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Gas Absorption Column Refurbishment

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Gas Absorption Column Refurbishment

Senior Design 2009-2010

Osa Bazuaye, Matthew Kieke, Aaron Miller, Alec van Tilburg, Scott Weiner

4/27/2010

The purpose of this project was to refurbish the gas absorption column in the Moody Engineering Building for use as a supplement to some engineering classes. The group broke the project up into five subsections and each subsection was addressed based on different requirements. After completing the refurbishment, each subsystem was tested separately before the system was tested as a whole. After completing the final system test, the results were analyzed and grades given based on completion of goals for each subsystem. The final project was viewed as a success because the majority of work was completed and the system is operational such that it can be used in classes next year.

Executive Summary

The purpose of this project was to refurbish the gas absorption column located on the 1st and 2nd floor of the Moody Engineering Building, so that it could be used as a supplement to the engineering curriculum, particularly for the unit operations class. The column needed refurbishment for use, since it has not been operational in nearly 40 years.

To accomplish this task, the various issues with the column were broken up into five separate subsystems: gauges, ventilation, cleaning, blower and chemical. Each subsystem was first analyzed to determine what needed to be addressed. The group determined the optimal solution to each subsystem based on a decision matrix. For the gauges subsystem it was determined that a new air flow meter and new air and water pressure gauges needed to be purchased. Additionally, new temperature thermocouples were to be made. For the ventilation system, a simple tubing system was to be used to vent outside the laboratory. For the cleaning subsystem, vinegar was to be tested and used to remove scaling. Also, a water softening system was to be built and installed. It was determined that a new blower and silencers needed to be purchased to address the blower subsystem. CO₂ was chosen as the new chemical and a delivery system based on a paintball gun canister and gas regulator was developed.

After design decisions were made, the group purchased and installed the various aspects of each subsystem. Using various testing methods, each of the subsystems was tested separately to determine effectiveness before the entire system was tested as a whole.

The results of testing showed that the original design goals were accomplished to varying degrees of success. All new gauges were purchased and installed into the system and appeared to be functioning properly. The temperature gauges were not replaced with thermocouples because on closer inspection they were revealed to still be in working order. A ventilation system was purchased and installed, but it restricted exit flow and increased air pressure to an unsafe level. However, based on the chemical chosen, a ventilation system was not actually needed for the column. Cleaning the column with vinegar worked effectively, such that about 80% of the scaling was removed. However, the water softening system did not soften the water to a degree as to prevent scaling, so the column cleaning is not permanent. A new blower was purchased for the column and provides approximately the same output as the old blower, but at a 19 dB decrease in noise. The CO₂ chemical delivery system was installed and operated successfully up until seven minutes of operation, after which ice formed on the gas regulator and the pressure from the regulator began to vary. The overall column was tested successfully, with an inlet CO₂ concentration of 4000 ppm reduced to 2500 ppm in the 3rd system test.

In conclusion, the group was able to successfully refurbish the gas absorption column, such that it is operational and can be used in unit operation class next year. A few recommendations for future operation of the column include cleaning or replacing the CO₂ flow meter, determining the exact cause of the CO₂ system pressure variation after seven minutes and remedying the problem, and using a de-ionized water or vinegar rinse to clean the column after each use to prevent scale buildup.

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1. Introduction

The purpose of this design project is to refurbish the gas absorption column located on the first floor of the Moody Engineering Building. A working gas absorption column has water flowing down a column that is filled with packing material while air is blown from the bottom of the column to the top. The air has a chemical injected into its stream before the air stream enters the column, and upon entering the column the chemical begins to be absorbed by the water. The packing material, which in this case is Raschig rings, is used to increase the surface area over which the water and air interact, allowing for more absorption.

This particular gas absorption column hasn't been operated in nearly 40 years, meaning many different aspects of the column are no longer working. All of the pressure gauges are defunct, and must be replaced, as well as the flow meters. Although the blower is still operational, it is oversized and too loud for a learning environment. The blower must therefore be replaced with one that produces less noise pollution, yet still operates at the same flow rate to the absorption column as the original blower.

The column has had hard San Antonio water running through it for many years, which is the reason the column glass and packing material are covered in scale. This scale must be removed from the column so that students are able to see exactly what is occurring within the column. Removing the scale will also make the column more aesthetically pleasing.

The final aspect of the gas absorption column that must be addressed is the chemical which will be injected into the air stream. The original chemical was Sulfur Dioxide (SO_2), but this chemical is not safe to use in a laboratory setting. A new, safer chemical that is soluble in water must therefore be chosen for use in the column. Also, since the chemical may be harmful to individuals at high concentrations, a ventilation system will have to be attached to the air outlet stream.

Once all of these issues have been addressed, the gas absorption column will be ready for use in a teaching environment, and will allow students to measure the decrease in concentration of the chemical in the air stream as it moves up the column, as well as the various pressures of the air and water streams.

2. Design Description

The final design was broken into five subsystems, including a subsystem for the gauges, the ventilation system, the blower, and the cleaning of the column. There is also a subsystem for the chemical that is to be used in the column. The original objectives pertaining to each subsystem have changed over the course of the project, but the final design for each subsystem still addresses the issues with the column that were previously discussed.

2.1. Original Design Objectives

The original design objectives included replacing the old blower and all of the pressure gauges, as well as each of the temperature gauges and both the air and water flow meters. A ventilation system was also going to be added to the top of the column, which would vent any noxious gases out of the building and into the atmosphere. A new chemical was going to be chosen for use in the Gas Absorption column, and a system which transports the chemical to the column was to be constructed. The concentration of the chemical in the inlet and outlet air streams was also going to be measured using a Gas Chromatograph (GC). The last design objective was to clean out the column, which had large amounts of scale buildup on both the column and the packing material in the column.

It was later determined that the temperature gauges and the water flow meter would not be replaced. Initially it was assumed that none of the gauges/flow meters were functional, but upon running the column it was obvious that the water flow meter worked perfectly, and the valve below the meter could still be used to adjust the water flow rate. There was also an increase in the temperature reading on the temperature gauges, showing that these gauges are still operable

despite their old age. However, the temperature gauges were going to be removed from the column, with thermocouples attached to a pre-existing Programming Logic Controller (PLC) acting as their replacement, which would provide a digital readout of the various temperatures throughout the column. It was later discovered that the PLC unit is actually not operational, therefore it was decided that the original gauges would be kept.

The original design objective concerning the ventilation system was to construct an actual vent that would be aesthetically pleasing, and would run from the top of the column to either the fume hood or a window in the building. However, due to both time and budgetary constraints, this elaborate system was scratched, and it was determined that either tubing would act as the ventilation system, or there would be none at all; this decision depended on the chemical that was chosen for use in the column.

It was quickly decided that using the Gas Chromatograph as the method of measuring the concentration of the chemical was not an option, due to the fact that the GC must be adjusted based on the chemical. To adjust the GC, packing material for a specific chemical must be purchased, and due to budgetary constraints this was simply not feasible. However, more research showed that depending on the chemical chosen, other methods of measuring the concentration would be more effective and easier for the individuals operating the gas absorption column. For example, if a hydrocarbon was used as the chemical, measuring the concentration would be quite simple using a GC because the one owned by the Engineering department has been calibrated for such a chemical, but if Carbon Dioxide were chosen, a gas detection pump would easily measure the concentration.

2.2. Gauges Subsystem

The gas absorption column originally had mechanical pressure gauges for the air and water inlet/outlet, most of which were no longer operational. For the gas absorption column to be fully functional again, the broken gauges had to be replaced, and this was done using newer mechanical gauges. Although mechanical gauges have a shorter lifetime compared to other

alternatives, such as digital gauges, budget constraints made mechanical gauges a necessity. In addition to all of the pressure gauges being replaced, the air flow meter was also replaced.

Based on the pressure calculations on the piping system and column, a sample of which can be found in Appendix A, the new air pressure gauges have a range of 0 to 60 inches of water; the new water pressure gauges have a range of 0 to 15 psi based on the range of the old gauges. These values offer a wider range of pressures than the pressures that were calculated, which will take into account any error within the calculations. Also, the new air flow meter has a range of 0 to 50 cubic feet per minute based on a test run on the column that determined the flow rate of air through the top of the column when the original blower was connected. The two air pressure gauges cost \$55 each, while the two water pressure gauges cost approximately \$22 each and the air flow meter cost \$45.86. A full budget can be seen in Appendix C.

In order to connect the gauges to the column, they first had to be installed onto a large board adjacent to the column for easy access. Therefore, the original openings for the air pressure gauges were widened using a circle saw, allowing the two gauges to fit firmly into the board. For the water pressure gauges, which had a connection directly underneath the gauge, rather than on the back, a small hole was drilled below the gauge, and a 90° iron pipe connection was used to connect the gauges to the column. The original connections to the column were still used; for the air inlet/outlet pressure gauges a hose barb was required along with hosing, which allowed the air to flow through the barb, then through the hosing and finally through the gauge. All four pressure gauges can be seen connected in Figure 1.



Figure 1: Pressure Gauges.

The new air flow meter was placed on the board in the same position as the original flow meter, but due to its smaller size, extra piping was required to connect the column to the air flow meter. The new air flow meter can be seen connected in Figure 2.

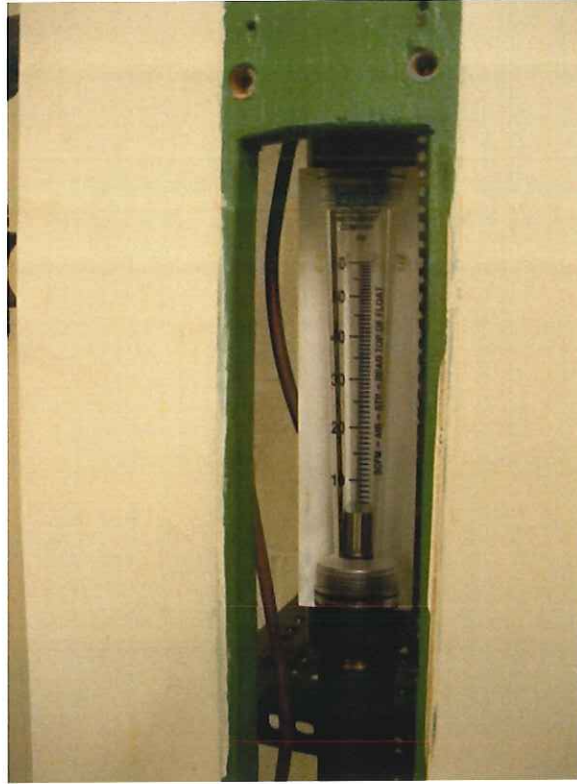


Figure 2. Air Flow Meter.

