CBE CHEMICAL CORPORATION

To: CE 428 Team
From: Dr. Ima Manager
Date: January 20, 2006
Subject: Packed Bed Fluid Dynamics and CO_2 Absorption Assignment

New environmental regulations prohibit the discharge of CO2 into the atmosphere. Many of our waste gas streams contain CO2 levels in excess of the new limit. The purpose of this memo is to ask your team to investigate the use of a packed bed scrubber to remove the CO2. We have available a lab-scale packed bed absorber that you may use to carry out your investigation. A description of the lab-scale system is attached along with rotameter calibrations and details of a suggested analytical technique. Specific details of your assignment are shown below:

Your assignment is to:

- Generate a graph of pressure drop across the packed column as a function of air flow rate [plot log ($\Delta p/L$) versus log G_y] for five air flow rates with a maximum of 8 scfm. Use water flow rates of 0, 200, 500, 1000, and 1700 cc/min. Also, determine regions where flooding occurs.
- Determine the number of transfer units for the absorption of CO_2 from air using both water and a series of flow rates of NaOH solution.
    - For the absorption experiment, set a flow rate for air of 4 scfm.
    - Calculate the carbon dioxide flow rate needed for a feed concentration of 0.9 % by volume. Set the CO_2 regulator on the cylinder to between 20 and 30 psig. The CO_2 analyzer can be calibrated using the air and CO_2 flow meters.
    - Use water at flow rate of 1000 cc/min.
    - Repeat using ~0.5 N NaOH at 200, 300, 400, and 500 cc/min. Analyze the feed NaOH at the start of the absorption runs and at the end of each absorption run.
    - Water effluent should go directly to the sink drain, and ***the effluent with NaOH must be collected, labeled, and held for treatment prior to disposal***.

The results you obtain for the 3/8 inch Raschig ring packing will be passed to a design group that will design a full-scale scrubber. I will expect a report of your results in a memo two weeks from the date of your experiment. You may find that McCabe, Smith, and Harriott's *Unit Operations of Chemical Engineering* and Perry's *Chemical Engineer's Handbook* will be useful references in your investigation.

Attachments: Description of Lab-scale Packed Bed Absorption Unit
Calibration Curves for the Air and Liquid Flow Meters
Titration Procedure for Determining NaOH and Na_2CO_3 Concentrations in NaOH solutions

Appendix 1. Description of Laboratory-Scale Packed Bed Absorber Apparatus

Apparatus

The packed column (see the schematic diagram below) consists of a 4" ID by 36" long section of borosilicate pipe sitting on a 4" by 2" borosilicate tee 12 inches long. Stainless steel top, bottom and side plates are sealed with Teflon gaskets and provided with air, liquid (water or NaOH solution) , sample, and pressure tap connections. About 30 to 36 inches of ceramic 3/8" Raschig ring packing is supported above the air entry point on a stainless tripod.

The water/NaOH effluent line is ½" stainless tubing with Swagelock fittings that, when tightened correctly, permit the level of the exit line, and thus the level of the liquid in the column bottom, to be adjusted. At high air flow rates the outlet will have to be raised, to compensate for the increased pressure drop and prevent the loss of a liquid seal and the flow of air from the bottom of the column.

Liquid entering the top of the column is distributed over the packing by a 4-armed distributor. The air, liquid, and CO2 feed rates are set manually and measured by rotameters. A water manometer is used to measure the pressure drop across the packing. An infrared CO2 analyzer (MSA Co.) samples the effluent air stream and indicates the CO2 level, typically 0.5 to 1.0% by volume, in this stream. The packing consists of ceramic Raschig rings, length 3/8 inch, width 3/8 inch, wall thickness 1/16 inch, nominal weight 51 lbm/cubic feet, equivalent spherical diameter 0.35 inch, 0.68 void fraction, surface area 134 sq feet/cubic foot.

