A Supplemental Lab Project to Reinforce Physical/Chemical Processes in an Environmental Engineering Course

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Abstract

No matter what their learning style students at Rose-Hulman appreciate hands-on experiences to reinforce principles taught in the classroom. Over the past several years a supplemental lab project has been developed to reinforce several topics covered in our "Unit Operations of Environmental Engineering" course. This course is an elective course offered by the Chemical Engineering Department to students who want a background in environmental engineering. The topics covered include sedimentation, filtration(including micro and ultrafiltration), adsorption, ion exchange, and membrane separations. A laboratory project has been developed to make drinking water out of raw sewage using sedimentation, granular filtration, carbon adsorption, deionization, ultrafiltration and chlorination. The project has had a natural appeal because students easily relate to raw sewage and drinking water. The purification process was constructed using Plexiglass® cylinders, Tygon® tubing, peristaltic pumps and permanently mounted on a 4 ft by 8 ft plywood panel. Water samples are taken after each unit operation and the following tests performed: Suspended Solids(SS), Total Solids(TS), Conductivity, pH, Chemical Oxygen Demand(COD) and Fecal Coliform Bacteria. In addition students visually examine the samples for clarity and odor. The lab time required by each student is about 5 hours. The above tests reinforce the principles presented in class and demonstrate to students that each unit operation does indeed work as theory predicts. The results of two student reports are presented and discussed. As the professor I normally take a sample of the purified water, make a cup of coffee and rather dramatically savor the beverage to make the final point--it does work. At homecoming students who have graduated return and talk about the class where they made drinking water from raw sewage. This is probably the best testimony to the effectiveness of the project.

Introduction

Some 20 years ago the Chemical Engineering department at Rose-Hulman introduced two elective courses covering environmental issues: an air pollution course and a water pollution course. The water pollution course was a survey course introducing students to the terminology involved cleaning up polluted water, a summary of significant legislation and an introduction to biological, chemical and physical treatment processes. The course has evolved over the years as most courses do and now covers mainly physical/chemical treatment processes because biological treatment processes are covered in another course. A survey of significant legislation and the unique terminology used in wastewater treatment is still covered. Some years ago I mentioned in class that using these physical/chemical treatment processes we could take municipal sewage and make drinking water. One student suggested we build a lab scale unit and use it to make high quality water from sewage and use the water to make coffee or tea for the annual open house. Using a 4 by 8 sheet of plywood we built the unit shown below in Figure 1.

Figure 1. Photograph of the Treatment Process

The treatment consists of the following unit operations: sedimentation, granular filtration, activated carbon adsorption, ion exchange, ultrafiltration and chlorination. I found the students probably learned more about cleaning up polluted water by doing this lab project than from the theory presented in the classroom. This is not surprising since engineers have always learned by doing. We did actually make and serve coffee that first year(I was younger and more naïve in those days) but haven't served the purified water to others since then due to legal considerations and the remote chance of contamination introduced in variety of ways. After the open house experience that first year I realized the unit could be used as a supplemental teaching tool. The next year I had the students make water of drinking water quality from municipal sewage and had them run several analyses after each unit operation then write a report explaining and discussing what pollutants were removed by each operation. Since then the class has been offered once each year and typically has an enrollment of 30 students. I divide them into groups of 3 with each group taking data on 3 of the 6 possible samples. The data taken by each group is collected, collated and distributed to all the groups for writing their reports. This provides sufficient data without each group having to spend an undo amount of time in the lab since the project is an additional workload. Each group spends approximately 12 hours collecting samples, performing the analysis and writing the report. This amounts to an additional 4 hours per student. A detailed description of the project is given in the following section.

Detailed Project Description

Domestic sewage is obtained from the preaeration chamber of the local wastewater treatment plant. Each of the unit operations used to purify the water is described below.

