Home Chemistry as a Tool for Understanding Environmental Chemistry

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Abstract *- Environmental chemistry focuses on understand ing the chemistry of natural water sources and water treatment, including concepts such as alkalinity, pH, and water hardness. It also includes atmospheric chemistry and organic chemistry related to the environment. Common experimental practices in environ mental chemistry courses are conducted in laboratories following specific guidebooks. Many times students have to use chemicals and equipment they hardly have any access to outside the laboratory. Additionally, some schools, specially in developing countri es, do not have enough equipment or chemicals for everyone in the classroom and students are obligated to work in large groups, where some students end up "watching" the practice instead of conducting it. The objective of this paper is to describe innovat ive environmental chemistry experimental practices that were developed in at the University of los Andes, to increase student's ability to design and conduct experiments, encourage students to be creative and make decisions, and to work in teams, according to ABET Accreditation Criteria (200 4-05) . These practices are conducted by students in their homes using "stuff" they can obtain from a supermarket. The guidebook for this course was designed such that students would have the main instructions on how to conduct the experiments but would be encouraged to find the proper conditions for the experiment to work properly and investigate other "stuff" they think could be interesting for understanding the topic. Practices include, among others, pH measurement, development of alkalinity curve s, and measuring of water hardness,. Acceptance by students has been good and practices have shown to provide students with a good understanding of the topic s. Some practices are also conducted at the university's laborator ies utilizing the necessary equipment and chemicals to give students the opportunity to see how those experiments are conducted in a professional environment . Practices were started during the fall 2003 and are still being conducted as part of the environmenta l chemistry course.*

Index Terms *— Environmental chemistry, experimental design „ home experimental practices,*

INTRODUCTION

Environmental engineering, especially in developing countries, is a new academic field. Engineering schools in Latin America have recently started offering environmental engineering as a major and many of these programs have not yet reached a point of economic equilibrium and are still working with lesser capital in terms of faculty and infrastructure than those in Europe and the US. Most environmental engineering programs require students to take many laboratory courses for the completion of their degree. Given of the lack of infrastructure, students are required to work in large groups and they end up "watching" the laboratory practice instead of conducting it.

The environmental chemistry course can be one of the most important courses for students pursuing a B.S. degree in environmental engineering. Many schools, such as M.I.T, The University of Wisconsin-Madison, Michigan State University, and Princeton University, have an environmental chemistry course as part of their environmental engineering undergraduate curriculum. Other schools, such as Stanford University and Georgia Institute of Technology do not have a specific environmental chemistry course, but offer courses such as water and soil chemistry, which are similar in content to part of the environmental chemistry courses taught at other schools. This environmental chemistry course, as well as many other chemistry courses taught to engineering students, has a profound need for complementary experimental laboratory practices.

Chemistry for Environmental Engineering

Many books that are basic to the environmental engineering area include sections on water chemistry, soil chemistry, the chemistry of organic contaminants, heavy metals and other compounds that are strongly related to the environment [1], [2], and [3]. This could be expected given the importance of those topics to processes such as water and wastewater treatment, air pollution control and pesticide incineration [3], [4].

There are many important concepts that are relevant to environmental engineers, including pH, water alkalinity, water hardness, oxidation-reduction, combustion and others. Some of these concepts are not very easy to understand and may require an experimental practice. The purpose of this paper is to describe innovative environmental chemistry experimental

practices that were developed at the University of los Andes, to increase student's ability to design and conduct experiments, to encourage students to be creative and to make decisions as well as working in teams, in agreement with ABET Accreditation Criteria (2004-05) [5].

