Environmental Sampling and Analysis: A Laboratory Course for 21st Century Environmental Engineers

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Abstract

Environmental engineering is evolving from a field primarily concerned with municipal water supply, wastewater treatment processes, and end-of-pipe treatment of industrial wastewater discharges to one in which pollution reduction must be evaluated at the process level. Our undergraduate curriculum includes a class on Environmental Sampling and Analysis. For many years, this class has remained essentially unchanged - a strong laboratory class devoted to learning the standard measurement techniques for the common constituents of concern in municipal drinking water and wastewater treatment. The emphasis on measurement techniques has been on manual, wet chemistry methods of analysis. Over the past several years, we have revised the class to (i) improve the students' understanding of the relationship between manufacturing processes and environmental protection, (ii) broaden the type of samples to include air and soil samples, and (iii) enhance the students' understanding of modern instrumental methods of environmental analysis.

To this end, each semester we have studied one to two manufacturing processes. The study of each process included identification of the pollutants of concern, analysis of the production and treatment of contaminants utilizing mass balances, equilibrium and kinetic concepts. Influent and effluent samples from key processes were collected and analyzed using state-of-the-art analytical techniques. Students then prepared interim and final project reports discussing their findings. A major emphasis was to force the students to synthesize the data from different analytical measurements to ensure internal consistency of their results. One of the additional goals of the course was to encourage active and cooperative learning concepts. All of the students worked in teams with rotating project managers. The project managers were responsible for organizing the teams' efforts and the overall quality of the report.

Introduction

A graduate from an environmental engineering program (or Civil Engineering with an environmental engineering emphasis) is expected to understand and utilize a wide range of analytical data. These data are used in analyzing whatever problem he or she is facing: designing a water or wastewater treatment plant, predicting the environmental consequences of a discharge, or contemplating process changes in an industrial setting. This ability to interpret data can be developed in a carefully constructed laboratory course in which the student gains exposure to a wide variety of environmental measurements. To this end, we have transformed our laboratory-based Environmental Sampling and Analysis course with the goal of modernizing it and incorporating the following three trends in environmental engineering:

- The approach to solving industrial environmental concerns now includes a far greater emphasis on process changes to minimize waste production;
- Environmental engineering is broadening, moving beyond the roots of the field in water (drinking water and municipal wastewater treatment) to air pollution control, solid waste engineering, hazardous waste control, and site remediation;
- Analytical measurements are becoming far more sophisticated, requiring lower detection limits and supplementing surrogate bulk measures of contamination (e.g., total organic carbon) with measurement and identification of individual compounds.

Description of the Previous Course

In order to understand the nature and significance of the changes made to our environmental sampling and analysis course, it is necessary to provide a brief description of our undergraduate curriculum and the previous course which served as the baseline for modifications. The curriculum in undergraduate civil engineering programs provides students with a general civil engineering background that meets ABET requirements. A student concentrating in environmental engineering generally takes one required introductory course and a small number of elective courses, such as water supply and wastewater engineering, groundwater hydrology, and hydraulics. CE370K, Environmental Sampling and Analysis has been a popular elective for students interested environmental engineering, especially those interested in water and wastewater. Environmental Sampling and Analysis is taken by seniors specializing in environmental engineering, most of whom have had at least one other environmental elective. The course, which had remained essentially unchanged for almost 20 years, can be described as a class in water chemistry with a major emphasis on the laboratory component.

The class meets twice per week, once for lecture (1.5 hours) and once for the laboratory (3 hours). At times, one or two air pollution laboratories were included, but in recent years, these were discontinued as equipment became outdated and could not be replaced. The laboratory exercises performed and associated equipment utilized for the past several years are shown in Table 1.

Samples and standards used in these laboratories usually included some that were made up in the laboratory from reagent chemicals to demonstrate quality control. Real samples varied with the experiment but were generally related to drinking water or wastewater treatment. For example, the hardness laboratory included influent and effluent samples from Austin's softening plant. The class lecture material has two components. First, the fundamental principles of water chemistry are taught. Topics include acid/base chemistry, solid/solution chemistry, gas/solution chemistry, and oxidation/reduction chemistry. Second, some time is spent preparing the students

Table 1. Synopsis of Laboratories Conducted Prior to 2001

Laboratory Exercise	Instrumentation Used
Solids analysis in water samples	Steam tables, ovens, balances
pH and alkalinity measurements	pH meters
Hardness (by titration)	Standard titration equipment
Conductivity measurements	Conductivity meters
Chemical Oxygen Demand	Test tube heating blocks; measurement by titration or spectroscopy
Biochemical Oxygen Demand	DO measurement by Winkler titration
Total Organic Carbon and Atomic Absorption (hands on demonstrations)	Total Organic Carbon Analyzer and Atomic Absorption Spectrophotometer
Tracer Analysis of various laboratory scale reactors	Laboratory scale continuous flow reactors; UV/VIS spectrophotometers
Jar tests for coagulation	6-place gang stirrers, pH meters
Total Coliform Analysis by filtration	Water filtration equipment; autoclave
Nitrite and Nitrate Analysis	UV/VIS spectrophotometer; cadmium reduction columns.
Chromatography (hands on demonstration)	Gas Chromatograph (Hewlett Packard 5890)

for the laboratory exercises, by explaining the laboratory procedures, equipment, principles of measurement, and quality control/quality assurance concerns.