Regulators are mounted in liquid and air supply lines in order to reduce the effect of supply pressure variations on the flow rates. A regulator on the cylinder of liquid CO2 is normally set at 20 to 30 psig. The liquid flow rate is controlled by the valve below the rotameter.

An NaOH feed system is provided. This comprises two 20 liter polyethylene tanks with stainless effluent line ball valves. The tanks feed a magnetic drive centrifugal feed pump that sends the NaOH solution to the liquid feed rotameter. The system may also be used for water. At a flow rate of 500 ml/min, this system will supply NaOH feed for 80 minutes, using 800 g of commercial grade NaOH.

SAFETY Precautions

1. Sodium hydroxide is potentially very dangerous to the eyes. Wear good eye protection at all times. Be sure the lab ventilation system is operating before using CO2. Be sure the CO2 cylinder valve is closed before ending the experiment. Know the safety shower and eye wash station locations.

2. Wear jeans or slacks, a long sleeved shirt, and sturdy shoes that give good traction on possibly wet floors.

3. Guard against electrical hazards by making sure that all equipment is well grounded using three-wire plugs and other means.

4. Handle with great care any solvents or other potentially volatile, flammable, toxic, or otherwise dangerous chemicals. In this experiment air, water, carbon dioxide, sodium hydroxide and a solution of sodium or potassium chloride are used. **Sodium hydroxide can damage the skin and can seriously damage the eyes.** Potassium chloride is toxic if ingested in large amounts. CO2 can be toxic in high concentrations.

5. Guard against falls, burns, cuts, and other physical hazards.

6. **THINK FIRST OF SAFETY IN ANY ACTION YOU TAKE**. If not certain, ask the TA or a faculty member before you act.

Comments about CO2 absorber operation

1. Turn on the MSA analyzer and allow to warm up for 30 minutes. Set the CO2 feed rate to zero. The analyzer should draw a room air, or column bottom, sample. Zero the analyzer meter using the control provided. (The analyzer menu can be used to suppress the audible alarm.)

2. Be sure to turn off the CO2 cylinder main valve when the runs are complete. Also close the regulator outlet valve, but not too tightly. Run the CO2 analyzer for about ten minutes after turning off the CO2 cylinder, in order to flush CO2 from the analyzer. Monitor the knockout flask below the analyzer for water, and shut down the analyzer immediately if water is seen. **Do not allow water to enter the analyzer.**

3. Check the CO2 cylinder pressure gage before and after the run. It should show the vapor pressure of liquid CO2 at ambient temperature. A lesser pressure means the CO2 cylinder contains no more liquid, and the TA must be informed.

4. The CO2 level in the gas space at the bottom of the column may not be equal to the CO2 level in the air/CO2 inlet line. This is because some CO2 may be absorbed by the pool of liquid in bottom of the column and the liquid falling from the packing. Thus the CO2 level calculated by blending the air and CO2 flows should be higher than that indicated by the analyzer sampling from the column bottom. The absorption by the liquid surface may slightly affect the accuracy of the NTU calculation.

