First Exam Chemical Engineering 120
23 March 2000

(25) 1. A new material has been synthesized that is called a mesoporous molecular sieve. One version consists of empty tubes (pores) of 1nm to 20nm in radius. These are placed in a hexagonal array. The walls of the pores (between the tubes) are 0.1 to 0.2nm in thickness.

A. If you assume that these were essentially thin slabs of solid of 0.2nm thickness and that the solid density is 2.2 g/cm\(^3\), what would you estimate the surface area (cm\(^2\)/g or m\(^2\)/g) of this solid would be?

B. If you assume that these are cylindrical tubes of internal diameter of 2 nm and have a wall thickness of 0.1 nm and that the solid density is 2.2 g/cm\(^3\), what would you estimate the surface area (cm\(^2\)/g or m\(^2\)/g) of this solid would be?

**Answer: From Notes**

\[
\begin{array}{c|c|c}
\text{Plate} & \text{Area} & 2 \times L \times W \\
\text{Volume} & t \times L \times W & t \\
\end{array}
\]

\[
\begin{array}{c|c|c}
\text{Area} & \text{Volume} & \text{Mass} \\
\text{Mass} & t \times \rho & \text{2nm for cylinders} \\
\end{array}
\]

\[
\begin{array}{c|c|c}
\text{Area} & \pi (r_o^2 - r_i^2) L & 2(r_o - r_i) \\
\text{Volume} & \pi (r_o^2 - r_i^2) L & (r_o^2 - r_i^2) \\
\end{array}
\]

<table>
<thead>
<tr>
<th>Plate 0.1nm</th>
<th>1cm(^3)</th>
<th>1m(^2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1nm</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10^{-7}cm</td>
<td>0.2nm*2.2g</td>
<td>10^4cm(^2)</td>
</tr>
<tr>
<td>= 2270 m(^2)/g</td>
<td></td>
<td></td>
</tr>
<tr>
<td>for cylinder:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1nm</td>
<td>2cm(^3)</td>
<td>1m(^2)</td>
</tr>
<tr>
<td>10^{-7}cm</td>
<td>0.41nm*2.2g</td>
<td>10^4cm(^2)</td>
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<tr>
<td>= 2330 m(^2)/g</td>
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(25) 2. MTBE (Methyl-tertiary-butyl ether, CH\(_3\)-O-C\(_4\)H\(_9\)) has become a ground water contaminant due to its common use as a gasoline additive and it's solubility in water. Just this week, President Clinton announced that it will be phased-out as a gasoline additive since it is leaking into ground water. You have been working on a process that can
separate MTBE from ground water to clean up contamination. A hydrophobic zeolite (molecular sieve) is to be employed. MTBE is removed from water passed over the zeolite until a maximum capacity for adsorption is reached. The zeolite can hold (adsorb) up to 20 weight percent of MTBE maximum. After this limit is reached, the zeolite can be regenerated by heating and reused to clean up more water.

A. How many gallons of water containing 200ppm (weight %) of MTBE can be cleaned with a load of 100kg of zeolite adsorbent prior to regeneration.

B. The zeolite is regenerated by heating to 100°C while Air is being passed through the bed. The regeneration process takes 2 hours at an air flow rate of 10 liters per minute. What is the average molar concentration of MTBE in this air effluent?

**ANSWER**

100kg of zeolite will adsorb 20kg of MTBE

Weight of water cleaned = \( \frac{20}{200} \times 10^{-6} \) kg =

<table>
<thead>
<tr>
<th>20kg</th>
<th>1</th>
<th>264gal</th>
<th>M3</th>
<th>1000lit</th>
<th>kg</th>
</tr>
</thead>
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<tr>
<td>20*10^{-6}</td>
<td>M3</td>
<td>1000lit</td>
<td>kg</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2640 gallons

CH3-0-C4H9 MW 88

2000gr 22.4l = 5091 liters

88g/ mole mole

1200liters air volume% 0.809221 = mole% = 0.0361 moles/liter
3 (25). HCL in nitrogen is exiting as a gas from a chemical process. You need to design a scrubber to clean this up. The gas contains 10 volume percent HCl with the balance N2 and is at a flow rate of 100 liters per minute. You have a 10 weight percent NaOH in water stream and will operate with 5% excess of NaOH in this "scrubber." The product will be NaCl in water and nitrogen exiting as a gas. Thus you have one gas stream coming in and one coming out and one liquid stream in and one out. What flow rate of NaOH solution do you wish to use and what will be the composition (mole %) of the two streams exiting the process?

