INTRODUCTION TO ENVIRONMENTAL ENGINEERING

Final Exam

Assigned: 10:00 am Friday 20 November 2015
Due: 5:00 pm Wednesday 25 November 2015

Note: Start every problem on a new page and type your answers. You may handwrite
your math within the text, if that’s easier for you, but then do so in a continuous
manner. No typed text on one page and handwritten equations on another page
because that’s a nightmare for the professor to grade!

Rule of engagement per Academic Honor Code:
No communications whatsoever among students. Questions may only be directed to
the instructor, either by email or by seeing him in person.

1. (15 points) Indicate whether each statement below is true or false.

1-1. Benzene has a molecular weight of 78 grams/mole and a density of 876.5 g/liter. If
two identical containers are filled to the top, one with benzene and the other with
water, the benzene one is heavier.
1-2. If measurements are precise but not accurate, then there is a bias.
1-3. When dissolved in water, limestone (CaCO₃) raises the pH.
1-4. When an oil droplet rises through water in a clarifier, its buoyancy force is the sum
of its weight and drag force.
1-5. A major advantage of a cyclone separator is its relatively low operating cost.
1-6. The efficiency of an electrostatic precipitator typically exceeds that of a cyclone.
1-7. In an industrial scrubber, the upward gas mixture is in chemical equilibrium with the
downward flowing limestone water solution.
1-8. Settling tanks are rectangular and clarifiers are circular.
1-9. The efficiency of a clarifier is defined as the ratio of the exiting number to the
incoming number of particles.
1-10. The overflow rate is the flow rate (in volume per time) that exits the settling tank.
1-11. When a settling column is used in the laboratory for the design of a new settling
tank, its height must be equal to the depth that the settling tank will have after
construction.
1-12. Because its Rfd value for oral ingestion is the lowest among tabulated values (see lecture slides on Risk Assessment), Methyl Mercury is the most benign substance among those listed in the table.

1-13. Ensuring sustainability of human activities is equivalent to not exceeding the carrying capacity of the earth.

1-14. Among the renewable energy technologies, wind turbines have the highest energy return on the investment.

1-15. A healthy environment is not the same as a pristine environment.

2. (10 points) An anaerobic digester is commonly used for processing the non-recycled portion of the sludge in wastewater treatment. This generates carbon dioxide and methane, and because methane smells bad and could also be used as a fuel, the emanations from the digester are collected in a large tank. The temperature is slightly elevated because of the biological activity, and the pressure is allowed to build up until a maximum pressure is reached. Once the maximum pressure is reached, the gas mixture is drawn out and used.

Consider the specific situation. A 1000 m³ tank holds a gas mixture that is 65% methane (CH₄) and 35% carbon dioxide (CO₂) on a volume basis at a pressure of 3 atm and at a temperature of 35°C.

(a) (4 points) What mass of each gas is contained in this tank?

(b) (3 points) How much more mass of methane could be held in the tank if the temperature were decreased to 25°C and the pressure remained the same?

(c) (3 points) If the rate of gas production is 400 kg/day at 35°C, what is the average residence time of a gas molecule in the tank?
3. (15 points) An existing circular settling tank has a depth of 3.50 m, a inner diameter of 2.50 m and an outer diameter of 8.80 m. It is always used with the same wastewater but under various flowrates. For the flowrate values listed below, the amounts of settled particles are the following:

<table>
<thead>
<tr>
<th>Flowrate $Q$ (m$^3$/day)</th>
<th>Mass removed (kg/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>15,000</td>
<td>6,291</td>
</tr>
<tr>
<td>12,000</td>
<td>5,857</td>
</tr>
<tr>
<td>9,000</td>
<td>4,961</td>
</tr>
<tr>
<td>6,000</td>
<td>3,622</td>
</tr>
<tr>
<td>3,000</td>
<td>1,948</td>
</tr>
<tr>
<td>1,500</td>
<td>995</td>
</tr>
</tbody>
</table>

For unchanged depth and inner diameter, what should be the outer diameter of a new settling tank that removes 85% of the particles (on a mass basis) of the same wastewater under a flowrate of 18,000 m$^3$/day?

4. (2 points) What do you call a person who for each of 350 days in the year drinks 2 liters of water, breathes 30 m$^3$ of air, and ingests 100 mg of soil?
5. (10 points) In discussions of renewable energy, there is always mention of some primary renewable sources of energy, such as the sun, then mention of conversion technologies, such as photovoltaic cells, to arrive at a derivative form of energy, such as electricity. Sometimes, the chain goes on, such as electricity passing through an electrical motor to generate mechanical motion.

List several other energy chains, of the types:

Renewable source of energy — (conversion technology) → Intermediate form of energy
Intermediate form of energy — (other conversion technology) → Useful form of energy

Grading rule: 0.5 point for every correct energy type and 0.5 point for every correct conversion technology, but minus 0.5 point for every incorrect energy type (such as non-renewable form of energy or not ultimately derived from a renewable source), incorrect conversion technology, or incorrect association.

Choice: For the last question, either do #6 or #7, but not both. If you submit answers to both, only the first of the two will be graded.

6. (8 points) What is the environmentally preferable way of storing information, silicon chips or plain old paper? The answer is not a priori obvious because silicon chips can hold many more bytes than paper, but their manufacture is also much dirtier than that of paper. Perform an analysis using energy of manufacture as a proxy for environmental impact. Your outcome should then reduce to comparing the number of MJ (mega-joules) of energy per GB (giga-byte) of information between silicon chips (say, RAM memory) and paper (say, printing & writing paper).

For numbers, draw from the following sources:
Energy to make a 32MB DRAM silicon chip:
  www.ce.cmu.edu/~hsm/NATO-ARW/pres/EricWilliams.ppt
Energy to make paper:
  It takes 27,500 BTUs to make a ream of 500 sheets of paper.
Information stored on paper:
  www2.sims.berkeley.edu/research/projects/how-much-info-2003/print.htm
7. (8 points) Consider the life-cycle energy analysis of a polyester blouse summarized below. The left pie shows the percentages of energy consumed in its life cycle; the right pie splits the consumer phase into its two primary components, laundering (= use of washing machine + electric dryer) and detergent manufacture. The sticks below show how much the energy requirements during washing and drying decrease when one switches from warm-water wash and electric drying to cold-water wash and air drying on a clothes line.

Re-do the first pie chart for the case of cold-water wash and air drying. In particular, what is the new percentage of energy spent during use?

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(Bishop, 2000, page 279)