A UNIT ON ACID RAIN IN A HIGH SCHOOL OUTREACH PROGRAM

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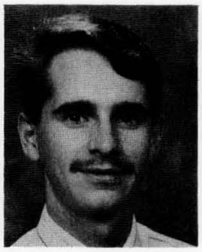

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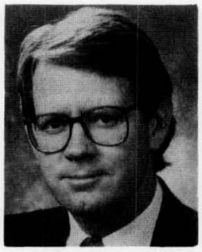

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Declining enrollment in engineering programs[1] has been a cause for concern in the educational community nationwide. To counter this downswing, engineering faculty may have to place greater emphasis on outreach programs in the future. (Bayles and Aguirre[2] described one such effort in the chemical engineering department at the University of Nevada, Reno.)

The Engineering College at the University of Wyoming has an outreach program aimed at high school science and math teachers and at high school seniors-to-be. Since many high school students are interested in environmental engineering as a career, in 1992 the Chemical Engineering Department contributed a unit on acid rain, with emphasis on chemical engineering analysis and solutions to this environmental problem. We will briefly describe the college outreach program in this article and will include details on our class dealing with acid rain.

ESP AND HISTEP
College Outreach Programs

The College of Engineering conducted outreach programs in June and July of 1992, with the help of financial support from the National Science Foundation. The June session was the Engineering Summer Program (ESP) for high school seniors-to-be, and the July session was the High School Teachers Engineering Program (HISTEP) for teachers of math, life and earth sciences, and physics. The program involved faculty from four undergraduate departments (chemical, mechanical, electrical, and civil and architectural engineering).

The goal of the ESP program was to introduce students to several of the engineering disciplines available to them on campus and to allow them to explore various career paths in engineering. They were exposed to several real-world issues through laboratory activities, computational work, and field trips, as well as through lectures and discussion.

There are many reasons why so few students are interested in engineering; the answer is not simply a lack of technical preparation in the secondary schools.[3] We felt that many school counselors and teachers do not effectively describe engineering as a career, so HISTEP was designed to show science and math teachers what engineers actually do. By giving them exposure and hands-on experience, we hoped to equip them to act as effective advocates for careers in engineering.

The three main interest areas in the ESP and HISTEP programs were

- Environmental Engineering
- Computer-Aided Engineering
- Materials Engineering

and each interest area consisted of three related subtopics. For example, in the environmental engineering area, faculty from electrical, civil, and chemical engineering discussed solar power, biological treatment, and acid rain. (The various topics for the

1992 programs are given in Table 1.) Students chose two of the three interest areas, thus covering six topics during the three-week program. A sample student schedule is given in Figure 1.

ESP participants were selected from applications which included high school transcripts, two letters of recommendation, and a 300-word statement explaining the student's interest in science and engineering. Thirty students were selected from approximately sixty-five applications from four states.

A total of twenty-three high school teachers participated in HISTEP, and they received continuing education credit for the program as well as a stipend and room and board. In addition to laboratory and discussion sessions led by the engineering faculty, the teachers participated in teaching- and learning-workshops and developed curriculum units based on their experiences in HISTEP.

THE ACID RAIN UNIT

Acid rain is normally associated with the northeastern United States, or northern Europe, or other areas with high industrial density, particularly those areas with power plants that burn high-sulfur coal. The Rocky Mountain West is not known for acid rain,[4] although cities such as Denver and Phoenix have some acid rain and "brown cloud" problems

TABLE 1
Research Topics in the Engineering Summer Program

Interest Area and Topics	Engineering Discipline
Environmental Engineering	
Acid Rain	Chemical
Solar Power	Electrical
Biological Perspectives	Civil
Computer-Aided Engineering	
NMR Image Processing	Chemical
Digital Electronics	Electrical
Electronic Materials/Manufacturing	Electrical
Materials Engineering	
Sports Dynamics	Mechanical
Composite Materials	Mechanical
Structural Engineering	Civil

Time	Monday	Tuesday	Wednesday	Thursday	Friday
7:30-8:00	Breakfast				
8:30-11:30	LAB	LAB	Plant Tour	LAB	LAB
11:30-1:00	Lunch				
1:00-4:00	LAB	LAB	Plant Tour	LAB	LAB
4:00-5:30	Recreation			Recreation	
5:30-6:30	Picnic	Dinner			
7:30-10:00		Entertainment		Entertainment	

Figure 1. Weekly schedule for the 1992 Engineering Summer Program

Activities included laboratory demonstrations and research using a water-sulfur dioxide scrubber, computer process simulations of the water-sulfur dioxide scribber, class discussions, and homework dealing with cost/risk/benefit analysis of electrical power production.