LABORATORY PRACTICES

Traditional educational laboratory practices, especially those conducted in schools located in developing countries may have some problems associated to them. First of all, the equipment available for analysis purposes might not be enough for the large number of students in each class. Thus, students need to work in groups of four people or more. Given the lack of space in the laboratory during the practice, maybe only two or three students are able to use the available equipment and conduct the practice, while the rest of the group stands aside and watches what the others are doing. As a result, many of the students in the class do not get involved with the topics that are being studied, and at the end of the course have noticeable less knowledge on the subject than those students that did work during the practices consciously. A second problem that can be encountered in traditional laboratory practices is that they sometimes do not encourage students to discus topics, because all instructions are provided and students are just required to follow them. According to ABET Accreditation Criteria (2004-05) [5], engineering students should be able to design and conduct experiments, and to analyze and interpret data by the time they graduate from the program. Since traditional laboratory practices do not encourage students to design experiments, this kind of practices could not be totally consistent with this criterion. Traditionally, students taking courses that include experimental practices (chemistry, biology, and physics) are given laboratory "cookbooks" [6] where they can find all the instructions on how to conduct the experiments and what materials and equipment they need to conduct them [7]. On those booklets students can also find the background of the topic that will be studied during the practices and, in some cases, they can even find what to expect during the practices. Thus, students are not required to design or discuss the experiment.

For this reason, the Department of Civil and Environmental Engineering of the University of los Andes in Bogotá, Colombia, developed a set of experimental practices to be used as part of the environmental chemistry course. The purpose was to teach students some important concepts associated to environmental chemistry while they learned how to design their own experiments. These practices were conducted with materials and equipment students could buy at the local supermarket.

Environmental Chemistry Practices

The students received laboratory guides and a syllabus on the first day of classes. There were five laboratory practices that students should conduct at home throughout the semester, which included pH measurement, alkalinity curve, water hardness, oxidation and combustion. All other practices were conducted at the university's laboratory including an alkalinity curve, to give students the opportunity to compare the observations and results they obtained at home using everyday "stuff" with those obtained utilizing conventional laboratory equipment. This procedure was first implemented during the fall of 2003 and repeated during the spring of 2004.

The laboratory guides were written such that students could get the main idea on how to conduct the experiments while providing them with the freedom to choose the appropriate reactant amounts, concentrations, and "equipment" they could use. All practices were conducted in groups of two to four students. The practices that were conducted at home were as follows:

- **pH Measurement:** Students were asked to boil red cabbage in water and remove it from the heat after a couple of minutes. After removing the cabbage leafs from the water, students were asked to let it cool and place the solution in a container. Red cabbage water has a rare property, changing color depending on the pH. Students were required to fill some cups with white vinegar, lemon juice, bicarbonate, antacid pills (e.g. TUMS) diluted into a little water, clear soda (e.g. Sprite), or any other clear liquid they could think of that could be interesting for the experiment. They were asked to add a few drops of cabbage water to each glass and observe how the color changed, depending on the substance that was contained in the cup. During the class period, students were given a figure that showed the pH of different substances including some of the substances they were asked to investigate during the experiment. Based on that figure and what they observed during the practice at home they were asked to give each investigated substance an approximated pH value. For this experiment students were not given instructions on quantities or concentrations. They were asked to include other substances additional to the ones that were suggested in the guides, to obligate them to discuss some experimental design details with other students in the group.
- **Alkalinity Curve:** Students were asked to prepare a solution using water and antacid pills or any dietary supplement constituted mainly of calcium carbonate. Quantities of water and calcium carbonate were left to students to determine. Cabbage water was added to the container with the calcium carbonate solution to determine the approximated pH. Subsequently, students were required to add lemon juice or vinegar to the solution and observe the change in color.

Students were supposed to determine the vinegar volume to be added each time, depending on how they expected pH to change based on the theory they learned during class. This practice was also conducted in the university's laboratory utilizing calcium carbonate solution, chlorhidric acid, and a pH meter, a couple of weeks after conducting the home practice. Students were asked to compare the results obtained in the laboratory with those obtained at home.