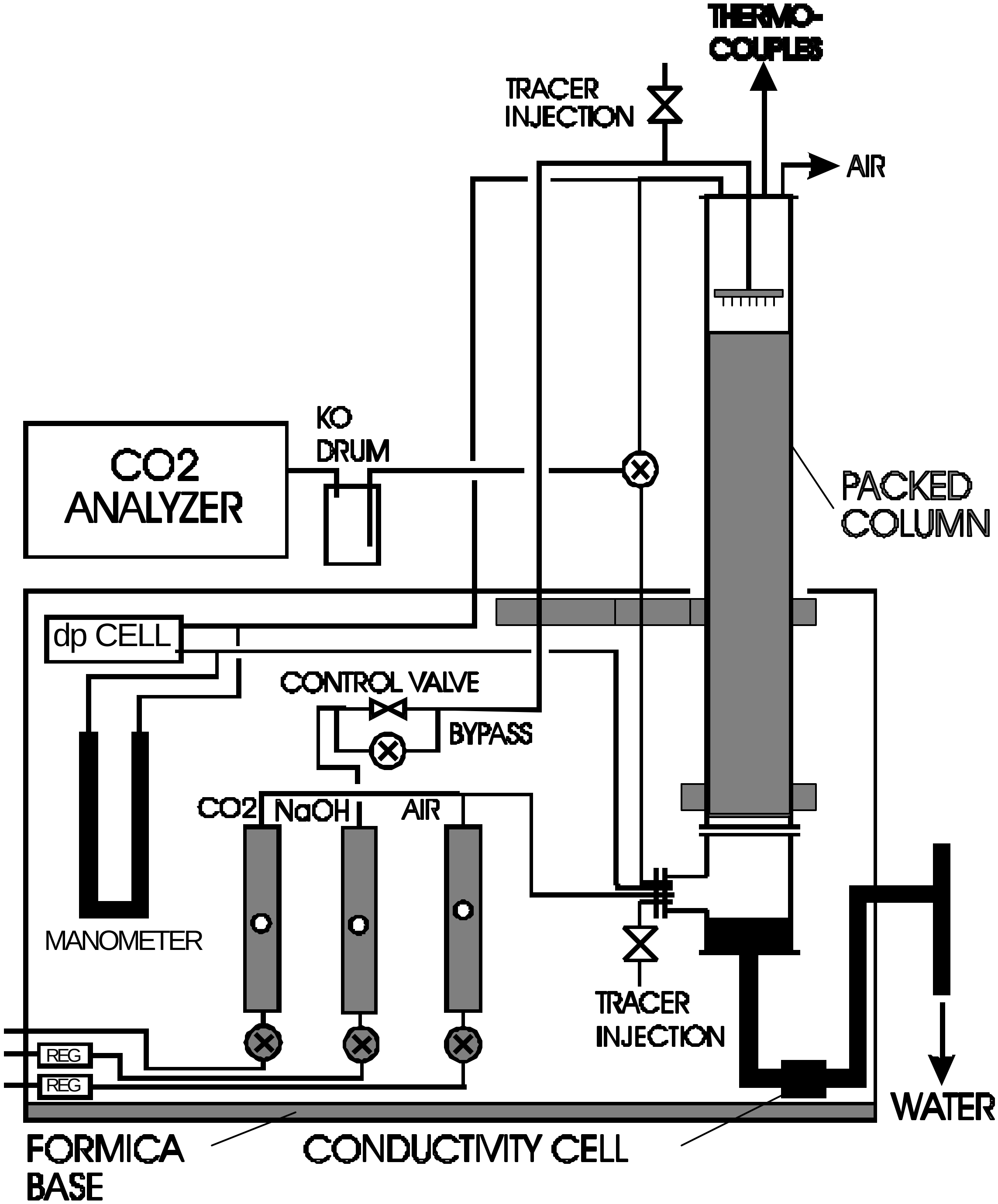


FIGURE 1. Schematic of packed-bed carbon dioxide absorber.

Appendix 2. Calibration curves for the air and liquid flowmeters in the gas absorption lab unit.

Calibration Curves for Gas Absorption Flowmeters								
	Manostat 36-541-125				Manostat 36-541-305			
Flowmeter	Air (cc/min)		Water (cc/min)		Air (cc/min)		Water (cc/min)	
Reading	SS	Glass	SS	Glass	SS	Glass	SS	Glass
150	4562	2313	130.4	53.5	65898	23564	1903	558.9
140	4295	2170	123.0	50.7	60615	21997	1778	518.1
130	4040	2050	116.0	47.7	55146	20247	1644	474.0
120	3780	1932	107.5	44.7	50086	18425	1523	434.1
110	3520	1807	101.0	41.5	44897	16751	1389	391.5
100	3256	1674	93.0	38.1	40051	14970	1257	351.8
90	2990	1535	85.0	34.6	35557	13153	1123	313.0
80	2708	1392	77.0	30.9	31086	11452	990	275.4
70	2400	1240	69.0	26.9	26848	9793	860	235.2
60	2117	1085	60.7	22.6	22503	8080	729	197.2
50	1780	928	51.6	18.2	18296	6494	598	159.2
40	1500	763	42.4	13.5	14257	4973	470	122.0
30	1145	590	33.0	9.2	10227	3512	347	83.7
20	868	395	22.2	5.2	6469	1976	224	48.6
10	480	185	9.4	1.6	2897	545	99	17.7

