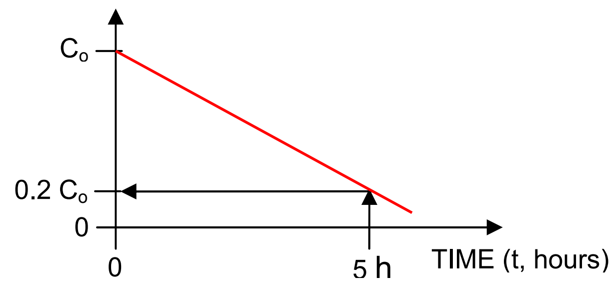
$C_t = C_o - k\,t$ ==> C_t vs. t is linear

At t = 0, $C_t = C_o$

At t = 5 h, $C_t = (1-0.8)C_o = 0.2C_o$

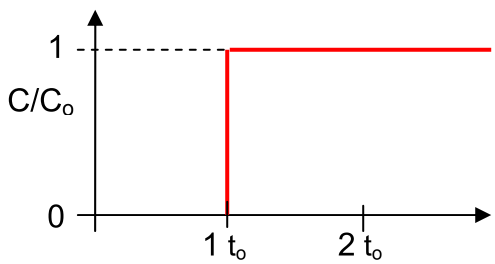
k = slope = $(C_o - C_t)/t$ =

= $(1-0.2)C_o/5 = 0.8C_o/5 = 0.16\ C_o$



1-c (5 pts) For an ideal Plug-Flow Reactor (PFR), plot (sketch) the normalized concentration of a tracer (C/C_o on the y-axis) versus the mean retention time (t_o on the x-axis) for the continuous input of a non-reactive tracer starting with a clean, ideal PFR.

A continuous-flow reactor with a uniform radial profile and no longitudinal dispersion.



1-d (5 pts) To what extent has hydraulic fracturing (or fracking) changed to estimated energy reserves in the US and in what form of energy? What is the main environmental concern with fracking?

Fracking has increased the estimates of natural gas (i.e., methane) energy in shale formations in the US from 400 to 4000 exajoules (EJ; 1 EJ = 10^{18} J)(i.e., 10-fold increase; D+M, p. 334).

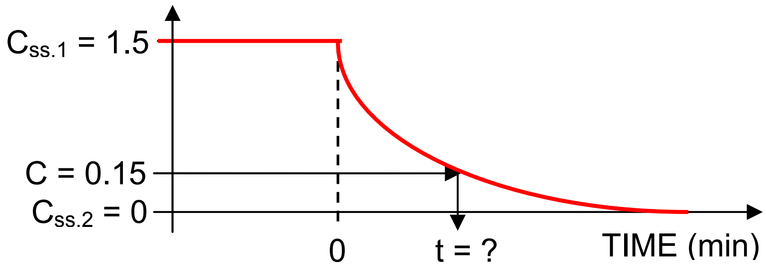
The main environmental concern with fracking has been linked to drinking water contamination in several US States, as well as methane in water/wastewater leads to combustion. The wastewater which contains hydraulic fracturing fluid additives may contaminate groundwater supplies used for potable water (D+M, p. 339).

1-e (5 pts) List three major hurdles that need to be overcome in order fuel cell technology using H_2 to be more widely used in automobiles.

- The cost of membranes needs to be reduced
- The life of membranes needs to be increased
- The operating temperature must be increased
- A suitable on-board H_2 storage system must be devised
- A H_2 infrastructure must be developed (D+M, p. 344)

2. (25 points) A 90-m^3 basement in a residence is found to be contaminated with radon coming from the ground through the floor drains. The concentration of radon in the room is 1.5 Bq/L (becquerels per liter) under steady-state conditions. The room behaves as a CSTR (i.e., CMFR), and the decay of radon is a first-order reaction with a decay rate constant of 2.09×10^{-6}/s. If the source of radon is closed off and the room is vented with radon-free air at a rate of 0.14 m^3/s, how long (in minutes) will it take to lower the radon concentration to an acceptable level of 0.15 Bq/L?

Sketch concentration vs. time:



Solution:

Step change from a steady-state to another steady-state.