Sedimentation

The raw sewage is characterized by running the following tests: COD(chemical oxygen demand), TS(total solids), SS(suspended solids), conductivity, pH, and fecal coliform bacteria. All tests are run using methods approved by Standard Methods for the Examination of Water and Wastewater published by the American Public Health Association. COD is run using Hach Company COD vials that use 2 ml samples. A handout has been prepared and distributed describing the procedure for running each test. All the equipment needed for doing the tests is provided in one of our labs. Sedimentation is normally the first unit operation used in most wastewater treatment plants to lower the SS level and this unit operation is covered in class. The sedimentation column used was assembled from a 6 inch plexiglass column 4 feet in length. This plexiglass tube was used because it was available in the chemical engineering stockroom. The feed enters at a point 1 feet above the bottom of the column. The overflow is taken approximately 5 inches below the surface to eliminate any floating material from passing on to the filtration operation. The feed rate into the column is normally set between 200 and 250 ml/min. This provides approximately an 80 minute residence time for sedimentation. No underflow is removed. A close-up of the sedimentation column is shown below in Figure 2. Sedimentation removes approximately 50% of the SS and a corresponding amount of TS. As expected the other analyses do not change. A significant part of the project is a written report describing and explaining the results. Each sample taken and analyzed provides the students opportunity to think about what they expect the results to be and what the analyses actually are. In the case of sedimentation, 50% removal of SS is not particularly good but it gives students the opportunity to discuss and explain the results, critique the particular column used and suggest any changes that would improve the SS removal efficiency.

Granular Filtration

The next unit operation used is granular filtration. Peristaltic pumps mounted behind the plywood panel pump the sedimentation overflow to the granular filtration step. This type of pump allows the flow rate to be accurately controlled. A plexiglass tube 4 inches in diameter and 4 feet tall was used as shown in Figure 1. Filter media were added as follows: 4 inches of 1 inch limestone, 6 inches of 0.5 inch limestone, 4 inches of 10 mesh sand and finally 4 inches of 20 mesh sand. The sand and rock were obtained from the Civil Engineering department and were used because they were available. The granular filter media were added in a reverse order so the water to be treated contacts the 20 mesh sand first. This filtration step is effective in removing about half of the remaining SS and a small amount of the COD. The setup works well until about 10 gallons of sewage is treated then the SS which collects on top of the sand causes a greater pressure drop than the system can handle. At this point no more sewage can be treated until the bed is backwashed. This particular granular filtration setup is not a particularly efficient one, but this setup provides students an opportunity to suggest ways of improving this purification step.

Activated Carbon Adsorption

The peristaltic pumps are used to pump the effluent from the granular filtration to the activated carbon adsorption column. Some 500 grams of Calgon F-400 granular activated carbon are added to the plexiglass column(4 inch diameter by 4 feet tall). The granular activated carbon is nominally 12 mesh in size. This operation removes about half of the remaining SS and removes a significant amount of the COD. The effluent is clear after this operation as seen in Figure 3. Two analyses don't significantly change: conductivity and coliform bacteria. This is as expected since activated carbon tends to remove nonionic molecules and conductivity is essentially due to the dissolved salts. Students are impressed that although the water looks very good at this point it is still loaded with bacteria. After about 6 gallons of water are treated the COD level in the water leaving the activated carbon column begins to rise significantly. This is an interesting point for discussion in the final report.

Ion Exchange(Deionization)

After the activated carbon step the water could be treated by ultrafiltration to make an acceptable drinking water. However by adding a deionization step the students can see the conductivity and TS drop to almost zero. The deionization column was purchased from VWR Scientific Corp(Barnstead D8902). The coliform bacteria level drops a small amount through the deionization column, but the water still has a very high level of coliform bacteria. This shows the students that water with almost everything removed and which looks very clear is still unacceptable for drinking. A mixed bed deionization column is purchased and discarded after each years use. An added benefit to having an ion exchange operation is that the exhaustion of the bed can be seen clearly by observing the color change in the resin. This cannot be observed visually in the carbon adsorption step. In addition as the color of the bed turns from purple to brown various color bands of shades of brown can be observed moving up the column. This reinforces the theory covered in class that ions are exchanged based on size and charge. Figure 2 shows these color bands. The sedimentation column, the granular filtration column and the activated adsorption column are also shown in Figure 2.

Ultrafiltration

A peristaltic pump is used to pump the water from the deionization bed to the ultrafilter. A rotameter and a surge tank were placed between the deionization column and the ultrafilter as seen in Figure 1. The rotameter was placed in the system to monitor the flow rate. Over the years various ultrafilters have been purchased and used. The main problem is the high pressure drops experienced after some 3 or 4 gallons of water are treated. All ultrafilters used have had a nominal pore size of 0.45 microns. After the ultrafiltration step the coliform bacteria analysis drops to essentially zero unless the filter experiences a breakthrough at some point. Sometimes the coliform bacteria level of the final water is not zero because the students are not always careful to clean the beakers, pipettes and syringes used in the analysis. Considering this is the first time some of the students have run any type of bacterial analysis this is an expected result. It does however point out the benefit of chlorination as a final step. It is pointed out to the students that just running one type of bacterial analysis doe not guarantee the absence of other types of bacteria. Coliform bacterial analysis is used as the bacterial determination because it is an easy analysis to perform. During the spring of 1998 Chas. Pfizer and Co. donated an ultrafilter and two cartridges used in their Terre Haute penicillin manufacturing facility. This filter is oversized for the other operations.

