Gas Absorption

Objective

The objective of this experiment is to analyze the performance of a gas absorption column and compare the results to accepted literature values. Additionally, open-ended problem solving skills are exercised in this investigation.

Introduction

Another new consulting project has been assigned to our group. Our client has a waste stream from their process that is 5% ammonia in air. We have been asked to examine the cleanup of this waste gas stream using a packed tower in our pilot plant. Since this is a new piece of equipment for our plant, I am asking you to perform the following tests and report your findings to me.

1. The clients are concerned about the range of operation of the packed tower. They are particularly concerned about flooding in the column. Please determine the flooding characteristics of the column. What range of liquid and gas flow rates is acceptable? For these tests use <u>air only</u> (no ammonia) and water. Compare the flooding velocities you obtain with those reported in the literature (see McCabe, Smith and Harriott, Figure 18.5).
2. Our clients ask that we perform mass transfer characterization tests with a total feed gas flow rate of approximately 1.0 lb-mole/hour containing their feed composition of 5 mole% ammonia. For these conditions, determine the performance of the column using various liquid flow rates. You may determine the ammonia composition in the liquid effluent by titration using 0.1 N HCl. For each test you run, please determine:
   - the mole fraction of ammonia in the effluent gas
   - the percent removal of ammonia in the column
   - the number of transfer units based on the overall mass transfer coefficient on the gas side (N_{oy}). Plot N_{oy} versus the liquid molal mass velocity.
   - based on the number of transfer units that you just found, and the height of the packing, plot the overall mass transfer coefficient based on the gas side, K_ya vs. the liquid molal mass velocity.
3. Based on your calculations and tests, can the column be used to process the clients' waste stream and produce an effluent gas containing no more than 1000 ppm ammonia? What recommendations can you make?

Please provide us a report on your investigation according to our previously agreed upon schedule.

References

W.L. McCabe, J.C. Smith & P. Harriott, *Unit Operations of Chemical Engineering*, 6th Ed., McGraw-Hill, New York (2001).

R.H. Perry and C. H. Chilton, Chemical Engineers Handbook, 5th edition, McGraw Hill, New York (1973).

Column Operation - Hydraulics and Flooding

There ***must be some air flow*** at all times during the operation of the column to prevent liquid from running back into the air rotameter line.

The operation of a countercurrent column with liquid flowing down and gas flowing up through the column cannot be operated at inappropriate flow rates. It is possible for the column to "flood". This is when the gas and liquid flows are such that the liquid flowing down is impeded by the gas flowing up and the liquid starts to fill the column. We want to measure flooding conditions in our column. Start by setting the air flow rate at a very high (near maximum) value. Have someone at the top of the column to watch for flooding. Start increasing the water flow rate. Wait a minute or two at each water setting to allow the column to adjust. Keep increasing the water flow rate until you can see the column flood. Have everyone in the group see what is happening. Record your observations (as rotameter readings for the air and water, and temperature of the water). Next, turn the water off, lower the air flow rate to about ¾ of your first setting and repeat the flooding experiment. Note that the determination of flooding is somewhat subjective, i.e., it is a judgment call as to when the column is flooding at a particular set of flow rates. Now turn the water off again. Try repeating the experiments with someone else observing the flooding. How well do the results compare? Try to be as unbiased as possible when you do this repeat experiment. A recommended experimental procedure is as follows:

1. Open valve 1. Set the air flow rate near to the maximum air rotameter reading.
2. Open valve 2 and fill the water tank to the side drain pipe. Maintain the tank level there during all experiments.
3. Close valve 4, then open it a few turns (to keep from overflowing the rotameter). Ensure that all other liquid valves are in an appropriate open or closed state. Turn on the water pump switch at the panel.
4. Set the water rotameter at some reasonable low value to start and observe the column's performance. Valve 6, attached to the red tube coming out of the column, should be adjusted so the water level in the liquid tube is below the air inlet and no air bubbles come out.
5. Gradually increase the water rate (valve 4) until flooding is observed. Adjust valve 6 so no air bubbles come out, and valve 2 to maintain the water feed tank level at the side pipe.
6. Remember: the ***air flow*** (valve 1) is the ***last*** item to turn off when the experiment is completely finished.