**Molecular Weights: Na= 23, O=16, C=12, H=1, Cl=35.5, S=32**

**ANSWER:**

10 liters/min HCl gas = 0.446 moles/min
Need 0.469 moles/min NaOH (5% excess)
10 weight % NaOH : 1kg = 1 liter solution = 100g NaOH = 100/40 = 2.5 moles/l
(900/18moles of H2O)
0.186 liters/minute of NaOH solution

Exit:
90l/min N2
0.186 l/min water containing
2.5 moles NaCl + 0.125 moles NaOH + 50moles water
Mole %: 4.7% NaCl; 95% Water. 0.24% NaOH
The Claus reaction (H₂S + SO₂ -> S + H₂O) is a common process to remove sulfur containing gases from natural gas wells where hydrogen sulfide is the major contaminant (e.g., in Canada). After the H₂S is separated, one third is fed to a reactor where it is burned with air to produce SO₂ (and water) from H₂S combustion. This sulfur dioxide reacts with remaining H₂S to produce water and sulfur. The sulfur is easily condensed to form a solid. Assume that the whole process (combustion + Claus) can be conducted in a single reactor and that no sulfur is present in the exit gas phase (only as a solid). 10 m³/min of gaseous hydrogen sulfide at 2 bar pressure and 200°C is fed to this combined process along with the required amount of air. The gasses exiting are at atmospheric pressure and 50°C. Note that the incoming stoichiometry is combined: one mole H₂S added to air at a ratio sufficient to produce only sulfur and water.

What is the composition (mole % and molar flow rate) of the products coming from this process for each of the following two conditions?

A. The ratio oxygen exiting the process to that entering is 0.05 and the molar ratio of water produced to H₂S entering is 0.9.

B. The effluent gas contains 1% volume SO₂ and 30% volume H₂O.

\[
\begin{align*}
&3/2O_2 + \ H_2S &\rightarrow &\ H_2O + &\ SO_2 \\
&3/2-3/2x & &\ 3-x &\ x+2y &\ x-y \\
&H_2S + &\ 1/2SO_2 &\rightarrow &\ H_2O + &\ 3/2S \\
&3-x-2y & &\ x-y &\ x+2y &\ 3y \\
\end{align*}
\]

<table>
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<tr>
<th></th>
<th>In</th>
<th>Out</th>
<th>Gas</th>
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<th>out 2</th>
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<tr>
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<td>6</td>
<td>6</td>
<td>6</td>
<td>6</td>
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<tr>
<td>O₂</td>
<td>3/2</td>
<td>3/2-3/2x</td>
<td>3/2-3/2x</td>
<td>.075</td>
<td>.12</td>
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<tr>
<td>H₂S</td>
<td>3</td>
<td>3-x-2y</td>
<td>3-x-2y</td>
<td>0.3</td>
<td>0.42</td>
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<tr>
<td>H₂O</td>
<td></td>
<td>x+2y</td>
<td>x+2y</td>
<td>2.7</td>
<td>2.58</td>
</tr>
<tr>
<td>SO₂</td>
<td></td>
<td>x-y</td>
<td>x-y</td>
<td>0.075</td>
<td>.09</td>
</tr>
<tr>
<td>S</td>
<td>3y</td>
<td></td>
<td>2.625</td>
<td>2.52</td>
<td></td>
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<tr>
<td></td>
<td>Σ</td>
<td>10.5-0.5x+2y</td>
<td>10.5-0.5x-y</td>
<td>9.0</td>
<td>9.1</td>
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</table>

<table>
<thead>
<tr>
<th>10m³</th>
<th>mole</th>
<th>10³</th>
<th>2bar</th>
<th>298K</th>
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<tr>
<td>min</td>
<td>22.4l_{STP}</td>
<td>m³</td>
<td>1bar</td>
<td>473K</td>
<td>60s</td>
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9.38 moles/second of H₂S in

1. ratio of O₂ out in gas phase to that coming in = 1-x
if this equals 0.05 then x = 0.95
ratio of water coming out to the H2S entering is x+2y/3
if this equals 0.9 then 2.7 = 0.95 +2y then 1.75 = 2y then y = 0.875

9.38 moles/second of H2S in
9.38 * 6/3 moles/second of N2 out 6/9 molar % of gas
9.38 * 2.7/3 moles/second of H2O out 2.7/9 molar % of gas
9.38 * 0.075/3 moles/second of O2 = SO2 out 0.075/9 molar % of gas
9.38 * 2.65/3 moles/second of S out solid 100%

2. (x-y)/(10.5-0.5x-y) = 0.01 ; (x+2y)/(10.5-0.5x-y) = 0.3 for gas phase
from this (x+2y)/(x-y) = 30 (dividing), thus: 32y =29x ; y =0.90x
0.1x=0.105-0.014x
x = 0.105/0.114 = .92 ; y = .83

9.38 moles/second of H2S in
9.38 * 6/3 moles/second of N2 out 6/9 molar % of gas
9.38 * 2.6/3 moles/second of H2O out 2.6/9 molar % of gas
9.38 * 0.12/3 moles/second of O2 2 out 0.12/9 molar % of gas
9.38 * 0.09/3 moles/second of SO2 out 0.09/9 molar % of gas
9.38 * 2.52/3 moles/second of S out solid 100%