2.3. Ventilation Subsystem

For the ventilation subsystem, it was determined that the best option was to connect a plastic ventilation tube to the exit air stream, which would exhaust the air from the top of the column out of the 2nd floor window in the Fluids/Heat Transfer laboratory. To implement this design, a plastic tube was placed into a stopper in the top glass piece of the column; the top piece of the column originally exhausted the exit air into a metal exhaust pipe and out into the lab. A hole was drilled into the middle of the stopper, allowing the plastic tubing to fit snuggly inside the stopper so as not to allow any gas flow into the room. The tubing runs to the back wall of the laboratory and out the 2nd floor window. The tubing runs for about 20 feet, and can be removed to shut the window when the column is not in operation. A picture of where the tubing is connected is shown in Figure 3.



Figure 3. Ventilaiton Connection.

Since the tubing is simply run through the laboratory, it may present obstacles to students/professors using the lab. However, the tubing can actually be completely removed from the column when the column is not being operated. Also, although the exit gas will contain CO_2 , the concentration of the CO_2 will be well below harmful concentrations. The tubing may therefore be removed permanently, allowing the exit gas to vent into the lab.

2.4. Cleaning Subsystem

As was previously mentioned, the gas absorption column was covered in scale buildup due to the hardness of San Antonio water, which exceeds 200 parts per million CaCO_3 , calcium carbonate. It was desired to soften the water before it entered the column, which would prevent the scale from forming in the column. However, it was determined that softening the water was simply not feasible given the scope of the project, which focused on getting the column up and running, as well as the budget constraints. The final design had the column cleaned multiple times using vinegar, which is a weak acidic liquid that can be attained at approximately \$0.59 per quart.

First the column was plugged, preventing any liquid flowing into the column from escaping the

column, and vinegar was then poured down the column until it was completely filled; a safety manual for this procedure can be found in Appendix D. The vinegar was allowed to sit in the column for 24 hours before it was drained out of the column. The vinegar was disposed down the drain, with water from the nearby distillation column diluting the vinegar running into the sewer for safety. This procedure was run 2 times for a higher removal efficiency. A comparison of the column before and after the vinegar washing can be seen in Figure 4.



Figure 4. Column Before Cleaning (left) vs After (right).

2.5. *Blower Subsystem*

Due to the loud noise produced by the original blower, it was decided that a new, smaller blower would replace the old, oversized blower. However, the operating conditions, such as the flow rate and pressure, of the original blower system were required before a new blower could be decided upon and purchased. After initial testing of the original blower using an anemometer, it was determined that the air flow rate required was approximately 14.9 cubic feet per minute (cfm). It was also calculated that the blower should operate at a pressure between 15.2 and 21.56 inches of water; these calculations can be seen in Appendix A.

A blower was purchased at \$885 that had a max flow rate of 10.62 cfm out of the top of the column, with a rated max flow rate of 55 cubic feet per minute at 0 psi, and a pressure range of 0 to 80.5 inches of water; with a flow rate of 10.62 cfm, the blower operates at approximately 10 inches of water. However, at this maximum flow rate, flooding appeared to occur in the top half of the column, meaning water stopped flowing smoothly down the column and began to back up towards the top of the column. This was easily fixed by lowering the flow rate of the air and water into the column to levels where no flooding was observed. The new blower also meets the group's sound requirements in that it is significantly quieter than the original blower, which allows for a better teaching environment. To decrease the sound level of the new blower even more, two silencers were added. The first silencer doubles as both an intake filter and a silencer, while the second silencer is a standard inline silencer, which is simply used to absorb sound. The inlet silencer, filter, and outlet silencer are all shown in Figure 5.

To prevent theft or tampering, the new blower was bolted down to the original blower mounting plate. New holes were drilled and tapped in the mounting plate and the new blower was bolted into these new holes. Also, unlike the original blower which required a separate motor, the new blower came equipped with a direct input motor, allowing for much more room on the mounting plate. A comparison between the old and new blower can be seen in Figure 5.

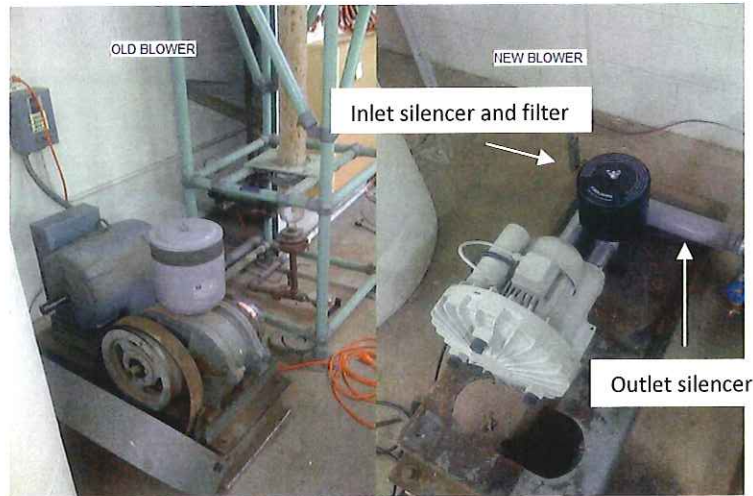


Figure 5: Old Blower vs New Blower.

The final aspect of the new blower dealt with the electrical system. Since the new blower only outputs one horsepower, a standard wall outlet was used for the power source, and an explosion proof switch was also installed for safety purposes. The switch can be seen in Figure 6.

Running the blower using the switch is extremely easy and safe, simply requiring the user to flip the switch up into the 'ON' position.



Figure 6: Switch.

2.6. Chemical Subsystem

The gas absorption column originally mixed SO₂, sulfur dioxide, with the air stream, but many problems arise when using this chemical. Most importantly, at high concentrations SO₂ becomes harmful to individuals working around the chemical, and at 100 parts per million this chemical becomes immediately dangerous to life or health¹. Even though the fumes from the column will be ventilated out of the laboratory, a leak could occur, and then the students, whose safety and education is the number one priority, would be placed in harm's way.

Therefore, CO₂, carbon dioxide, was chosen as the chemical to use in the gas absorption column. CO₂ becomes immediately dangerous to life or health at 40,000 parts per million², and this concentration will not be reached when running the column using a small CO₂ canister that operates at a low pressure. In fact, the highest concentration of CO₂ in the column should be approximately 5000 parts per million based on testing. Also, since the chemical must be absorbed into the water that flows counter-currently from the gas, the chemical must have a high solubility; CO₂ has a solubility of 0.0033 moles per 100 milliliters of H₂O, which will allow for the H₂O to effectively absorb most of the CO₂.

The final design for the chemical subsystem includes a 20 ounce tank of CO₂ which is connected to an ASA adapter, as shown in Figure 6. The adapter is then connected to a pressure regulator for CO₂ via a system of reducers and nipples, as well as a nut made exclusively for CO₂. This system is shown in Figure 6.

Ref Format

¹ *Niosh Pocket Guide to Chemical Hazards*. New York: Claitor's Law Books and Division, 2005. Print.

² *Niosh Pocket Guide to Chemical Hazards*. New York: Claitor's Law Books and Division, 2005. Print.

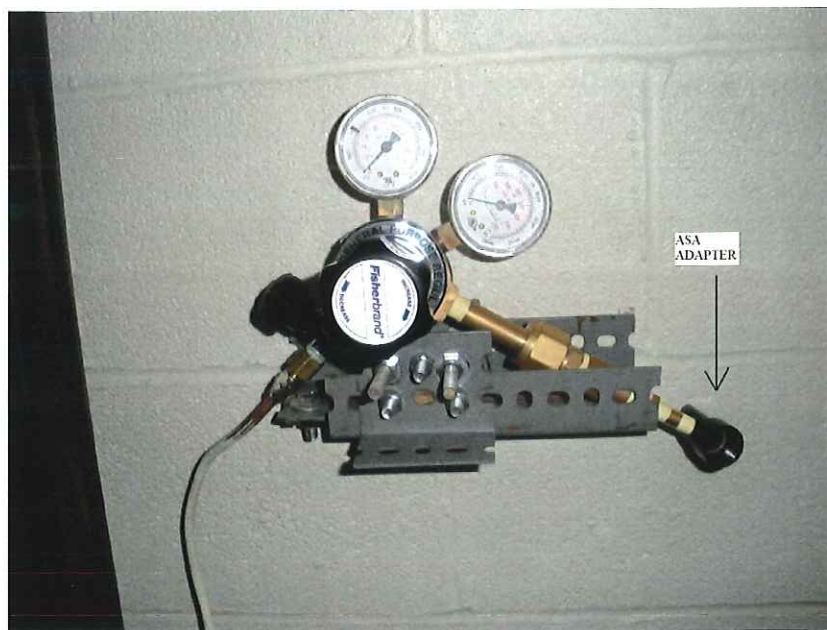


Figure 7. CO₂ System.

The CO₂ canister was obtained for \$24.87, and can be refilled at a price of \$4, while the ASA adapter, which is used to prevent liquid carbon dioxide from escaping the canister and entering the regulator, was obtained for \$19.99. The ASA adapter is also necessary due to the design of the CO₂ canister; the canister has a small nipple on the top which must be pushed down to allow CO₂ to escape, and the ASA adapter has an identical nipple which aligns with the canister, allowing the carbon dioxide to flow from the canister safely into the column. All of the threads on the reducers and nipples are lined with Teflon tape for gas, which keeps the CO₂ from escaping the CO₂ system.