For a CSTR and a first-order decay rate, the step function response is:

$C_t = C_{SS} + (C_o - C_{SS}) \exp[-(k + t_o^{-1})\,t]$ (Eq. 1)

where: C_{SS} = new steady-state concentration
k = first-order rate constant (d^{-1})
t_o = mean retention time (d)

For this case, $C_{SS} = 0$ and Eq. 1 becomes:

$C_t = C_o \exp[-(k + t_o^{-1})\,t]$ (Eq. 2)

$t_o = V/Q = 90\ m^3/0.14\ m^3\text{-s} = 643$ s

Substitute known values to Eq. 2:

$0.15/1.5 = \exp[-(2.09 \times 10^{-6}/s + 1/643\ s)\,t]$

$0.10 = \exp[-0.00156\,t]$

Take the natural log of both sides:

$-2.303 = -0.00156\,t$

t = 1,476 s x 1/60 min/s = 24.6 min

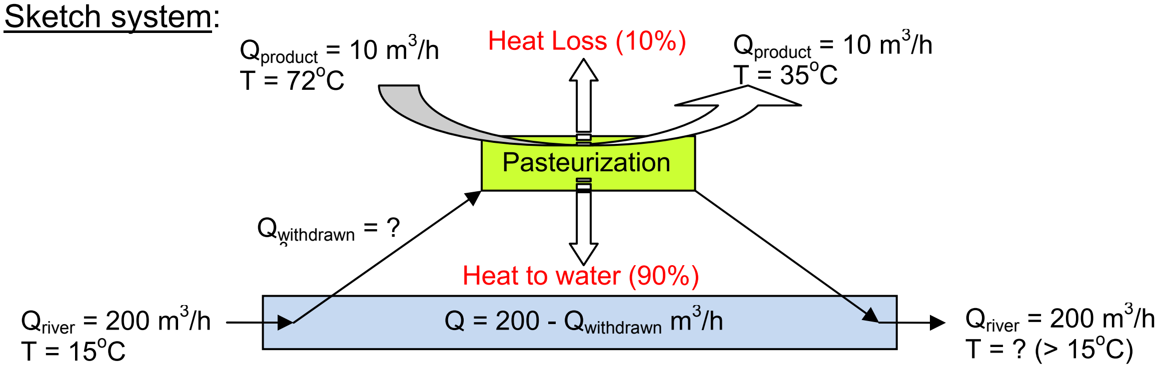
3. (25 points) A food processing plant uses pasteurization and then cooling and refrigeration to avoid spoilage of a liquid product. The pasteurized liquid product has a flow rate of 10 m^3/h and the following properties: density, 1,100 kg/m^3; specific heat capacity, 5 kJ/kg · °C; temperature, 72°C. The plant uses river water at 15°C to pre-cool the liquid product after pasteurization to 35°C through a heat exchanger.

A) Calculate the minimum flow rate (m^3/h) of river water needed to achieve pre-cooling of the hot, pasteurized liquid product assuming that 10% heat is lost to the surroundings during heat exchange and that the water temperature after cooling should not exceed 25°C.

B) If the flow rate of the river upstream of the cool water intake is 200 m^3/h, determine the temperature of the river water immediately downstream of the plant water discharge assuming completely mixed conditions and no water losses.

NOTE: Use the following properties for water: density, 998 kg/m^3; specific heat capacity, 4.18 kJ/kg · °C.

<u>Sketch system</u>:



<u>Solution:</u>

A) Energy (Heat) balance:

Heat exchanged from the liquid product to water (H_1) + heat lost (H_2) = heat removed from the liquid product (H_3)

Heat change = $M\ c\ \Delta T$

H_3 = 10 m^3/h x 1,100 kg/m^3 x 5 kJ/kg · °C x (72 – 35)°C = 2,035,000 kJ/h

$H_1 = H_3 - H_2 = H_3 - 0.1H_3 = 0.9\ H_3$ = 0.9 x 2,035,000 kJ/h = 1,831,500 kJ/h

Heat removed by the water = $M\ c\ \Delta T$

$$\text{Water mass flow} = \frac{\text{Heat removed}}{c\ \Delta T} = \frac{1{,}831{,}500\ \text{kJ/h}}{4.18\ \text{kJ/kg}\cdot{}^{\circ}\text{C} \times (25 - 15)^{\circ}\text{C}} = 43{,}816\ \text{kg/h}$$

Water flow rate = water mass rate/density = 43,816 kg/h x 1/998 kg/m^3 = **43.9 m^3/h**

B) At the point of mixing warm discharge and the upstream river,

$$T_{river} = \frac{(Q_{river\ after\ withdrawal} \times T_r) + (Q_{discharge} \times T_d)}{Q_{river}} =$$

$$= \frac{[(200 - 43.9)\text{m}^3/\text{h} \times 15^{\circ}\text{C}] + (43.9\ \text{m}^3/\text{h} \times 25^{\circ}\text{C})}{200\ \text{m}^3/\text{h}} = 17.2^{\circ}\text{C}$$