Column Operation - Absorption

Prior to coming to the laboratory for your prelab session, obtain the MSDS sheet for anhydrous and aqueous ammonia. Many websites have this information available. Be sure to review this safety information prior to your prelab checkout.

It is important that you perform some preliminary calculations BEFORE you attempt to run the experiment. This includes your desired air and ammonia rotameter settings, and an estimate for the amount of HCl solution a single titration should require. Note the ammonia rotameter is calibrated in SCFM AIR. From Perry's, the ratio of flow rates for two different fluids A and B at the same rotameter reading is given by:

$$\frac{w_A}{w_B} = \frac{K_A}{K_B}\sqrt{\frac{(\rho_f - \rho_A)\rho_A}{(\rho_f - \rho_B)\rho_B}}$$

where w = mass flow rate, $\rho_{A,B}$ = fluid densities, ρ_f = float density (stainless steel in this case), $K_{A,B}$ are flow parameters for the rotameter that depend on the tube diameter, the float diameter, the weight of the float, and the density and viscosity of the fluid. If we assume that the K's are relatively constant for air and ammonia, and note that $\rho_f >> \rho_{A,B}$, then this relation simplifies to:

$$\frac{w_A}{w_B} = \sqrt{\frac{\rho_A}{\rho_B}} = \sqrt{\frac{PM_A/RT}{PM_B/RT}} = \sqrt{M_A/M_B}$$

where M_A and M_B are the molecular weights of the gases. Note that we have assumed that the ideal gas law applies in order to arrive at this relationship. Thus, if we let A = air (MW = 29) and B = ammonia (MW = 17), then we get:

$$q_{NH_3} = \sqrt{\frac{\rho_{NH_3}}{\rho_{Air}}}\left(\frac{\rho_{Air}}{\rho_{NH_3}}\right)q_{Air} = 1.3R_M$$

Thus the actual ammonia volumetric flow rate will be 1.3 times the indicated volumetric flow rate of air (the rotameter reading, R_M) for the ammonia rotameter. Note that the standard conditions for rotameter calibration are 70°F and 14.7 psia. In this experiment, we will introduce a gas stream of 5 mol. % ammonia gas in air into the bottom of the column. At the same time, water will be flowing down the column to absorb some of the ammonia. Since we have already done some flooding experiments, we should be able to select some "safe" (non-flooding) flow rates for the column. We want about 0.5 lb-moles/hr total gas flow rate to the column. From these specifications, determine what your air and ammonia rotameter settings should be.

To perform a run:

1. Turn on the red, lighted switch behind the column stand on the 1st floor. This will activate an exhaust fan above the column.
2. Set the air flow rate to the desired value.
3. Switch on the water pump, and adjust valve 4 to achieve your desired water flow rate. Adjust the flow of water into the tank to maintain the level at the side drain pipe. Check the water level periodically.
4. Adjust valve 6 so the water level in the column liquid drain tube (to which valve 6 is attached) is high enough that no air bubbles escape from the tube. However, do not allow the liquid level to rise above the gas inlet tube. Check often. There should be a visible column of water in the outlet line at valve 6.
5. Open the ammonia tank valve and gas pressure regulator, and set the ammonia feed rate to the desired value. Check the settings periodically.
6. Let the column operate for a few minutes until it has reached "steady-state" conditions.
7. Take a liquid sample by opening valve 7 (flush the system some each time you take a sample). Titrate with HC1 to determine the dissolved ammonia concentration coming out of the column (you might want to take more than one sample). You can also grab a sample from the effluent line from the column where it enters the drain.
8. Repeat steps 1 through 7 with different water flow rates as necessary. Be ***sure*** to record all of your necessary data with each run (rotameter settings, water temperature in and out, etc.).
9. When shutting down the column, turn off the air last.