Due to the high pressure within the CO₂ canister, which exceeds 900 psi, the chemical must pass through a pressure regulator; if the canister was simply attached to the column, the high pressures could cause the canister to shoot violently off of the connection. The regulator allows for the canister to be safely attached to the column, and it also allows the user to lower the pressure of the CO₂ entering the column. Since 20 ounces is not a large amount of CO₂, it was determined that the outlet pressure of the regulator should be set at approximately 25 kPa. At this pressure, a small amount of CO₂ will enter the column, allowing the 20 ounce CO₂ canister to last multiple experiments based on testing, in which a canister would last approximately 2

✓ unclear

experiments depending on the regulator's pressure. Although a 20 ounce paintball canister was chosen as the initial storage unit for the Carbon Dioxide, a larger CO₂ compressed gas cylinder could be used on the column rather than the paintball canister. If a compressed gas cylinder is used, the current CO₂ connection will obviously need to be revised to fit the valve on the cylinder. The pressure in the compressed cylinder is higher than the pressure of the paintball canister, and would therefore require the pressure regulator as well. Also, using a larger compressed cylinder is going to require more safety measures, especially when handling the cylinder, due to the large amount of pressurized Carbon Dioxide that is stored in the cylinder; a leak in the larger compressed cylinder would be catastrophic.

The CO₂ flows from the regulator through a small gas pipe which is connected to a gauge displaying the CO₂ flow rate, and then the CO₂ enters the column. Unfortunately, this gauge does not function properly, and the replacement of the gauge would have put the group over the budget limit. Although it would be desirable to replace this gauge, the amount of CO₂ entering the column can easily be determined based on the pressure of the CO₂ entering the column. A sample of these calculations, as well as the calculations required to determine the operating pressure of the regulator, are seen in Appendix E.

The final aspect of the chemical subsystem involves measuring the amount of CO₂ in the inlet and outlet air streams. To accomplish this task, a gas detection tube is used; the gas detection tube is placed in a gas detection pump, and the pump is then placed in front of the inlet and outlet air streams. A lever on the pump is pulled out, at which point the tube begins to take a sample, which is analyzed over a period of 2 minutes. After 2 minutes, the user will clearly be able to see the concentration of CO₂ in the sample based on a color change in the tube. For example, if the concentration of the CO₂ was 200 parts per million, the tube would have a solid blue color up to the 200 ppm marking, and the rest of the tube would be white. Figure 8 shows a picture of the gas detection tube and pump.

) not clear in FG



Figure 8. Gas Detection Pump (above) & Tubes (below).

To test the outlet stream, the ventilation system will be detached and the tube will be placed in front of the outlet air stream, as previously shown in Figure 3. To test the inlet stream, a t-connection is placed in the piping right before the air enters the column; the connection has a gate valve connected to it, which, when opened, allows air to flow out into the atmosphere. Therefore, the tube will be placed in front of this gate valve to test the inlet air stream. The t-connection and gate valve can be seen in Figure 9.



Figure 9. T-Connection & Gate Valve at Inlet Air Stream.

The gas detection tubes have an error $< 10\%$ of the reading, but will give the user a good approximation of the concentration of CO_2 in the inlet and outlet air streams. The gas detection pump costs approximately \$165, while a pack of 10 gas detection tubes cost \$30.

3. Methods

During design testing, each subunit of the final design was tested before a full scale test of the entire system was undertaken. All subunit tests were carried out separately, to avoid confounding variables. The results for each test are discussed in section 4.

The first system to be tested was the cleaning system. The group designed a proof of concept test, to evaluate the effectiveness of using vinegar for scale removal on the column. To conduct the test, a small amount of scaled packing material was removed from the top of the column and placed into a plastic bucket. The bucket was then filled with vinegar, such that the packing material would be fully submerged as in the actual cleaning procedure. The packing was left to soak over a period of three days, with visual inspection after 24 hours and after 72 hours. A qualitative measuring technique of visually inspecting the packing was used to analyze the effectiveness of the vinegar treatment in the proof of concept. This same qualitative measuring

redundant...

test was used after completing the full scale cleaning. The group visually inspected the column and compared the results to pictures of the column taken before the cleaning to analyze the success of the cleaning.

The water softening subsystem was also first examined using a proof of concept test. In this proof of concept, the flow into the water softening canister was scaled back to that of water coming out of a sink. The canister was placed in the sink, such that the water was allowed to flow into the inlet tube from the faucet and then out of the outlet and down the drain. The water was allowed to flow through the canister for one to two minutes in order to obtain an equilibrium inside the canister before a sample was taken from the outlet stream of the canister. This sample was then taken to Pool Mart, where it was analyzed to determine hardness, due to the fact that hard water forms scale. This hardness was then compared to the hardness of the water sample taken directly from the faucet.

The actual water softening subsystem was tested while attached to the column as it would be during normal operation. Water was piped through the water softening canister at 3 gallons per minute (gpm) which was originally determined as a final design specification. The canister was again allowed to come to an equilibrium, by running water through the canister for one to two minutes before a test sample was taken. Due to various difficulties, the canister was tested under varying conditions; these conditions included using whole salt pellets, hand crushed pellets and ground pellets. After each test, a water sample was taken to be analyzed at the pool supply store for hardness.

To test the operation of the new blower, the group had to ascertain that air was being blown through the column at the same rate as the previous blower while at a much quieter noise level. To test the noise of the blower, the group used a decibel meter held near the blower during operation. Unfortunately, the decibel meter was purchased after the original blower had been dismantled, so a reading could not be ascertained for comparison to the replacement blower. However, the group estimated the approximate noise level of the old blower based on comparison to other common noise levels. This estimation was compared to the reading off the

decibel meter for the new blower to determine the noise reduction of the new blower. In addition, the group performed a simple test to determine if the new blower was able to run at the same capacity as the old blower. Using an anemometer, the group measured air velocity at the top of the column, with the glass cap removed for both the old and new blower. Using these measurements, a comparison of blower performance was done.

After testing the blower, the group proceeded to test the air flow meter hooked up in line with the blower and column. To complete this test, the group turned on the blower with the blow-off gate valve on the blower completely closed and the valve connected to the flow meter completely open. This allowed all of the air from the blower to flow through the flow meter and into the column, rather than having some of the air bleed out through the gate valve. A reading was taken after the meter had come to equilibrium and this value was compared against the flow calculated based on the velocity test using the anemometer as described previously. These values were qualitatively assessed to determine the accuracy of the flow meter.

The ventilation system was also tested using just the air flow from the blower. The blower was turned on and the valve opened up to maximum air flow rate. The ventilation tubing was then connected to the ventilation port on the glass top of the column. The system was allowed to run while air flow rate and air inlet pressure were monitored. The results were then recorded.

The air and water systems were tested together, to ensure that the blower would not flood during operation. Another purpose of this test was to find the appropriate air and water flow rates for safe operation of the column. First, the blower was turned on and air was allowed to flow through the column at the maximum flow rate. After a minute, the water was turned on at 3 gpm, and air and water pressures were observed. The group also watched for flooding in the column. The air and water flow rates were then adjusted to decrease any flooding in the column. The proper flow rates were noted at an equilibrium where the column would not flood.

To test the CO₂ system, the group connected the CO₂ canister to the gas pressure regulator, which was hooked up to the column through a chemical flow meter. The blower was turned on

and a sampling port was opened at a T-connection right before the air enters the column. The regulator valve was slowly opened to maximum flow at a pressure of 200 kPa. The valve on the chemical flow meter was then fully opened to allow maximum gas flow rate through the column. A CO₂ measurement tube was prepared and a sample taken at the open sampling port. The reading from the detection tube was recorded and compared to a background reading taken with the blower on, but the CO₂ system unconnected. The CO₂ system was also tested for leaks by simply applying soap water to all of the connections used to attach the CO₂ canister to the pressure regulator. If there were any leaks in the system, the soap water would begin bubbling.

For the final test, the entire gas absorption column was be tested, with the CO₂ system connected. First the blower was turned on, and the air flow rate was set at approximately 20 cubic feet per minute. The water was then turned on and set at approximately 0.5 gallons per minute. The gas line was then opened, and the CO₂ canister was connected, with the regulator's outlet pressure being set at approximately 25 kPa. A sample was then taken at the T-connection right before the air enters the column, and another sample was taken at the top of the column, where the air stream exits. This process was done a number of times, each time altering the inlet pressure, air flow rate, and water flow rate.

4. Results

As previously stated, the proof of concept test concerning the cleaning of the column was a qualitative test, meaning the results of the test were purely descriptive. After the packing material had sat in the vinegar for approximately 24 hours, it appeared as if 75% of the scale had broken off of the packing material, and after 72 hours, approximately 90% of the scale had broken off of the packing material, proving that vinegar does in fact remove the majority of the Calcium Carbonate buildup.

Although the original design objective was to merely clean the column, it was decided that the best option would be to clean the column, and then provide a means with which the column would not scale up after having water run through it; the means was a water softening subsystem.

The results of the faucet test on this subsystem showed that before the water was run through the water softening canister the total hardness of the water was 138 parts per million (ppm) Calcium Carbonate, and after the water ran through the canister the total hardness was 81 ppm Calcium Carbonate. These results show that the water softening canister reduces the total hardness of the water. However, the water flow rate from a faucet is going to be much smaller than the water flow rate through the column, which is the reason another sample of treated and untreated water was analyzed with the water softening canister hooked up to the column. The results showed that before the water entered the canister, the total hardness was 240 ppm Calcium Carbonate, and the exit water had a total hardness of 208 ppm. Although there is an obvious decrease in the hardness, the Langelier Saturation Index (LSI) determines if the decrease in hardness is enough to prevent scale. The LSI, which is a function of the total hardness, pH, total alkalinity, and temperature of the water, will be a negative value if scale will not form, and will be positive if scale will form. The water analysis for the water exiting the softening canister actually had an LSI of 0.4, meaning that scale would still form; an example of the LSI calculations can be found in Appendix F. Therefore, the water softening canister was scrapped, due to the fact that it failed its given objective of preventing scale within the column.

The decibel test on the new blower gave a result of 71.1 decibels, while it was estimated that the old blower operated at approximately 85 - 90 decibels, based on the decibel chart seen in Figure 10.