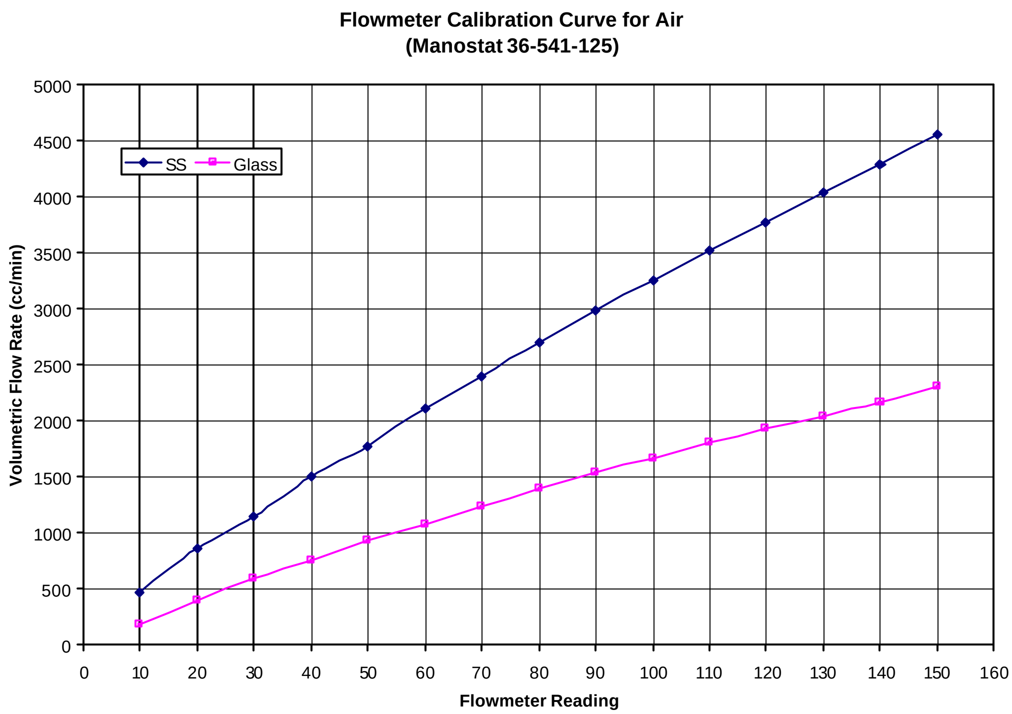
CO2 ROTAMETER

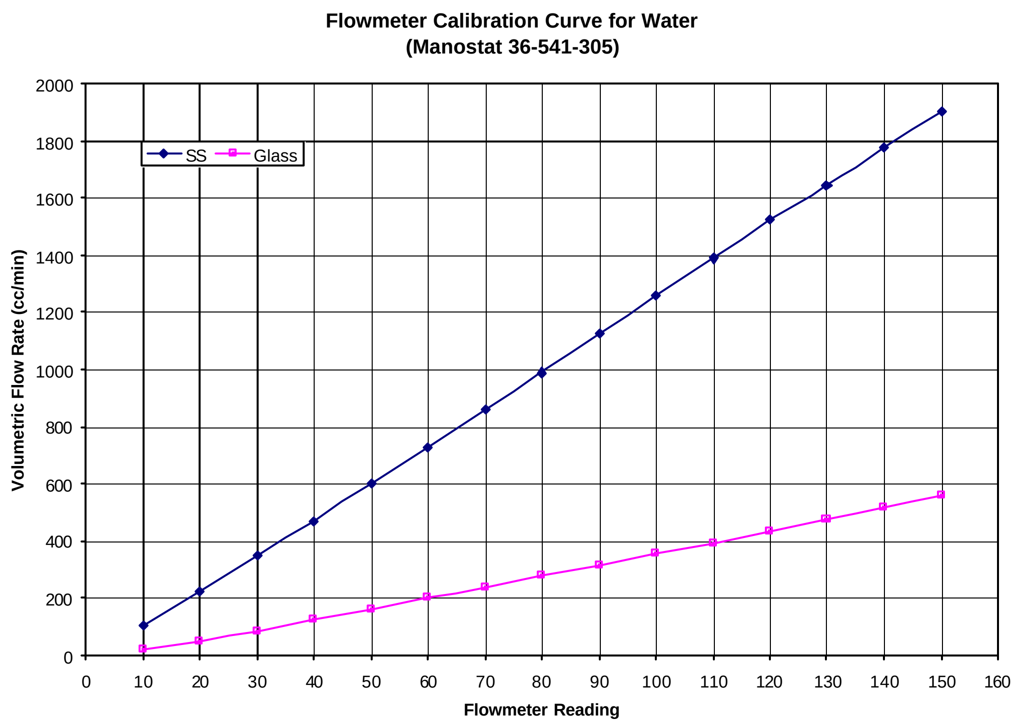
For gases, rotameter float position depends mostly on velocity head. Gas rotameters used for various gases are often calibrated with air. The rotameter labeled for CO2 has been calibrated for air as shown above. For an equivalent float position:

$$r_{air} V^2_{air} = r_{co2} V^2_{co2}$$

$$\frac{V_{air}}{V_{CO2}} = \sqrt{\frac{r_{co2}}{r_{air}}} = \sqrt{\frac{44}{29}}$$ assuming ideal gases

so Air Equivalent Flow Rate = CO2 flow rate * 1.23


Flowmeter Calibration Curve for Air
(Manostat 36-541-125)
Volumetric Flow Rate (cc/min)
Flowmeter Reading
SS
Glass
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160


Flowmeter Calibration Curve for Water
(Manostat 36-541-305)
Volumetric Flow Rate (cc/min)
Flowmeter Reading
SS
Glass
0
200
400
600
800
1000
1200
1400
1600
1800
2000
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160

Appendix 3. Titration Procedure for Determining NaOH and Na_2CO_3 concentrations in NaOH solution.