CHEE 4550
Fall 2006

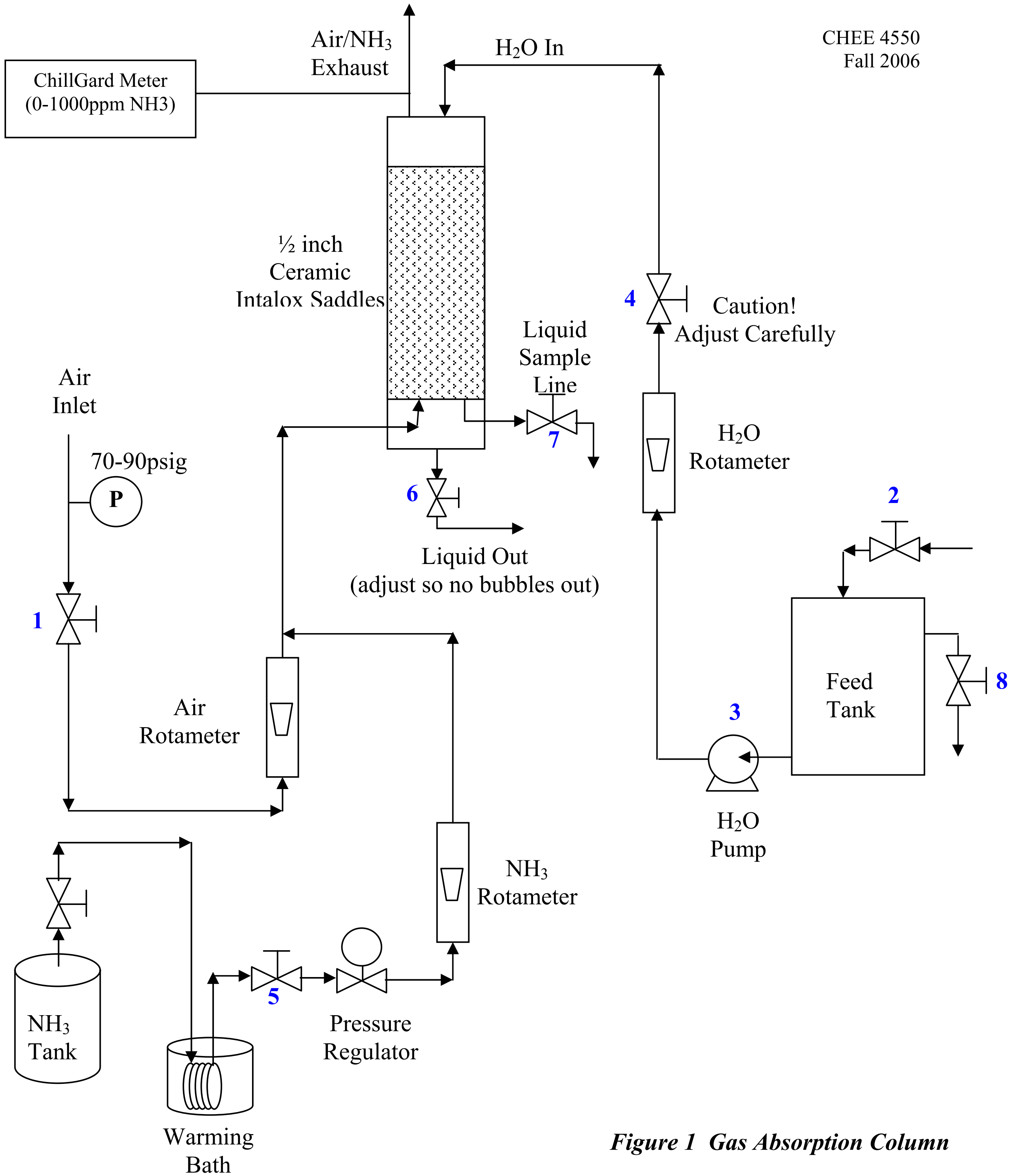

Figure 1 Gas Absorption Column