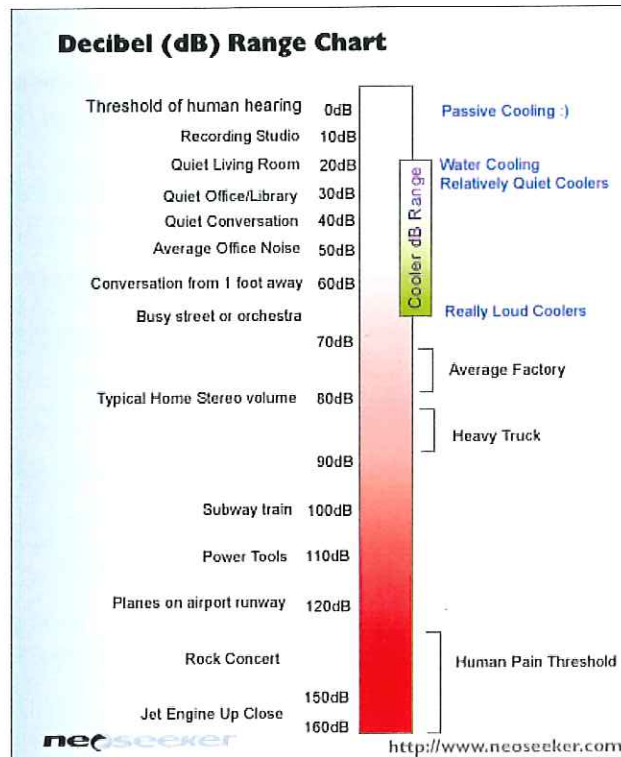


Figure 10. Decibel Chart.³

These results clearly show that there has been a drastic decrease in the noise pollution emitted from the blower, which was one of the main objectives set out at the beginning of the project. The results for the anemometer test on the new blower were 10.6 cubic feet per minute, which is slightly less than the results of the anemometer test on the old blower, which had an air flow rate of 14.88 cfm. Although these values are slightly different, they show that the new blower has a flow rate fairly close to that of the old blower, which was desired so that optimum absorption would occur. According to the air flow meter, the air flow through the column was approximately 14 cubic feet per minute, showing that the meter is fairly accurate. The discrepancies between the air flow rate found using the anemometer and the air flow read from the meter can be attributed to non-linear air being blown out of the column, which will produce some error in the anemometer reading.

The temperature and pressure gauges were also tested qualitatively to ensure that they were

³ "Decibel Chart." *Umlan*. Web. <http://www.uml.com/img/reviews/h84/cooler_decibel_chart.jpg>.

operating. The air pressure gauge, under normal conditions, gave a reading of approximately 25 inches of water for the inlet air, and approximately 0 inches of water for the outlet air, due to the fact that the pressure gauge is connected to a T-connection which is opened to the atmosphere. However, when the opening on the outlet air was closed, the outlet pressure rose to approximately 6 inches of water. Also, as the air flow was increased, the pressure for the inlet air rose steadily, which is due to the fact that as the velocity increases, the pressure drop increases. The results for testing the water pressure gauges showed that the inlet and outlet pressure of the water are both extremely small, on the order of approximately 0-1 psi; when the water flow increased, the pressure also increased. The temperature gauges were also observed during the water pressure gauge test; the temperature for the inlet and exit air rose by approximately 3 °C, showing that the air temperature gauges are still able to detect an increase in the temperature due to warm air being blown into the column. The air is expected to be warmer than ambient air because energy is required to run the blower and push the air through the piping system; this process heats the air. A similar reading was done on the water inlet/outlet temperature gauges, and an increase in temperature of 2 °C resulted, showing that the water temperature gauges work as well.

Before the ventilation system was attached to the column, the air inlet pressure was approximately 25 inches of water. As soon as the tubing was plugged into the top of the column, the air inlet pressure increased to approximately 50-60 inches of water. This shows that the current tubing being used has too small of a diameter (~ ¼ inch). Although unnecessary, if a ventilation system is desired, a larger piece of tubing will be required.

After all of the gauges were tested, along with the ventilation system, the entire system without the CO₂ was tested. At a water flow rate of approximately 20 cubic feet per minute (cfm) and an air flow rate of 3 gallons per minute (gpm), the column clearly began to flood. The air and water flow rates were decreased until they were at approximately 20 cfm and 0.5 gpm; at these flow rates, the water ran smoothly through the column, and no flooding was visibly occurring, showing that these flow rates are the rates at which the column should be operated at.

In testing the CO₂ system, it was calculated that the CO₂ concentration in the air stream was approximately 300 parts per million before the gas canister was connected, and over 5000 ppm after the canister was connected. In general, the concentration of CO₂ in the air stream will not be so high, but since the regulator was set at 200 kPa, a large amount of CO₂ began entering the air stream. As previously stated, the optimum operating pressure is actually 25 kPa. In addition, the testing for leaks showed no visible leaks in the connections between the gas canister and regulator.

The test of the entire gas absorption column at an inlet pressure of 100 kPa, an air flow rate of 20 cfm, and a water flow rate of 0.5 gpm resulted in a concentration of CO₂ at the inlet of 5000 parts per million, and a concentration of CO₂ at the outlet of 3000 ppm. At the higher pressure of 100 kPa, more CO₂ is going to flow into the column, causing the concentration to increase; setting the first test at 100 kPa shows that even with high concentrations of CO₂, the column still effectively transfers the chemical to the water phase.

The second test was run at the pre-determined regulator pressure of 25 kPa, an air flow rate of 20 cfm, and a water flow rate of 0.5 gpm. At these operating conditions, the concentration of CO₂ at the inlet was 4000 ppm, while the concentration of CO₂ at the outlet was 5000 ppm. The cause of this erroneous data was traced back to the fact that approximately 7 minutes after the CO₂ canister was connected, the regulator pressure began to fluctuate between 25 kPa and 100 kPa, meaning more CO₂ was flowing into the column, increasing the chemicals concentration in the column.

For the third and final test, the column was run at a regulator pressure of 25 kPa, an air flow rate of 20 cfm, and a water flow rate of 0.5 gpm. These operating conditions provided an inlet CO₂ concentration of 4000 ppm and an outlet CO₂ concentration of approximately 2500 ppm. The purpose of the third test was to see if the operating conditions produced the same inlet CO₂ concentration. Also, based on the data from the second and third tests, the concentration for these tests obviously decrease from the inlet air stream to the outlet air stream, showing that the water is absorbing CO₂ as the air flows up the column. A table showing all readings made

during each of the three tests can be seen in Table 1.

Table 1. Gas Absorption Column Testing.

	Test 1	Test 2	Test 3
Water Flow Rate	0.5 GPM	0.5 GPM	0.5 GPM
Air Flow Rate	20 CFM	20 CFM	20 CFM
Regulator Pressure	100 kPa	25 kPa	25 kPa
Gas Inlet Temp	75 °F	71 °F	72 °F
Gas Outlet Temp	70 °F	72 °F	72 °F
Liquid Inlet Temp	72 °F	74 °F	73 °F
Liquid Outlet Temp	70 °F	70 °F	70 °F
Gas Inlet Pressure	25 in H ₂ O	25 in H ₂ O	25 in H ₂ O
Gas Outlet Pressure	0 in H ₂ O	0 in H ₂ O	0 in H ₂ O
Liquid Inlet Pressure	0 PSI	0 PSI	0 PSI
Liquid Outlet Pressure	0 PSI	0 PSI	0 PSI
Chemical Inlet Concentration	5000 PPM	4000 PPM	4000 PPM
Chemical Outlet Concentration	3000 PPM	5000 PPM	2500 PPM

5. Conclusions & Recommendations

The original goal was to replace all of the pressure gauges and air flow meter with working gauges/meters that are both aesthetically pleasing and easy to read. As was previously shown, the air/water inlet and outlet pressure gauges fit perfectly onto a pre-existing gauge board, are large enough to read, and give valid pressure readings. The temperature gauges also work when the column is in operation, while the air flow meter, although not necessarily aesthetically pleasing, provides a reading that is very similar to the calculated air flow through the column. The only gauge that does not work properly is the chemical flow meter, which can either be replaced, or fixed by cleaning the tube; replacing this flow meter was never a design goal.

Gauges Subsystem: A

The ventilation subsystem is an obstacle in the Heat Transfer/Fluids laboratory, and it also increases the pressure drop through the column, which are the reasons why it has been removed from the column. This may seem like a failed subsystem, but the initial goal was to provide a ventilation system dependent on the chemical used in the column. Since CO₂ at concentrations of 5000 parts per million and lower is not harmful, it was determined that a ventilation system is not necessary.

Ventilation Subsystem: C

The next design objective was to clean the column. Although a water softening system was an option that would prevent scale from forming in the future on the column, the goal was merely to clean the column; it was a short term goal rather than a long term goal. The multiple vinegar washes clearly removed the majority of the scale from the column, allowing individuals to see exactly what is occurring within the column.

Cleaning Subsystem: A

The new blower was to have an air flow of approximately 15 cubic feet per minute, and the noise pollution of the new blower was to be reduced compared to the old blower. Also, the blower should be able to push air through the piping system and through the top of the column easily. Not only has the noise level decreased by 19 decibels, but the blower also has a flow rate of approximately 20 cfm at the bottom of the column as well as at the top of the column, showing that the air easily flows throughout the entire column. The blower is also much smaller and safer to use, and also utilizes a switch which is safe to operate.

Blower Subsystem: A

The final design objective was to choose a chemical for use in the gas absorption column, and to build a system which will transport the chemical into the inlet air stream. Not only is CO₂ extremely inexpensive, safe to use, and water soluble, but the actual system has no major or minor leaks, and the CO₂ flows smoothly from the canister to the column. However, 7 minutes after connecting the CO₂, the CO₂ system begins to malfunction, which leads to inaccurate concentration measurements. This is not viewed as a major failure of the CO₂ system since 2 out of the 3 tests run on the column were easily completed within 5 minutes of connecting the chemical, but this malfunction is something that must be addressed.