This titration procedure uses a 0.1 N HCl titrant and two indicators, phenolphthalein and methyl orange.

1. Take a 5 ml sample of the feed or effluent sodium hydroxide solution into a 125 ml flask or beaker.
2. Titrate with 0.1 N HCl with a phenolphthalein indicator solution until you observe a color change from pink to clear.
3. Record the volume of HCl used. Call it ***A.***
4. Add methyl orange indicator and Titrate with 0.1 N HCl until the solution becomes pink. Call the amount of HCl used with the methyl orange, ***B***.

Calculate the amount of Na_2CO_3 in the caustic solution by

$$mol/l\ Na_2CO_3 = \frac{2B(ml\ HCl) \times 0.1\ N\ HCl}{5\ ml\ alkaline\ sample}$$

$$mol/l\ NaOH = \frac{((A-B)(ml\ HCl)) \times 0.1\ N\ HCl}{5\ ml\ alkaline\ sample}$$

(1 N HCl=1 mol/l HCl, 1 N NaOH=1 mol/l NaOH, and 1 N Na_2CO_3=2 mol/l Na_2CO_3).

Chemistry:

$NaOH + H^+ \rightarrow Na^+$ by Phenolphthalein Indicator

$Na_2CO_3 + H^+ \rightarrow NaHCO_3 + Na^+$ by Phenolphthalein Indicator

$NaHCO_3 + H^+ \rightarrow Na^+ + CO_2 + H_2O$ by Methyl Orange Indicator