Figure 2. Photograph Showing Ion Exchange Color Bands

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Examples of Student Results

The Tables shown below give results from groups doing the project during the Spring quarter of the 1996 and the 1998 academic years. The picture in Figure 3 shows qualitatively the effect of each unit operation. The beakers are numbered the same as the samples in the Tables below.

Sample 1: Raw wastewater
Sample 2: After sedimentation
Sample 3: After granular filtration
Sample 4: After carbon adsorption
Sample 5: After deionization
Sample 6: After ultrafiltration

These results are typical of other classes. Samples are normally taken after treating 3 gallons, 6 gallons, 9 gallons and 12 gallons of sewage. This provides results showing the effect of the amount of wastewater treated. All data taken are shared with all groups for use in writing the final report. The data presented below are the average of 2 groups. In every class at least one group takes data that shows obvious errors. This is expected since in every class some students have never run any of these analyses before except pH and conductivity.

Figure 3. Visual Display of Treated Water

Table 1. Results from Spring Quarter 1996(6 gallons treated)

Sample	TS ppm	SS ppm	COD ppm	pH	Conductivity	Coliform Bacteria no/100 ml
1	960	100	190	7.6	1410	900,000
2	950	50	200	7.5	1440	800,000
3	870	22	70	7.3	1380	100,000
4	890	6	45	7.6	1460	300,000
5	8	0	0	6.1	6	60,000
6	-	-	-	6.3	-	<8

Table 2. Results from Spring Quarter 1998(3 gallons treated)

Sample	TS ppm	SS ppm	COD ppm	pH	Conductivity	Coliform Bacteria no/100 ml
1	1010	91	160	7.9	1450	1,000,000
2	960	48	140	7.6	1500	1,000,000
3	940	22	155	7.3	1440	failed test
4	815	14	65	6.9	1430	500,000
5	3	0	0	7.2	2	100,000
6	-	-	-	8.0	6	1200

A dash in the above Tables indicate no analyses were run. Samples for coliform bacteria were diluted but still the level was so high in samples 1-5 as to make anything beyond one significant figure questionable. The ultrafilter cartridge used in the spring of 1998 had some obvious problems and reinforced to the students that very good looking water could be contaminated.

The results normally show that sedimentation works about as well as expected given the residence time and the size of the suspended solids. Visually there is still significant haze in the water after granular filtration which indicates some very small suspended particles. Most students conclude that the carbon adsorption doesn't work as well as they expected, but upon further analysis they realize the contact time is only about 15 minutes which is not much for most granular activated carbons. They also realize that there are probably other carbons available that would be more efficient. The results also show that the ion exchange resin is effective in removing the remainder of the COD which provides an interesting discussion topic. Students who are perceptive realize that a significant part of the TS are dissolved inorganics, probably salts from the hardness in the original water.

Conclusions

Although we don't actually make coffee from the purified water, students consistently comment on the course evaluation forms that they feel they have learned much more about purifying polluted water and about the unit operations of sedimentation, granular filtration, carbon adsorption, ion exchange and ultrafiltration from doing this supplemental lab project than from the classroom material. As the professor I still chlorinate the water using sodium hypochlorite and make my morning decaf which seems to give the students a chuckle. Students certainly feel the 4-5 additional hours required has a good cost/benefit ratio. We don't get into the economics of this purification process but we do take some class time to discuss the pros and cons of using this process on a large scale.

Construction Information

Dimensions and materials specifications for each of the treatment operations have been listed above. Photographs showing additional construction details can be obtained from the author by e-mailing him at jerry.caskey@rose-hulman.edu. Flow between each treatment operation was controlled by 3 peristaltic pumps that have the capability of 2 flow channels per pump. These pumps were government surplus pumps, but Masterflex® pumps sold by Cole-Parmer would be appropriate. One advantage in using peristaltic pumps is they are positive displacement pumps and within broad pressure drop limits give a constant flow rate. We found the flow rate was easily controlled. A rotameter was mounted on the board to indicate the flow rate did stay constant throughout an entire run(see Figure 1).

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