Chemical Subsystem: C

As previously shown, the overall system clearly has gas absorption occurring; the concentration of CO₂ in the inlet air stream is greater than the concentration of CO₂ in the outlet air stream, showing that the water is absorbing some of the CO₂ from the air. The overall objective of this project was to produce a functional gas absorption column, and based on this information, that is exactly what has been provided.

Overall System: A

However, there are a few recommendations for the future which could possibly make the gas absorption column run even better. In order to prevent scale from occurring in the future, de-ionized water, which can be obtained for free from the Chemistry department, could be run through the column, but this would require a holding tank for the de-ionized water and a piping system to get the water from the holding tank into the existing piping network so that it could be run through the gauges. Also, a small vinegar wash could be performed after each column operation to wash out all the hard water from the column. This would take a small amount of vinegar on the order of 1-2 gallons and would only need to be performed once after the column was run. Both of these options require time better used for running experiments on the column, so it is recommended that research on magnetic water softeners be done; the magnetic water softener simply attaches to the inlet water pipe and creates a magnetic field which effectively de-ionizes the water.

Since the ventilation system currently being used creates a large increase in the pressure drop through the column, a larger piece of tubing could be used. However, it is recommended that the column do without a ventilation system, which will allow the air stream to exit into the laboratory.

The chemical flow rate meter could possibly have an oil buildup, which is causing the ball bearing in the meter to stick to the bottom of the meter. It is therefore recommended that the meter be taken apart and cleaned. If a thorough cleaning doesn't fix the gauge, then a replacement could be purchased. One possible replacement is the RWS Series NPT CO₂ flow meter, which runs from \$65 - \$105. However, this flow meter is made specifically for Carbon Dioxide, so no future changes could be made to the chemical used in the column if the RWS flow meter is purchased.

W3h?
Lst?

It is recommended that more tests must be run on the CO₂ system to determine exactly what the cause is of the pressure variation after 7 minutes. Due to the extremely cold temperature CO₂, ice could be building up in the gas line, which forced the pressure to increase, allowing the CO₂

to push past the blockage. If this is the reason, the gas pipe could be wrapped in heating tape, which will keep any ice from building up in the line.

*Tested?
Speculation*

Finally, so that flooding or injuries do not occur, the operating conditions shown in Table 2 should be met:

Table 2. Column Operating Conditions.

Air Flow Rate	10 - 20 CFM
Water Flow Rate	< 1 GPM
Regulator Pressure	~ 25 kPa

Also, the CO₂ canister should also be handled with care, and before the canister is attached to the ASA adapter, the user must ensure that an O-ring, as seen in Figure 11, is in the adapter. If the O-ring is missing, CO₂ will shoot out of the adapter, which not only wastes CO₂, but it will also harm an individual due to the chemicals freezing cold temperature. A more detailed Absorption Column Instruction Manual can be found in Appendix G.



Figure 11. ASA Adapter (Encircled) + O-Ring.

What Ending?

Appendix A. Sample Pressure Calculations

Column Pressure

Volumetric Flow Rate

Volumetric Flow Rate_{H₂O} = .67 ft³/minute

Volumetric Flow Rate_{air} = 14.3 ft³/minute to 285.75 ft³/minute

Density

P_{H₂O} = 62.28 lb/ft³

*P_{air} = .0718 lb/ft³ at room temperature

Mass Flow Rate = Volumetric*Density

Mass_{H₂O} = 41.73 lb/minute = GL

Mass_{air} = 1.03 to 20.517 lb/min = Gg

Need ratio of Mass Flow Rates

G_L/G_g = 2.03 to 40.5

Flow Parameter

(G_L/G_g)*sqrt(P_g/P_L) = .069 to 1.38 = Flow Parameter

Based on this Flow Parameter and the pressure at flooding (2 in H₂O)

Capacity Parameter = .68 to 1.75 (from Fig. 10.6-5)

Operate column at 50% flooding conditions

New Capacity Parameters = .5*Capacity Parameter = .34 to .875

Keep same Flow Parameter

From Fig. 10 in Appendix B, operating pressure ranges from .15 to .18 in H₂O/ft = P

Based on a column that is approximately 13 feet:

P*Height = 1.95 to 2.34 in H₂O

*Disregarded any change in density due to presence of CO₂

Pipe Pressure

Minor Head Loss

*Assumed a flow rate of 60 ft³/minute

$$\text{Area} = (1/4)*\pi*D^2 = A \quad (1)$$

$$Q = \text{Volumetric Flow Rate} = 60 \text{ ft}^3/\text{minute} \quad (2)$$

$$\text{Velocity} = Q/A = V \quad (3)$$

There are 4 changes in Diameter of the pipe:

$$D_1 = 2.75 \text{ inches} = .23 \text{ ft}$$

$$D_2 = 2.25 \text{ inches} = .1875 \text{ ft}$$

$$D_3 = 1 \text{ inch} = .0833 \text{ ft}$$

$$D_4 = 1.25 \text{ inches} = .104 \text{ ft}$$

Length of section with each diameter:

$$L_1 = 2.81 \text{ ft}$$

$$L_2 = 4.1 \text{ ft}$$

$$L_3 = 6.3 \text{ ft}$$

$$L_4 = 7 \text{ ft}$$

From this and (3), Velocity is calculated:

$$V_1 = 24.07 \text{ ft/s}$$

$$V_2 = 36.217 \text{ ft/s}$$

$$V_3 = 183.5 \text{ ft/s}$$

$$V_4 = 117.34 \text{ ft/s}$$

Contributions to minor head loss:

D₁: 2 90° bends (KL = 1.5)

1 gate valve, assumed fully open (KL = 0.15)

1 tee (KL = 0.9)

D₂: 2 90° bends (KL = 1.5)

D₃: 3 90° bends (KL = 1.5)

1 180° bends (KL = 1.5)

D₄: 5 90° bends (KL = 1.5)

$$H_{l,minor} = \rho(V^2)\Sigma KL/2 \quad (4)$$

$$P = .0718 \text{ lb/ft}^3 = .0022 \text{ slugs/ft}^3$$

$$H_{l,minor1} = (.0022 \text{ slugs/ft}^3) * (24.07^2 \text{ ft}^2/\text{s}^2) * (1.5 + 1.5 + 0.15 + 0.9) / 2$$

$$H_{l,minor1} = 2.58 \text{ lb/ft}^2 = .4955 \text{ in H}_2\text{O}$$

$$H_{l,minor2} = .8322 \text{ in H}_2\text{O}$$

$$H_{l,minor3} = 42.72 \text{ in H}_2\text{O}$$

$$H_{l,minor4} = 21.83 \text{ in H}_2\text{O}$$

$$\mathbf{H_{l,minor} = 65.88 \text{ in H}_2\text{O}}$$

Major Head Loss

*Calculated major head loss at each diameter change

$$\text{Reynolds Number} = \rho VD / \mu \quad (5)$$

$$\mu = 3.85 * 10^{-7} \text{ lbf-s/ft}^2$$

$$Re_1 = (.0022 \text{ slugs/ft}^3) * (24.07 \text{ ft/s}) * (.23 \text{ ft}) / (3.85 * 10^{-7} \text{ lbf-s/ft}^2)$$

$$Re_1 = 31634.9$$

$$Re_2 = 38804$$

$$Re_3 = 87346$$

$$Re_4 = 69733.5$$

*Assumed piping made out of commercial steel

Equivalent Roughness = $e = .00015 \text{ ft}$ for commercial steel

$$e/D_1 = .000652$$

$$e/D_2 = .0008$$

$$e/D_3 = .0018$$

$$e/D_4 = .00144$$

Using these values, the corresponding Reynolds values, and the Moody chart, shown in Fig. 11 in Appendix B, the corresponding friction factors were:

$$F_1 = .0245$$

$$F_2 = .025$$

$$F_3 = .0255$$

$$F_4 = .024$$

$$H_{l,major} = (F_p L V^2) / (2 * D) \quad (6)$$

$$H_{l,major1} = (.0245) * (.0022 \text{ slugs/ft}^3) * (24.07^2 \text{ ft}^2/\text{s}^2) * (2.81 \text{ ft}) / (2 * .23 \text{ ft})$$

$$H_{l,major1} = .03675 \text{ in H}_2\text{O}$$

$$H_{l,major2} = .1518 \text{ in H}_2\text{O}$$

$$H_{l,major3} = 13.7 \text{ in H}_2\text{O}$$

$$H_{l,major4} = 4.7 \text{ in H}_2\text{O}$$

$$\mathbf{H_{l,major} = 18.59 \text{ in H}_2\text{O}}$$

Pressure Drop

$$\Delta P = (1/2)\rho(V_4^2 - V_1^2) + \gamma Z_2 + H_{l,major} + H_{l,minor} \quad (7)$$

$$\gamma = \rho * \text{gravity} = .0022 \text{ slugs/ft}^3 * 32.2 \text{ ft/s}^2 = .0708 \text{ lb/ft}^3$$

$$Z_2 = 1 \text{ ft}$$

$$\mathbf{\Delta P = 87.24 \text{ in H}_2\text{O}}$$

Appendix B. Figures.

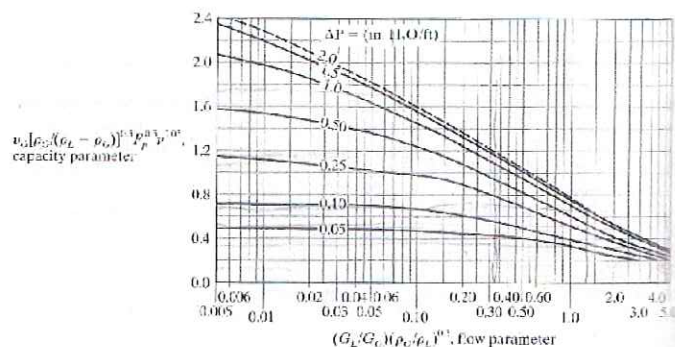


FIGURE 10.6 5. Pressure-drop correlation for random packings by Strigle. (From R. F. Strigle, Jr., *Random Packings and Packed Towers*, Houston: Gulf Publishing Company, 1987. With permission from Elsevier Science.)