Several aspects of the class have proven to be excellent and were retained. The class is intellectually rigorous and has received very high ratings from the students for three professors (co-PIs Katz, Lawler, and Speitel) in recent years. The class is divided into laboratory groups of three students, and each group performs its own experiment every week. Laboratory reports are extensive, and reinforce technical writing concepts learned in our required class in Technical Communication. These reports are done by student groups (i.e., one report for each group) and account for 50% of the grade. Students improve dramatically during the semester in their abilities to present, analyze, explain, question, and interpret laboratory data. These skills are vital because environmental engineers are always dependent on data that has been obtained by others, and experience with laboratory techniques is rare after students leave an academic setting.

Nevertheless, the class was in obvious need of updating. The choice of exercises reflected a narrow, outdated view of the field, as indicated above. Some of the current measurements were of diminished importance in the field, whereas others not performed are now much more important. The class, in short, was an excellent class for 1975, but not an excellent class for 2003.

The Revised Course

The updated course in environmental sampling and analysis contains several new elements, while maintaining the basic structure of the class. The course was revised in accordance with the three current trends in environmental engineering noted above: a strong industrial component to prepare students for new approaches to environmental engineering, an expansion of the type of measurements beyond drinking water and municipal wastewater samples, and more exacting analytical measurements. The changes in each of these three aspects of the class are explained below.

Industrial Component. Modern environmental engineers are expected to work closely with industry to reduce environmental contamination. This aspect of environmental engineering has been totally absent from our undergraduate curriculum, and the University of Texas is not different from many other universities in this regard. Our goal is to develop in the students the ability to analyze industrial processes from the point of view of an environmental engineer. Issues such as the utilization of raw materials; the possibilities for recycling waste streams; the ways in which pollution reduction might be possible (or has been attained); and the interaction of air, water, and solid waste are faced by all industries. Although details vary by industry, the approach to solving the environmental dilemmas raised by manufacturing processes is general. Our intent is to make the general clear by investigating the details of a few different industries.

Thus, the subject matter of the class includes a strong component of industrial process engineering throughout the semester. This subject matter is incorporated in three ways. First, two representative but different manufacturing industries are selected, and students are expected to read some literature about the production processes in these industries. Second, field trips are made to the two industries and are designed in coordination with the industry representatives to elucidate both the manufacturing process and the concomitant production of wastes. Third, samples from various process and waste streams (air, liquid, or solid waste) are obtained from the industries and analyzed in the laboratory.

We find that students in the class are far more motivated to learn now that they can place their work in context. To be asked to measure the concentration of some constituent in a sample that means nothing to you is simply an academic exercise with little apparent value. However, to obtain the sample oneself, or at least to know exactly where it comes from in a water treatment plant or an industrial process, is motivating. Our engineering students are not intrinsically motivated to know details of analytical methods, but they are motivated to obtain and use data in engineering situations. Bringing this class closer to how environmental engineers actually use analytical data in their professional lives has enhanced the learning of the analytical methods and expand the content of the class.

Two examples of industrial settings in the Austin area that we have examined in this course are the manufacturing of semiconductors and electroplating operations. Semiconductor manufacturing is complex—manufacturing thousands of units with tolerances measured in micrometers presents special problems with respect to contamination. Detection of contaminants at extremely low levels is essential; even measurement of the total organic carbon content of semiconductor water poses an interesting analytical challenge, for example. Concentrations that would be considered extremely low in municipal wastewater and acceptable in drinking water might be unacceptably high in a particular process stream at Motorola. Similarly, very low levels of air contamination in the semiconductor manufacturing facilities can destroy the product. In contrast, electroplating operations generally produce wastes that contain high concentrations of metal ions to water that are often removed through on-site treatment operations that can be readily simulated in the laboratory. Other industries also have unique characteristics but similar needs to exercise care in controlling both their manufacturing and the associated production of waste. Exposing students to industrial sites has turned out to be instructive and motivating.