- **Water Hardness:** A very important concept in environmental engineering is the hardness of water. What happens when water is hard and people add soap to it? What is meant by water hardness? To answer these questions students conducted an experimental practice at home utilizing antacid pills, water and soap. Students were asked to prepare a calcium carbonate and a soap solution and add soap solution to the calcium carbonate solution. Following, students were asked to add soap solution to water that did not contain antacid and compare results obtained during the two procedures. No directions were given on concentrations or quantities to be added and students were required to make decisions on that matter.
- **Oxidation:** Oxidation is one of the processes that can be observed through the everyday life. Rusted chains and bolts are common objects people are used to see but do not usually understand. The objective of this practice was to give students an understanding of the oxidation process. For this practice students were asked to place a steel bolt into a glass of water and another one in vinegar and leave them there for a week. They were asked to compare results obtained and indicate why they obtained different results. Students were also required to use a third substance (different form vinegar and water) and conduct the same procedure as with water and vinegar and compare results.
- **Combustion:** During the complete combustion of hydrocarbons, CO_2 and water vapor are produced. Students were required to collect gases produced while burning a candle. The students were asked to use a funnel, a hose, a glass and cabbage water to verify visually that the resulting gases could be CO_2 and water; for this purpose, students used two important concepts. When water vapor collected form the burning candle reaches the walls of a cold glass, it condenses forming water droplets. Furthermore, when CO_2 is collected though a funnel and conduced to a water container, CO_2 dissolves into the water and the pH changes. If the water in the container has cabbage water, it should change colors during the experiment. Figure 1 shows pictures of some of the results obtained by one group of students.

FIGURE. 1
PICTURE TAKEN BY STUDENT DURING LABORATORY

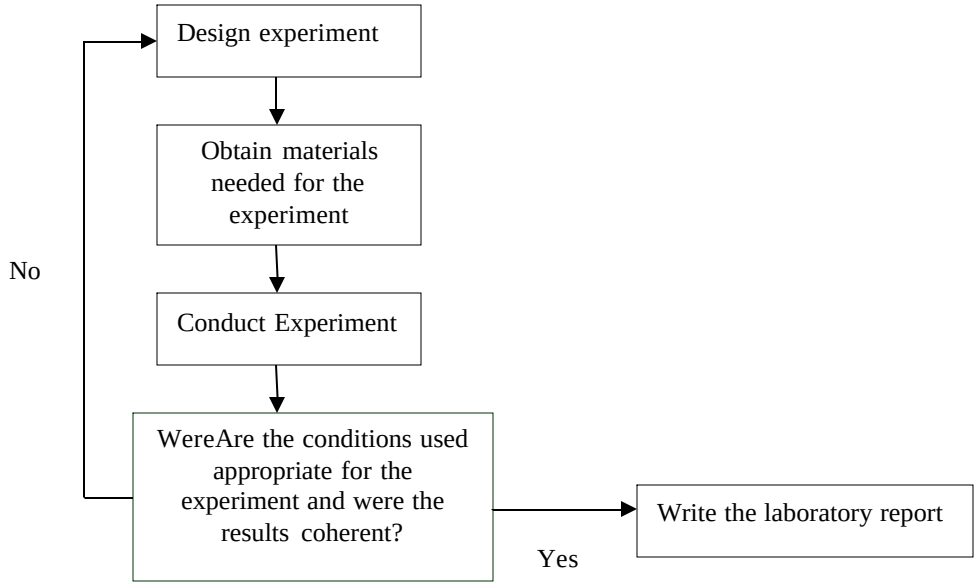
As it was explained, all the previously described experiments were conducted by the students at home. All the materials they used, which included cabbage, sodium bicarbonate, TUMS, plastic cups, a funnel, a hose, lemon juice, vinegar, a candle, etc., were easily obtained at a local supermarket. Students had the opportunity to see the chemistry of elements they see and use often at home. The purpose of asking students to work in teams was to encourage them to discuss experimental strategies and be able to design the experimental practice based on previous knowledge and the ideas that each student presents during the discussion.

