The local Division of Environmental Quality mandates that your company increase the SO₂ collection efficiency of your limestone scrubber from its current level, 90%, to 95%. You propose to do this by increasing the height of your scrubber. By what factor must the height be increased? Please state your assumptions.
Problem 2.0
The Department of Energy estimates that US energy demand will double over the next 25 years. Is this consistent with the disaggregated approach taken in Homework Assignment 1 and the data below?

\[
\text{Energy (kJ/yr) = Population} \times \frac{\text{Energy (kJ/yr)}}{\text{Person}}
\]

Use the following data and assume that the growth rates remain constant.

<table>
<thead>
<tr>
<th>1990 amounts</th>
<th>Population</th>
<th>(kJ/yr)/person</th>
</tr>
</thead>
<tbody>
<tr>
<td>250 x 10^6</td>
<td>320 x 10^6</td>
<td></td>
</tr>
<tr>
<td>Growth, r (%/yr)</td>
<td>0.6</td>
<td>0.5</td>
</tr>
</tbody>
</table>

Problem 3.0
A 100-MW, coal-fired power plant, with overall efficiency 33.3\%, emits 0.6 lbm SO₂/10^6 Btu coal burned. The SO₂ scrubbing system captures 90\% of the SO₂ leaving the boiler. How many kg/yr of dry solid waste are produced if you assume all of the captured SO₂ is converted to CaSO₄·2H₂O?

Problem 4.0
A kerosene heater is tested in a well-mixed, 27-m³ chamber having a volumetric inflow of 10 m³/h. The rate of outflow is the same and the temperature and pressure are approximately constant at 20°C and 1 atm. The concentration of NO in the chamber after one hour of operation is 4.7 ppm (by volume). Estimate the mg/h of NO emitted by the heater.

Problem 5.0
Your friend worries too much. Please help them calculate the weight fraction of particulate from the air they breathe that is retained in their body. This is the overall collection efficiency. The following data is available.

The collection efficiency of their respiratory system as a function of particle size is

\[
\eta(D) = \begin{cases} 
\frac{D}{a} & \text{for } 0 < D < a \\
1.0 & \text{for } D \geq a 
\end{cases}
\]

where \(a\) is 5 µm. The cumulative distribution function, by weight, for the particulate in the air is
\[ \Phi(D) = \left( \frac{D}{D_{\text{max}}} \right)^3 \text{ for } 0 < D \leq D_{\text{max}} \]

where \( D_{\text{max}} \) is 20 \( \mu \text{m} \).
Air Pollution Control Engineering  
CH EN 5305/6305  

Third Examination, Wednesday, 13 December 2006  
Prof. Geof Silcox  
Chemical Engineering  
University of Utah  

Write all work on this paper.  
Open books, homework, and notes.  

1) Please read each problem carefully and completely before attempting to solve it.  
2) Please write out all equations that you use and state all values substituted in those equations. Please show all of your work to ensure that you receive full credit for a solution.  
3) Please report numerical results with a minimum of three significant figures, if possible.  

Scoring Summary  
Problem 1.0  _________/ 30 points  
Problem 2.0  _________/ 30 points  
Problem 3.0  _________/ 30 points  
Problem 4.0  _________/ 30 points  
Problem 5.0  _________/ 30 points  
Total  _________/150 points
Problem 1.0
The collection efficiency of particles in the human respiratory track is roughly as follows.

<table>
<thead>
<tr>
<th>D, μm</th>
<th>η(D)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 1</td>
<td>0.25</td>
</tr>
<tr>
<td>1 &lt; D &lt; 10</td>
<td>0.25 + 0.326 ln(D)</td>
</tr>
<tr>
<td>&gt; 10</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Given the particle-size distribution data below, estimate the overall collection efficiency, η₀.

<table>
<thead>
<tr>
<th>D, μm</th>
<th>Φ(D), by mass</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.625</td>
<td>0.14</td>
</tr>
<tr>
<td>1</td>
<td>0.18</td>
</tr>
<tr>
<td>10</td>
<td>0.37</td>
</tr>
<tr>
<td>15</td>
<td>0.47</td>
</tr>
<tr>
<td>&gt; 15</td>
<td>1.0</td>
</tr>
</tbody>
</table>

Problem 2.0
Consider a gravity settler that is made of three identical, completely mixed (horizontally and vertically) settlers arranged one after the other. Each has height H = 5 m, width W = 5 m, and length L = 7 m. A particle-laden gas flows steadily through the settlers with volumetric flow Q = 2.50 m³/s. The terminal settling velocity of the particles is 0.8 cm/s. Find the collection efficiency for the settler consisting of the three units in series.

Problem 3.0
An ESP is treating flue gas from a coal-burning utility boiler. The efficiency of the particle removal is 98%. After switching to a new coal the efficiency drops to 93%. By how much must the collection area be increased to maintain a collection efficiency of 98%, assuming that the volumetric flow rate of flue gas is unchanged?
Problem 4.0
Table 25-28 of the 7th edition of *Perry’s Chemical Engineers Handbook* states that more than 90% destruction of aromatic hydrocarbons requires a residence time of 0.3 to 0.5 s at 1400 to 1500°F. As noted on page 373 of your text, in the presence of excess oxygen, the rate of combustion of hydrocarbons is approximately

\[
\frac{dC}{dt} = -kC
\]

where the rate constant is

\[
k = A \exp \left( -\frac{E}{RT} \right)
\]

Recall that \( E \) is the activation energy, \( A \) is the frequency factor, and \( R \) is the gas constant (1.987 cal/(mol K)). Using the values for \( A \) and \( E \) for toluene in Table 10.4, p. 374 of the text, verify the results quoted above from Table 25-28 of Perry’s.

Problem 5.0
Exhaust gases with the properties of air are cooled from 1000 K to 400 K by spraying liquid water at 20°C into the gas. The flow rate of the exhaust gases is 12 m³/s at 1000 K and 100 kPa. Calculate the required flow rate of the liquid water. Please use the following data in your calculation.

Heat of vaporization of water at 20°C, \( h_{fg} = 2453.5 \text{ kJ/kg} \).
Average specific heat of air, \( C_{pa} = 1.075 \text{ kJ/(kg K)} \).
Average specific heat of water vapor, \( C_{pw} = 1.88 \text{ kJ/(kg K)} \).