Expanding the type of samples measured. The second trend noticeable in environmental engineering practice is the expansion of the field from its origins in drinking water and municipal wastewater treatment. The revisions to our existing class recognize these trends and requirements and include measurements of air and soil samples. For example, for the past two years we have coordinated with the Texas Commission on Environmental Quality (TCEQ) to utilize their mobile air monitoring unit for measurement of particulate matter in ambient air. This unit is equipped with PM-10, PM 2.5 and Total Particulate samplers. TCEQ loans the equipment to us for a 72-hour time period. They also instruct the students how to use the equipment and discuss the regulatory issues. Because the TCEQ has a website that contains current ambient air quality data, the students are able to compare their data to other sampling locations in the area. Our original goal was also to use a portable gas chromatograph in one or both industrial settings to measure for specific organic contaminants in an air stream. However, due to proprietary reasons, it was not possible to gain permission from the industries to conduct these analyses at the sites examined. As a result, we have modified this phase of the course to analyze specific organic contaminants in indoor air.

More exacting measurements. The revised course uses state-of-the-art analytical equipment purchased over the past several years for many of the measurements. These instruments include an atomic absorption spectrophotometer, an inductively coupled plasma spectrophotometer, a low level total organic carbon analyzer, a gas chromatography system equipped with either a mass spectrometer or an electron capture detector, diode array UV/Vis spectrophotometer, and a portable photoionization detector. For each of these instruments, our goal is to teach the students the theory of the analysis, the types and number of standards required to analyze data from the instrument, the analytical limitations of the technique, and the operation of the equipment. One of our goals is to stress the requirements for quality control, the limitations of each method, and the need to integrate results and conclusions derived from different methods to understand process performance. For example, because we employ complementary analytical techniques for analyzing inorganic and organic components of the samples, we can emphasize the need to ensure consistency between results from different methods. It is also possible to emphasize the meaning of reporting a concentration as "non-detect" since some of the techniques used have different analytical detection limits.

Course Structure

The new course structure still includes a lecture and laboratory component. Each week, the students learn a new analytical technique and employ this technique to analyze samples from the two different industries. They are required to produce a laboratory report for each analytical method employed. However, the laboratory reports focus not only on reporting the data for each sample, but also on interpreting the results within the context of the industrial setting. The students are asked to evaluate how the water has changed as a result of the industrial operation and any treatment processes. In addition, the students are required to prepare a report at the end of the term that describes one of the industrial processes and evaluates current waste production and treatment. The students are expected to understand not only the few industries that have been studied in depth but understand general principles of waste production in manufacturing, waste reduction approaches, and environmental analysis in industrial settings.

Students are expected by the end of this class to be knowledgeable in environmental chemistry, including both theoretical concepts from the lecture material on equilibrium chemistry and knowledge of the measurement methods and analytical techniques from the laboratory. To facilitate a deeper understanding of the analytical techniques, a class web site has been established that contains links to tutorials associated with each method. Many of these websites reflect a great deal of development effort and their availability on-line has been a great asset to this course.

One of the other key components to the structure of this class is the team approach used to enhance collaborative learning. The students work in groups of four throughout the term. All laboratory reports and the final project report are group efforts. One of the interesting features of the working teams is the division of labor in each group. Each week, a different student assumes responsibility for managing the laboratory. This student is responsible for assigning tasks to be performed by each group member during the laboratory. In addition, the project manager ensures that the data from the group is disseminated to the other groups. The project manager is also responsible for ensuring the quality of the laboratory report. The role of the project manager is similar to the role of a manager in a consulting firm. Thus, students acquire experience in managing time and personnel to achieve a specific deliverable.

Using the approach described above , the revised environmental sampling and analysis course addresses a number of ABET 2000 criteria, including the ability:

- to function in multidisciplinary teams;
- to communicate effectively;
- to obtain knowledge of contemporary issues involving technology; and
- to use techniques, skills, and modern engineering tools necessary for engineering practice.

This undergraduate class develops and enhances skills in all of these areas. The class emphasizes the close relationship of basic chemistry and engineering solutions. The group work in the laboratory and on the reports develops the ability to recognize and utilize different talents within a team. Our experience is that high expectations for the laboratory reports, reinforced by detailed feedback, allow students to learn how to utilize each other's talents to maximum advantage. The industrial perspective and applications to real systems are areas that have been missing in the past renditions of this class, but are an integral part of the new class. Our intention is to take a class that is already quite good and make it excellent, and then make the essential elements of the class accessible to other professors throughout the world.

Summary

In summary, we have developed a laboratory based course in which local municipal and industrial plants and processes are used to illustrate the breadth of problems that students in environmental engineering will face in their careers. The field trips, laboratories, lecture material and student report requirements enable students to generalize from their experience in this class. The theoretical concepts presented in lecture are immediately applied to an actual process. By understanding the origin and context of the samples to be analyzed, the students are active learners in this class, desiring to know the outcomes of their analyses.

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