RESULTS AND DISCUSION OF RESULTS

During the past year it was observed that this kind of experimental procedure may have many advantages compared to traditional experimental practices. Some of the advantages that were encountered associated to this specific educational tool are listed below:

- **Provides Students with the Ability to Design and to Conduct Experiments:** The design procedure during the practices was complex. First, students had to discuss the experimental strategy based on knowledge they acquired during the lecture and the directions given in the laboratory guide. Following the design phase, students conducted the experimental practice. Sometimes, during the practice, students noticed that the experimental conditions they selected were not appropriate for the practice and had to redesign and start over, until proper conditions were achieved. The experimental design process is showed in Figure 2.
- **Encourages Students to Do More than What They Were Asked To:** in some cases students did more than what they were required to. For example, during the pH measurement practices, some groups studied 10-20 more substances out of curiosity; they tried every shampoo, conditioner, soap, drink, food and detergent they found at home. During the oxidation practice, some students used five or more substances, instead of three, as they were asked to. This phenomenon shows that students are motivated by the practices, and motivation is very important during the learning process [8].
- **Helps Students to Understand the Studied Topic:** In many cases, during the design phase students were required to go to their notes and consult text books on the studied topic. During the practice, students were able to physically see changes (e.g. color changes), which helped them understand the chemical reaction occurring. In cases like this, improved understanding may occur [8].

FIGURE. 2
EXPERIMENTAL DESIGN PROCESS



The course survey conducted during the two semesters (fall 2003 and spring 2004) showed that most students enjoyed the home practices. Comments on the laboratory practices included "practices are pertinent, they are not too difficult and we can learn a lot", "practices are interesting and fun to do", and "I like the practices very much; I think it is great we can conduct them at home utilizing elements we commonly see, because this helps us see these topics closer to our everyday life".

Even though, in general, these practices were appropriate for the environmental chemistry course and the objectives were accomplished, it was found that this kind of experimental practices may have some disadvantages compared to traditional laboratory practices. Disadvantages include the following:

- **Professors Have No Control on the Teams:** Since students work at home, the professor has no control on student's

participation during the practice. In fact, as during many other group home works, it is common that one or two students in the team do not do any work and let their teammates do the whole work. This problem could be observed in some teams. In some cases, only one student conducted the whole practice, and the following practice was conducted by some other student in the group, and so on. During the evaluations, students that had actively participated during the experimental practices performed better than students that did not actively participate during the practices.

- **Safety Issues:** In some cases, students may use harmful substances for their experiments and the instructor cannot control whether students use the appropriate protective wear or work in spaces that are well ventilated.

To control the two problems listed previously it is recommended that a few changes are performed on the experimental procedure. First of all, the laboratory guide book should have a safety section explaining all dangers students could be exposed to while conducting the practices and what protective wear they should use during the experiments. Up to date, this section is not included in the laboratory guide book and this may lead to possible accidents.

To control the participation of students during the practices, it is recommended that some evaluation method different from the laboratory report is used. A quiz could be done after each laboratory report is handed in to ensure that each student participates during the conduction of the experimental practice.

This investigation can help other professors in thee field of engineering, by providing them with an idea that can be accommodated to teach engineering students how to design and conduct experiments.

CONCLUSIONS

As part of the environmental chemistry course, a set of home laboratory practices was designed at the University of los Andes. The main objective of these experimental practices was to provide students with a deeper knowledge in environmental chemistry while encouraging them to design and discuss experimental procedures and work in teams. To evaluate the effectiveness of this kind of experimental practices, students were asked to hand in laboratory reports. Course surveys were used to learn student's opinions on the practices. In general, course surveys showed that students enjoyed the practices and found them interesting and useful for understanding the studied topics. Students that actively participated during the practices showed a deep understanding on the studied topics. It is recommended that a few changes are performed on the laboratory guide book to include safety recommendations and that the evaluation method of the course is changed to encourage students to participate actively during the practices. In general, this kind on non-traditional experimental practices showed many advantages compared to traditional methods, in which they require that students design and conduct experimental practices, while encouraging team work (as recommended by the ABET (2004-05) Accreditation Criteria [5]). These practices may also encourage students to do more that what they were asked to, which is not easily done at the University's laboratory, and the fact that students had to design their own experiments helped them understand the topic better.

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