Please type your answers. You may handwrite equations between lines of typed text.

Do not limit your answers to just math and numbers. Explain in words what you do and why you do it. Also, start each new question on a new page, with your name on top.

Application of the Honor Principle for this exam: As for the mid-term exam, no communications whatsoever are permitted between students. All questions are to be referred exclusively to the professor.

1. (5 points) A 50-50 mixture on a molar basis of methyl mercaptan (CH₃SH) and methanol (CH₃OH) is being destroyed by incineration on a continuous basis. The rate of disposal is 450 kg/hour.
   (a) (2 points) What are the combustion reactions?
   (b) (3 points) What is the minimum airflow (in m³/s at 15°C and atmospheric pressure) necessary to guarantee complete combustion of both substances?

2. (5 points) A pond will be dug to treat a dilute municipal wastewater before discharge into a nearby river. The inflow to the pond is projected to be \( Q = 400 \text{ m}^3/\text{day} \) with biochemical oxygen demand (BOD) concentration \( C_{in} = 25 \text{ mg/L} \). The purpose of the pond is to allow time for significant decay of BOD to occur before discharge into the environment. The first-order decay rate constant is anticipated to be 0.25/day. What should be the volume of the pond to reduce the BOD concentration to 6 mg/L?
   Assume steady state, neglect evaporation, and express your answer in cubic meters.

3. (5 points) Since the volume determined in the previous problem is rather large, the municipality is now considering digging a narrow elongated pond that would work as a plug flow reactor. What is the new volume of the pond?
4. (5 points) An existing settling tank has the characteristics listed below. When it treats water with particles of characteristics given below, what is its collection efficiency?

<table>
<thead>
<tr>
<th>Tank characteristics:</th>
<th>Depth of settling zone</th>
<th>H = 3.5 m</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incoming flow rate</td>
<td>Q = 19,200 m³/day</td>
<td></td>
</tr>
<tr>
<td>Width of settling zone</td>
<td>W = 10 m</td>
<td></td>
</tr>
<tr>
<td>Length of settling zone</td>
<td>L = 40 m</td>
<td></td>
</tr>
<tr>
<td>Water density</td>
<td>ρ_f = 998 kg/m³</td>
<td></td>
</tr>
<tr>
<td>Water viscosity</td>
<td>μ = 1.01 x 10⁻³ kg/(m.s)</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Particle characteristics:</th>
<th>Approximate shape</th>
<th>spherical</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter</td>
<td>d_p = 22 µm</td>
<td></td>
</tr>
<tr>
<td>Density</td>
<td>ρ_p = 2.5 x 10³ kg/m³</td>
<td></td>
</tr>
</tbody>
</table>

5. (5 points) Determine the minimum necessary horizontal area for an activated-sludge aerator operating under the following conditions:
   - Volumetric flow rate: 5400 m³/day
   - Aerator depth: H = 6 m
   - Incoming substrate concentration: S_in = 250 mg/L
   - Exiting substrate concentration: S_out no more than 20 mg/L
   - Half-concentration constant: K_S = from 50 mg/L in winter to 60 mg/L in summer
   - Cell growth rate: k_m = from 1.1 /day in winter to 1.8 /day in summer
   - Cell death rate: k_d = 0.05 /day
   - Yield rate: Y = 0.55
   - Recycle ratio: R = 0.20
   - Cell concentration ratio in recycled substrate: X_r/X = 5.

6. (5 points) A dusty airflow contains particles 8 µm in diameter and of density equal to 1800 kg/m³. Design a conventional cyclone of standard proportions (Lapple type) that will remove 90% of these particles from a 2.5 m³/s airflow. In particular, what should be the values of the body diameter (D), inlet height (H), inlet width (W) and total height (L_b + L_c)?
   A useful number in this context is: Air viscosity = μ = 1.80 x 10⁻⁵ kg/(m.s).

7. (5 points) An electrostatic precipitator with 6,000 m² of collector plate area is 97% efficient in treating 200 m³/s of flue gas from a 200 megawatt power plant. How much more plate area would be required to increase the efficiency to 98% and to 99%, with unchanged voltage? Assume that the various particles all share the same drift speed.
8. (5 points) Hydrogen sulfide (H₂S) is a malodorous and corrosive gas that often comes together with methane but must be scrubbed from the gas flow before using the methane. One method is to pass the gas mixture through a gas water solution that scrubs the H₂S but leaves the CH₄ alone. Once in water, H₂S decomposes to some degree depending on the pH. The gas-water transfer and in-water reaction are:

\[
\begin{align*}
\text{H}_2\text{S in gas} & \leftrightarrow \text{H}_2\text{S in water} \\
\text{H}_2\text{S in water} & \leftrightarrow \text{H}^+ + \text{HS}^- 
\end{align*}
\]

Based on reasoning alone (no numbers necessary), tell whether the process is more effective at high or low pH values?

9. (5 points) Consider the energy required to move students to grade school in the morning using busses. Suggest 5 options for reducing this energy need that range from shallow redesign to deep ecology and redesign.

10. (5 points) According to Dr. Polashenski, continued growth in global energy consumption is estimated to demand an additional 490 eJ/year of energy supply by year 2050. Assuming that we also want to keep the atmospheric CO₂ level below 500 ppm in order to mitigate further climate change impacts, we would need to provide this additional energy supply in the form of carbon-free technology.

If the plan calls for 50% of the new capacity to be in the form of wind turbines, how many 1.5 MW turbines should be installed per month between now and end of 2050? For the calculation, consider that wind turbines operate intermittently, generating their rated power only 40% of the time.