Figure 12. Chart Used To Determine Pressure in Column.⁴

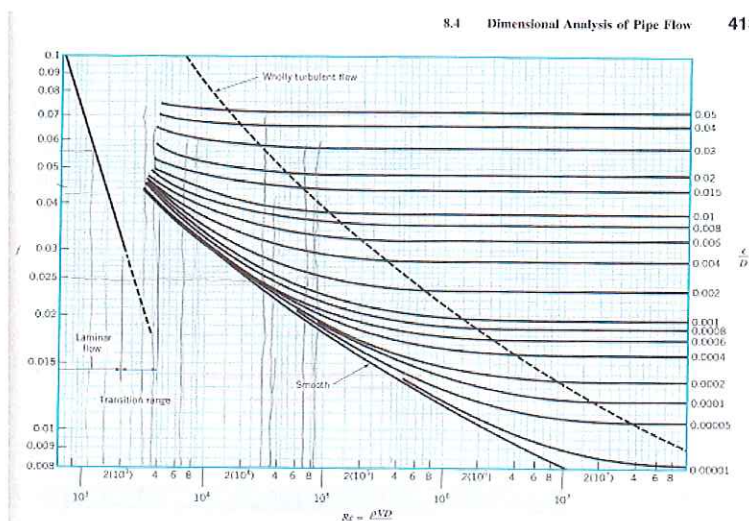


FIGURE 8.20. Friction factor as a function of Reynolds number and relative roughness for round pipes—the Moody chart. (Data from Ref. 7 with permission.)

Figure 13. Moody Chart.⁵

⁴ Geankoplis, Christie J. *Transport Processes and Separation Process Principles: (includes Unit Operations)*. Upper Saddle River: Prentice Hall Professional Technical Reference, 2007. Print.

⁵ Munson, Bruce Roy, Donald F. Young, and T. H. Okiishi. *Fundamentals of Fluid Mechanics*. New York: Wiley, 2002. Print.

Appendix C. Budget

Date Reviewed: 4/16/2010
Reviewed By: Osarieme Bazuaye
Group Name: Gas Absorption Group
Advisor Name: Dr. Matt Alexander

[illegible]

Total Income	\$2,499	\$2,499
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* - regulator valued as shown

Expenses												Status (Check one)			
Date	Item Description		Vendor	Vendor Catalogue Number	Status (Placed/Pending/Cleared)	Budgeted Amount	Actual Amount	PO #	Internal	Dept	Purchase Order	PCARD	Reimburse-ment		
		GAUGES													
2/5/2010	Air flow Meter	Instrument	7510-2-1-64-03		cleared	94.57	94.57					x			
2/17/2010	Air Pressure Gauges (2)	Lesman Instruments	Dwyer MiniHelic 2-5002		cleared	111.00	124.00					x			
1/26/2010	Water Pressure Gauges (2)	Granger	4FFLB		cleared	33.90	36.43					x			
		VENTILATION													
11/13/2009	Ventilation System	Home Depot			cleared	12.66	12.66		x				x		
		CLEANING													
10/22/2009	Vinegar for Test	National Vinegar			cleared	6.00	6.00		x						
12/5/2009	Vinegar for Cleaning Column	National Vinegar			cleared	47.40	47.40		x						
4/13/2010	Vinegar for Final Cleaning of Column	National Vinegar			cleared	70.90	70.90								
2/1/2010	Water Softening Salt	Home Depot			cleared	5.00	5.61		x				x		
2/1/2010	Water Quality Test Kit	Pool Mart			cleared	10.00	21.60		x				x		
		GAS SYSTEM													
3/1/2010	Canister of CO2	Academy Outdoors			cleared	30.00	34.44		x				x		
3/1/2010	ASA Adapter	Paintball Mart			cleared	45.00	12.00		x				x		
1/19/2010	Gas Pressure Regulator	Chem. Dept.			cleared	675.25	675.25		x						
3/2/2010	Manual Gas Sampling Pump	Cole Palmer	EW-86260-00		cleared	165.00	165.00					x			
3/2/2010	CO2 Gas Detection Tubes	Cole Palmer	EW-86260-70		cleared	30.00	30.00					x			
	shipping for gas system	Cole Palmer			cleared		6.77								
		BLOWER													
1/26/2010	Fuji Regenerative Blower	Granger	63D19		cleared	885.00	898.60					x			
1/26/2010	Silencer/Filter Inlet	Granger	42681		cleared	45.25						x			
1/24/2010	Muffler	Granger	4FY58		cleared	85.15						x			
	Total cost plus shipping for Silencers	Granger			cleared	2.00	132.40								
		MISCELLANEOUS													
11/13/2009	Supplies (Nuts, Bolts)	Home Depot			cleared	9.58	9.58		x				x		
2/17/2010	Hex Bushing for Blower	Granger			cleared	4.06	4.06					x			
2/8/2010	Pipes, Elbows, Reducers etc	Home Depot			cleared	49.32	49.32		x				x		
2/8/2010	CO2 Pressure Fittings	Proxair			cleared	9.27	9.27		x				x		
3/9/2010	Pipe Fittings (Reducers, Connectors etc)	Home Depot			cleared	15.00	15.00		x				x		
3/9/2010	Pipe Fittings CO2 System (Bushing etc)	Home Depot			cleared	15.40	11.40		x						
3/9/2010	Pipe Fittings for CO2 System (Bushings etc)	Home Depot			cleared	3.71	3.71								
3/9/2010	Pipe Fitting for Pressure Gauge	Home Depot			cleared	14.31	15.47								
4/27/2010	Printing and Binding of Final Report	Ginnys Printing			planned	6.525	0								
	Total Expenses					2,699.26	2,709.44								

	Budgeted	Actual
Budget Remaining	10.09	-8.99

Appendix D. Safety Procedure for Cleaning Column

In the decision table for cleaning the gas absorber column, the group decided that the best option to clean the column would be to test cleaning solutions on the column before attempting to clean the entire column. The group decided to first test with vinegar (acetic acid) as it is cheap, easy to obtain and less potentially dangerous than other options considered. However, the group does recognize that there are safety concerns in working with vinegar, especially in large quantities as needed to clean the column. The purpose of this safety plan is to document safety concerns in the cleaning of the column and to plan a strategy to mitigate and minimize these concerns. In order to deal with safety concerns, the group will address the following areas: protecting self, minimizing volatiles created, and contingency plans.

As the column spans from Dr. Terrell's second floor lab, down to the shop floor, both Dr. Terrell and Manuel Garza should be alerted before any work is started in cleaning the column. The ideal time to work on the column, would be on a Friday afternoon as there will be less people needing to use the labs. Also, the vinegar can sit in the column over a weekend, when people won't be in and out of the lab and shop.

While acetic acid is present in low concentrations in vinegar (generally 5-8%), it can still be an eye and skin irritant, especially when used in large volumes. In order to protect against possible spills or splashing when working with vinegar, the group will wear gloves and eye protection at all times when handling the vinegar. Since the vinegar will need to be poured from the second floor lab, the first floor machine shop area around the column should be cleared prior to pouring any vinegar from the second floor.

In order to minimize acetic acid fumes released into the building, the group proposes to recap the column after pouring the vinegar into the column. From this cap a small tube will run out to the window in the 2nd floor lab (similar to the solution used by the

distillation column group). This will route any fumes from the column out to the atmosphere, where they can disseminate harmlessly.

To dispose of the vinegar, the group plans to simply drain the column through the existing network of pipes into the sewer system. Before doing this, the group will check with the health and safety coordinator on campus to check the acceptability of such an option. In addition, the water drainage pipe leading to the sewer will also be turned on to help further lower the concentration of acetic acid going into the sewer system.

If a spill were to occur, the group will have baking soda on hand to neutralize the acetic acid from the vinegar. In case of an emergency, the group will review chemical safety procedures and locate the nearest eyewash station to the 2nd floor lab.

Appendix E. CO₂ Calculations

$$.00145 \frac{g}{mL} \text{ CO}_2 \text{ in water} * 1000 \frac{mg}{g} * 1000 \frac{mL}{L} = 1450 \frac{mg}{L} \text{ CO}_2 \text{ maximum in water}$$

$$\text{For actual solubility of 75\% } .75 * 1450 \text{ ppm} = 1088 \text{ ppm}$$

$$218 \text{ mg of CaCO}_3 \text{ in 1 L H}_2\text{O} * 44 \frac{g}{mol} \text{ CO}_2 * 1 \text{ mol CaCO}_3 \frac{1}{100 \text{ g}} = 95.92 \text{ ppm CO}_2 \text{ in water}$$

$$1088 \text{ max ppm in water} - 95.92 \text{ ppm already in water} = 992 \text{ ppm transfer from air to water}$$

$$1 \text{ gpm water flow} = 3.79 \frac{L}{min} * 99 \frac{mg}{L} = 375.2 \frac{mg}{min}$$

$$375.2 \frac{mg}{min} \frac{CO_2}{1000 \text{ mg}} * \frac{1 \text{ mol}}{44 \text{ g}} = .0085 \frac{mol}{min} \text{ CO}_2$$

$$.0085 \frac{mol}{min} * 22.4 \text{ L} = .191 \frac{L}{min @ STP}$$

$$@ \text{ average pressure of 400 psi } P_1 V_1 = P_2 V_2$$

$$14.7 \text{ psi} * .191 \text{ L} = 400 \text{ psi} * V_2$$

$$V_2 = .00702 \frac{\text{L}}{\text{min}}$$

$$\frac{.591 \text{ L canister}}{.00702 \frac{\text{L}}{\text{min}}} = 84.2 \text{ min for one canister}$$

Appendix F. Langelier Saturation Index Sample Calculation

$$LSI = f\{ [Ca^{2+}], [Mg^{2+}], [HCO_3^-], pH, T(^{\circ}C), TDS \}$$

Where $[X] \rightarrow$ concentration of X radical in water in ppm

pH \rightarrow pH of water at that Temperature

T \rightarrow Temperature of water in $^{\circ}C$

TDS \rightarrow Total dissolved solids in water in ppm

If $LSI > 0$, Scaling will occur

If $LSI < 0$, No scaling will form

Calculations done Using Online Calculator at:

<http://www.lenntech.com/calculators/langelier/index/langelier.htm>

Example: Using Water Quality information from SAWS website about average characteristics of San Antonio Water.