4. (25 points) Consider the combustion of propane (C_3H_8):

$$C_3H_8 + O_2 \rightarrow CO_2 + H_2O$$

A) Balance the equation
B) Calculate the mass (grams) of oxygen required and the mass (grams) of carbon dioxide produced by burning 100 g of propane.
C) Calculate the energy savings per kg propane burned (kJ/kg) if a condensing furnace as opposed to a non-condensing furnace is used.
Note: Standard enthalpy of water: for liquid, -285.8 kJ/mol; for gas, -241.8 kJ/mol

Solution:

A) Balanced equation: $C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$ (Eq. 1)

B) Mass of oxygen required:

Propane MW: 44
Oxygen MW: 32
Carbon dioxide MW: 44

From Eq. 1, above:

(5 mol O_2/mol C_3H_8)(32 g O_2/mol O_2)(1/44 mol C_3H_8/g C_3H_8)(100 g C_3H_8) = 363.6 g O_2

Mass of carbon dioxide produced by burning 100 g of propane.

From Eq. 1, above:

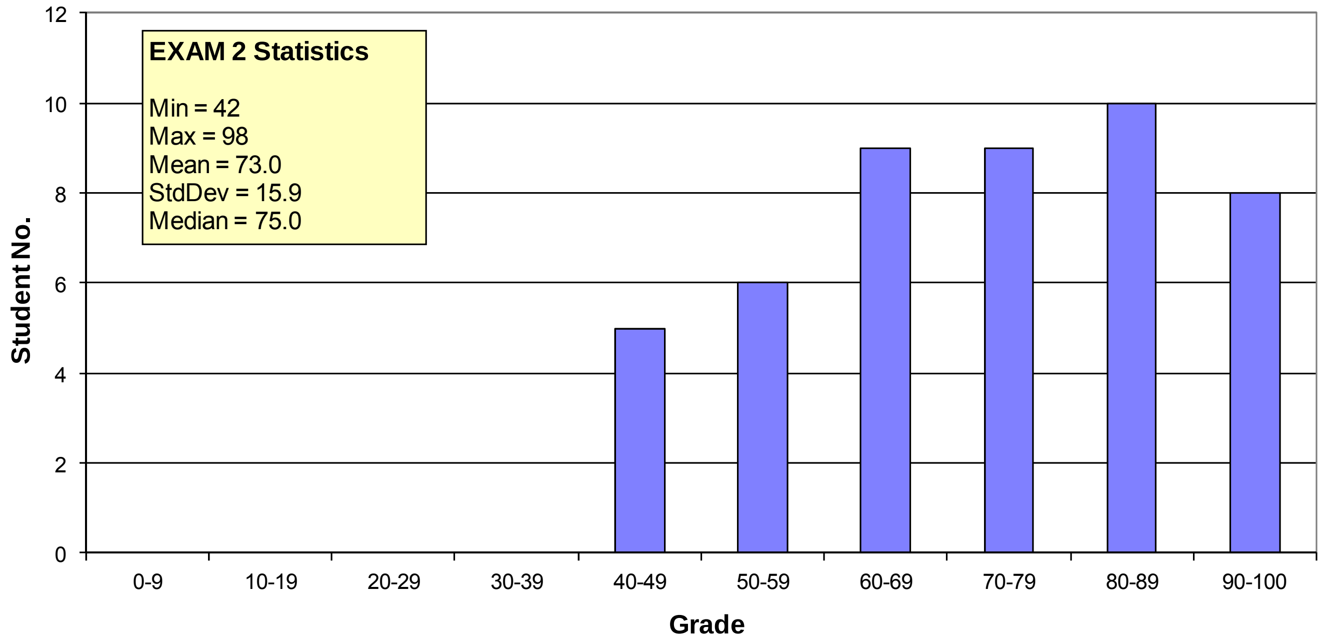
(3 mol CO_2/mol C_3H_8)(44 g CO_2/mol CO_2)(1/44 mol C_3H_8/g C_3H_8)(100 g C_3H_8)=300.0 g CO_2

C) Condensing the produced water will save 285.8 - 241.8 = 44 kJ/mol water

Based on Eq. 1, above:

(4 mol H_2O/mol C_3H_8)(44 kJ/mol H_2O)(1/44 mol C_3H_8/g C_3H_8)(1000 g C_3H_8/kg C_3H_8)

= 4,000 kJ/kg C_3H_8


EXAM 2 Statistics
Min = 42
Max = 98
Mean = 73.0
StdDev = 15.9
Median = 75.0
Student No.
12
10
8
6
4
2
0
0-9
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20-29
30-39
40-49
50-59
60-69
70-79
80-89
90-100
Grade