$[Ca^{2+}] = 76.6$ ppm

pH = 7.7

$[Mg^{2+}] = 16.5$ ppm

T = 20 $^{\circ}C$

$[HCO_3^-] = 218$ ppm

TDS = 309 ppm

Calculated LSI = 0.22

> 0, therefore Scaling will form.

Water softening salt replaces Ca^{2+} ion, so manipulating $[Ca^{2+}]$ to reduce LSI,

LSI closest ≤ 0 , when $Ca^{2+} = 45.8$ ppm

Appendix G: Work Breakdown Structure and Schedule Gantt Chart

WBS

- 1. Project Work
 - 1.1. Initiating the Project
 - 1.1.1. Problem Statement
 - 1.1.1.1. Library Research
 - 1.1.1.2. Brainstorming
 - 1.1.1.3. Writing/Editing
 - 1.1.2. Charter
 - 1.1.2.1. Review DocSpec
 - 1.1.2.2. Define Scope
 - 1.1.2.3. Define Requirements
 - 1.1.2.4. Writing/Editing of Charter
 - 1.1.3. Problem Description Presentation
 - 1.2. Initial Design
 - 1.2.1. Literature Review / Investigation
 - 1.2.2. Brainstorming Approaches
 - 1.2.3. Analyzing/Testing Potential Approaches
 - 1.2.4. Consultation with Experts
 - 1.2.5. Design Development
 - 1.2.5.1. Specifying Function
 - 1.2.5.2. Choosing Parts
 - 1.2.6. Documentation
 - 1.2.6.1. Design Matrix
 - 1.2.6.2. Design Review Presentation
 - 1.2.6.3. Design Report
 - 1.3. Proof of Concept
 - 1.3.1. Ordering Parts
 - 1.3.1.1. Blower
 - 1.3.1.2. Decibel Meter
 - 1.3.2. Construction
 - 1.3.2.1. Water Softening Kit
 - 1.3.2.2. Ventilation
 - 1.3.3. Testing/Evaluation
 - 1.3.3.1. Anemometer Test
 - 1.3.3.2. Water Softening Test
 - 1.3.3.3. Blower On/Off Test
 - 1.3.4. Documentation
 - 1.3.4.1. Safety Contingency Plan
 - 1.3.5. Notification of Concerning Parties
 - 1.3.5.1. Manuel Garza
 - 1.3.5.2. Dr. Terrell
 - 1.3.5.3. Harold Lovejoy, Director of Environmental Safety
 - 1.4. Final Design
 - 1.4.1. Specifying Functionality
 - 1.4.2. Ordering Parts
 - 1.4.2.1. Gauges
 - 1.4.2.2. Blower
 - 1.4.2.3. Water Softening Salt
 - 1.4.2.4. Ventilation System
 - 1.4.2.5. CO₂ Canister
 - 1.4.2.6. Pressure Regulator
 - 1.4.2.7. Gas Detection Kit
 - 1.4.3. Construction
 - 1.4.3.1. Thermocouples
 - 1.4.3.2. Blower Stand
 - 1.4.3.3. Water Softening System
 - 1.4.3.4. Replacing parts
 - 1.4.3.4.1. Blower
 - 1.4.3.4.2. Gauges
 - 1.4.3.5. Board for Gauges
 - 1.4.4. Testing/Evaluation

- 1.4.4.1. Blower
 - 1.4.4.2. Gauges
 - 1.4.4.3. Water Softening System
 - 1.4.4.4. Complete System
 - 1.4.4.5. Solubility Test
 - 1.4.5. Documentation
 - 1.4.5.1. Bill of Materials
 - 1.4.5.2. Assemblies
 - 1.4.5.3. Final Report
 - 1.4.5.4. Final Presentation
 - 1.5. Closeout
 - 1.5.1. Cleanup of area/project
 - 1.5.2. Clearance Form
2. Administrative
- 2.1. Planning
 - 2.1.1. Work Breakdown Structure
 - 2.1.2. Schedule
 - 2.1.3. Budget
 - 2.1.4. Project Plan
 - 2.1.5. Writing/Editing
- 2.2. Project Management
- 2.2.1. Monthly Management Reviews
 - 2.2.2. One-on-Ones w/Dr Nickels
- 2.3. Self-Peer Evaluations
- 2.4. Group Meetings
- 2.5. Executive Summary
3. Course Content (Non-Project)
- 3.1. Reading
 - 3.2. Studying
 - 3.3. Homework/Quizzes
 - 3.4. In-Class time

Name		Begin date	End date
---Contact Dept. Head		12/7/09	12/8/09
Anemometer Test		12/9/09	12/10/09
Pressure Calculations w/ Ventilation		12/9/09	12/10/09
Choose New Blower/Find Decibel Level		12/9/09	12/10/09
Go Over Blower w/ Alexander		12/10/09	12/11/09
Order Gauges/Flow Meters		12/10/09	12/16/09
Order Blower		12/11/09	12/16/09
Purchase Softening Salt		12/16/09	12/17/09
Research Regulator		12/16/09	1/13/10
Research Packing Material for GC		12/16/09	1/13/10
Purchase Regulator		1/14/10	1/16/10
Purchase Packing Material		1/14/10	1/16/10
Purchase CO2 Canister		1/14/10	1/16/10
Put New Budget Together		1/14/10	1/16/10
Construct Thermocouples		1/14/10	1/22/10
Construct Water Softening System		1/15/10	1/22/10
Disconnect Water Flow Meter		1/22/10	1/23/10
Replace Gauges/Flow Meters		1/22/10	1/26/10
Connect Thermocouples		1/22/10	1/26/10
Construct Blower Stand		1/25/10	2/9/10
Put Together Revised Plan		2/2/10	2/3/10
Replace Blower		2/9/10	2/16/10
Come Up w/ Testing Plans		2/9/10	2/13/10
Work On Presentations		2/12/10	2/16/10
Test Water Softening Canister		2/16/10	2/20/10
Test New Blower/Gauges/Flow Meters		2/16/10	2/20/10
Test Thermocouple System		2/16/10	2/20/10
Connect Regulator		2/22/10	2/23/10
Connect CO2 Canister/Test Regulator		2/23/10	2/25/10
Test Entire System		2/25/10	2/27/10
Correct GC w/ Packing Material		3/1/10	3/3/10
Run Sample Through GC/Solubility Test		3/3/10	3/6/10
Address Any Open Issues		3/8/10	3/27/10
Work On Final Report Draft		3/29/10	4/13/10
Work On Final Presentation		4/15/10	4/22/10
Revise Final Report		4/22/10	4/27/10

Appendix H. Gas Absorption Instruction Manual

1. Before running the water down the column or starting the blower, check all valves to ensure that they are closed. On the white board next to the column, there are 2 flow meters, one for the air flow and one for the water flow, both of which are shown in Figure 14.
2. Turn the valve directly beneath the water flow meter all the way to the right (clockwise).



Figure 14. Air (left) & Water (right) Flow Meters.

Next is the pressure regulator, which is mounted on the machine shop wall to the left of the gas absorption column. There is a small valve situated on the left hand

side of the regulator (which has 2 pressure gauges attached to it), which is shown in Figure 15.



Figure 15. Rotate Encircled Valve Clockwise.

3. Rotate the pressure regulator valve all the way to the right (clockwise). Do not confuse this valve with the larger valve sticking out from the regulator, which is used to adjust the pressure.
4. Finally, ensure that the O-ring is situated firmly within the ASA adapter, which is a black piece of metal attached to the pressure regulator. The ASA adapter, along with the O-ring, can be seen in Figure 16.

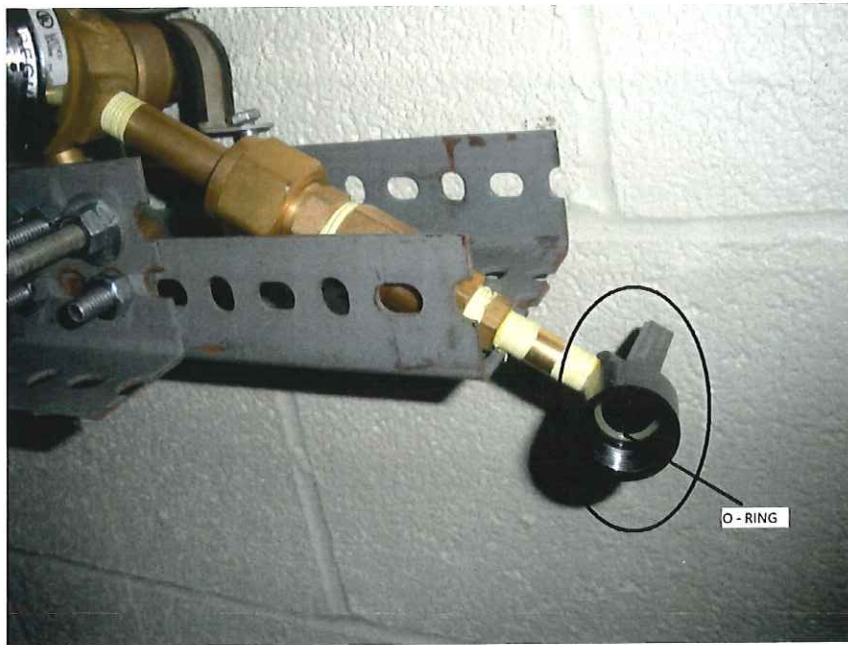
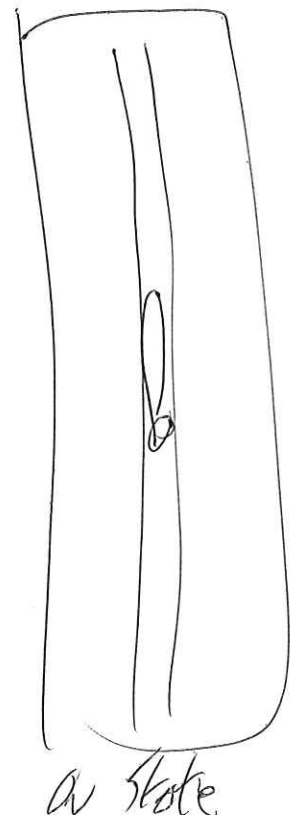


Figure 16. ASA Adapter (Encircled) + O-Ring.

5. Now that all of the safety precautions have been covered, the experiment can begin. The first objective is allow water to flow down the column. To do this, flip the blue lever, situated in between the distillation column and the machine shop doors, up by 90°. The lever is shown in Figure 17.



Figure 17. Water Lever (Off-State).



6. Immediately after the water lever has been flipped on, the valve situated directly beneath the water flow meter should be turned SLOWLY to the left (counter-clockwise) until the water flow meter shows a reading in between 0.5 to 0.7 gallons per minute. The reading is made based on the bottom of the piece of metal in the meter, as shown in Figure 18.



Figure 18. Water Flow Meter.

7. Next, turn the blower on. This is a very simple process, and can be achieved by flipping the safety switch, located above and behind the blower, into the 'ON' position. This process can be seen in Figure 19. Now go to the white gauge board and take a reading from the air flow meter; it should be approximately 20 cubic feet per minute (based on the bottom of the metal piece in the meter).



Figure 19. Blower Switch.

8. This step is crucial and involves only analyzing the process occurring inside the gas absorption column, focusing ones attention mainly on the top of the column. If it appears that the water is beginning to build up, and is not flowing evenly down the column (this process is called flooding), immediately rotate the water flow meter valve to the right, which will decrease the water flow. One can also rotate the air flow meter valve to the right, which will decrease the air flow, and will also stop flooding from occurring. At an air flow of 20 cfm and a water flow between 0.5 and 0.7 gpm, flooding should not occur. However, this step should always be followed to ensure the safety of the individuals operating the column.
9. Once it has been ensured that flooding is not occurring, rotate the chemical valve all the way to the left, or counter-clockwise. This valve is located on the bottom left hand corner of the white gauge board, and is shown in Figure 20.

↓ of either?



Figure 20. Gas Valve.

10. Next, attach the CO₂ canister to the pressure regulator. To do so, connect the canister to the ASA adapter, which is situated to the right of the regulator, as previously shown in Figure 15. Any testing must now be done within 7 minutes. After 7 minutes, the regulator pressure will begin to fluctuate, which will cause errors in the concentration measurements taken. From this point on, keep an eye on the regulator pressure to ensure it is constant.
11. Next, rotate the small valve on the left of the regulator to the left (counter-clockwise), which will allow CO₂ to flow from the canister into the column. The left hand pressure gauge, situated on top of the regulator, reads the outlet pressure, and should be set at approximately 25 kPa to ensure that the canister is not exhausted before any measurements can be made on the column. If the pressure

reading is over 25 kPa, rotate the large knob on the front of the regulator to the left until the pressure reaches approximately 25 kPa. This process is simply reversed if the outlet pressure is below 25 kPa.

12. Now pressure readings can be taken. All of the pressure gauges are on the upper left side of the white gauge board, with the air inlet/outlet pressure gauges being situated directly above the larger water inlet/outlet pressure gauges. These gauges can be seen in Figure 21. The air outlet pressure gauge should output a reading of approximately 0 inches of water, while the air inlet pressure gauge should be approximately 25 inches of water; these values will vary based on the ventilation system attached to the column. The water inlet/outlet pressures should be extremely small, on the order of 0-1 psi.



Figure 21. Air/Water Inlet/Outlet Pressure Gauges.

13. Finally, the concentration of CO₂ in the inlet and outlet air streams can be measured. To do so, the user will require the gas detection pump and 2 gas detection tubes, both of which are shown in Figure 22.



Figure 22. Gas Detection Pump (Above) & Gas Detection Tube (Below).

14. Using these tubes is not a difficult process, but does involve a couple steps. First, both tips of the gas detection tube must be broken off. To do so, place the tube in the small hole situated on the top of the pump, as shown in Figure 23. Gently push the tube to the left until the glass tip snaps off. Once the tip has been broken off, dispose of the glass tips in the trash. Be careful not to get cut on the edge of the tube. They are sharp!



Figure 23. Hole In Which Ends of Gas Detection Tubes Are Broken.

15. Next, SOFTLY push the tube into the opening on the top of the pump, with the concentration values increasing in the direction of the pump, as shown in Figure 24.



Figure 24. Tube + Pump Ready For Sample.

16. Ensure that the red circle situated near the handle of the pump is aligned with the '100' on the lever. Finally, while the pump is in front of the sample stream, slowly pull the handle out until it stops. After the handle has been pulled out, the pump can be removed from the sample stream. If somebody is not timing this procedure, the user can simply look on the top of the handle; once 2 minutes has elapsed, a small glass ball will turn white.
17. To take measurements from the inlet flow, the user must rotate the gate valve located under the gas inlet temperature gauge, which is behind the column, all the way to the left (counter-clockwise). When the user is finished testing the inlet air stream, the gate valve should be closed. This process is shown in Figure 25.

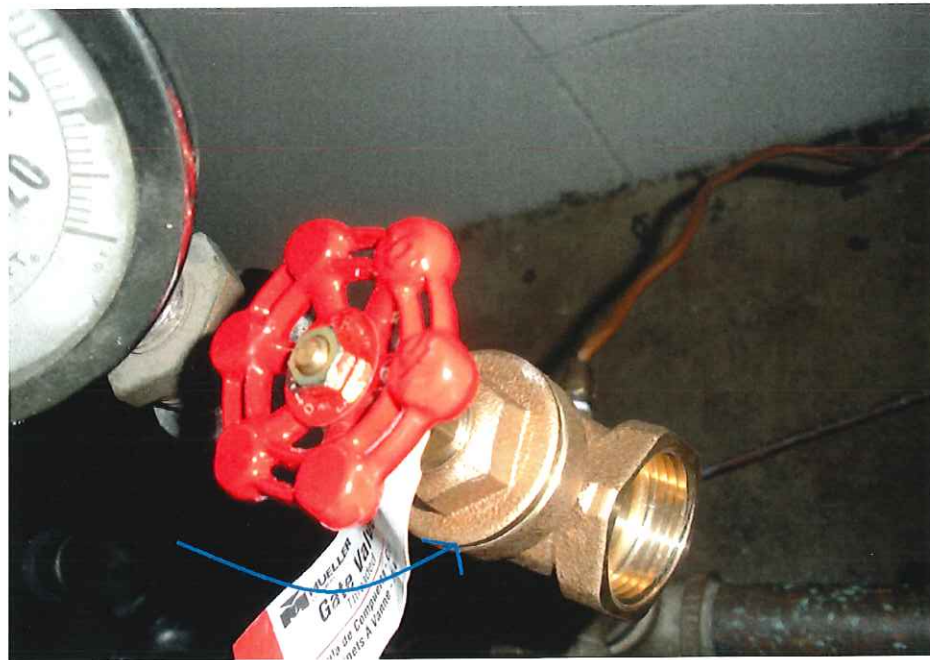


Figure 25. Gate Valve At Inlet Air Stream.

18. The outlet flow measurements can be taken at the top of the column, located on the 2nd floor of Moody in the Heat Transfer/Fluids lab. The plastic tubing acting as the ventilation system can simply be detached from the column, and one can take measurements from the resulting air flow out of the column. If the ventilation system is not attached, the measurements are taken in the same position; the gas outlet temperature gauge is connected to a T-connection. The

bottom of the T-connection is vented into the Heat Transfer/Fluids laboratory, as shown in Figure 26. Take measurements at this opening.

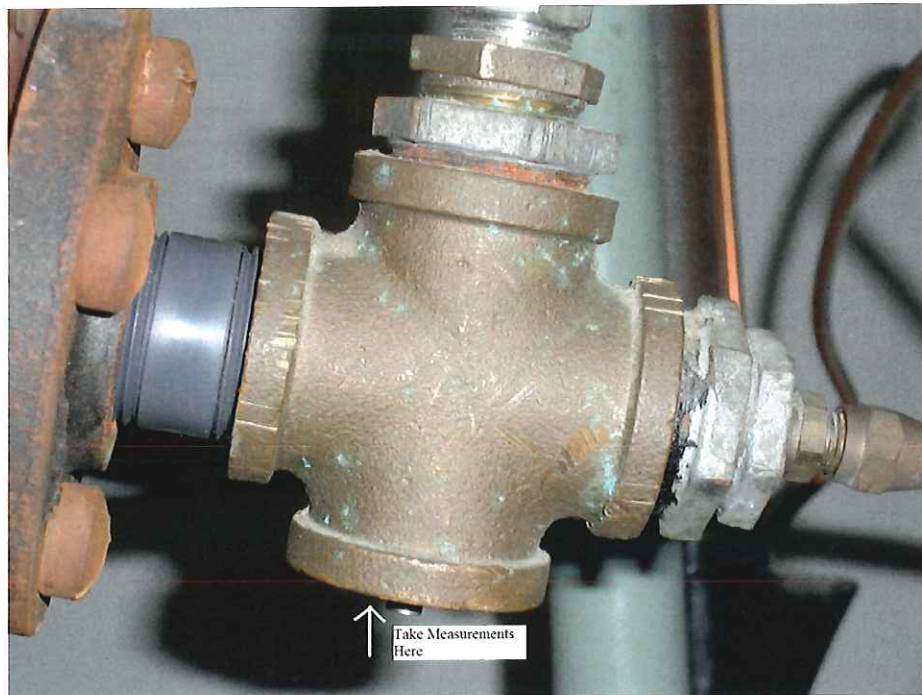


Figure 26. Outlet Measurements Taken Here.

19. Disconnect the CO₂ canister. Allow any CO₂ that is still in the piping to blow out of the ASA Adapter.
20. Flip the blower switch into the 'OFF' position.
21. Flip the blue water lever down, shutting off the water flow to the column.
22. Rotate the water flow meter valve (located directly below the water flow meter) all the way to the right (clockwise).
23. Rotate the valve attached to the left side of the pressure regulator all the way to the right. Due to the cold temperatures of CO₂, rotating this valve may be difficult at first. Give it a few minutes to thaw, and then rotate the valve closed. DO NOT force the valve closed.