familiar to many students. Nevertheless, the topic is pertinent for students living in this area of the country. Pedagogically, studying acid rain allowed us to explore a wide range of integrated industrial activities (such as mining, transportation, combustion, and flue-gas cleanup) associated with a very familiar and acceptable product—electricity. Wyoming is the nation's leading coal producer; most of the coal is low-sulfur and is used by electrical utilities. Some of the participants in the course had parents or spouses working in coal mining operations or in power plants, and thus they were already acquainted with the subject of air quality. Most of the students were also aware of the 1990 Clean Air Act which focused attention on electrical utilities that burn coal. In addition, the Rio de Janeiro "Earth Summit" was much in the news during the summer of 1992, and newspaper and other reports were plentiful, stimulating student interest and awareness. Thus, the participants in our program were highly motivated to explore some of the technological and societal issues associated with acid rain.

We used several methods to introduce students to the history and technology of power production and to methods of dealing with acid rain. Activities included laboratory demonstrations and research using a water-sulfur dioxide scrubber, computer process simulations of the water-sulfur dioxide scrubber, class discussions, and homework dealing with cost/risk/benefit analysis of electrical power production.

Since we wanted our unit to be more than just a technological treatment of acid rain, we also emphasized the many possibilities for work in areas related to clean-up and preservation of the environment. Additional information on chemical engineering and environmental issues was disseminated through videotapes, plant tours, department tours, newspaper clippings, and handouts. Students were asked to consider the benefits of power production as well as the societal costs and risks, and a good deal of time was devoted to roundtable discussions of these issues and the technology involved.

As can be seen from Figure 1, the unit was conducted in four three-hour days (not counting offcampus plant tours). A typical day began with forty-five to sixty minutes of class discussion, videotapes, numerical solutions to homework, and question-and-answer sessions. On the first day of class, each student was given a folder of handouts (over fifty pages) which included details of all laboratory demonstrations, blank data sheets, and calculation details. Also included were notes on the history of air pollution, several tables and charts dealing with energy production and usage, and questions designed to foster thought about cost/benefit analysis. A few newspaper clippings and magazine articles dealing with environmental issues in general were also included in this handout.

LABORATORY ACTIVITIES

To illustrate the meaning of acidity, we introduced and discussed the pH scale on the first day of class, and to quantify the concept, we asked the students to measure the pH of several common fluids—tap and distilled water, soft drinks, vinegar, solutions of sodium bicarbonate and sodium hydroxide, and soap solutions. We used three analytical methods to measure the pH: indicator solution (Fisher Brand Universal Indicator, pH range of 4 to 12); pH papers; and a digital pH meter.

We divided the students into smaller groups to make the pH measurements. As we expected, while pH measurements using the various techniques were sometimes in good agreement, at other times they were not. Also, comparison of measurements made by using the same analytical method, but by different classes at different times, showed some discrepancies. This gave us an opportunity to talk about concepts such as precision, accuracy, reproducibility, personal technique, and use of different analytical methods. This in turn led to consideration of the all-too-familiar situation where opposing groups involved in an environmental discussion present seemingly conflicting data, analysis, and interpretation. We took this occasion to emphasize the role of the engineer in objectively gathering and reporting data.

The pH studies taught students that living things can tolerate a wide range of pH, but that chemistry, concentration, dosage, duration, and other factors are important. The discussion on experimental error and technique illustrated the difficulties involved in quantifying the level of acidification at a given location. In some cases there are little or no historical pH data, making it difficult to estimate the rate of acidification. We also cite the possibility of conflicting and erroneous measurements, and point out that all of these factors have contributed to the controversy over the rate, extent, and even the existence of damage due to acid rain.[5]

To show how sulfur oxides contribute to acid precipitation, the students used a Bunsen burner to ignite a small amount of pure sulfur held on a spatula. The burning sulfur was then inserted into the headspace of a flask partially filled with water and the Fisher indicator. As the sulfur dioxide was absorbed, there was a rapid color change from green to bright red, vividly demonstrating the acidification of water by sulfur dioxide. Repeating the experiment using a pH meter allowed a more precise measurement of pH.

We spent most of the laboratory time in operating a water/SO_2 scrubber (see Figure 2). This gas/liquid absorption column is constructed of plexiglas and is four feet high, three inches in diameter, and is packed with hollow glass cylinders. A compressor feeds air to the column, while SO_2 is supplied from a cylinder. Electronic mass flow meters and needle valves on each line allow measurement and control of the inlet gas composition. In our work, a nominal composition of two mole percent SO_2 in the inlet air stream was used. Tap water is fed to the top of the column with a pump, and water flow rates are measured and controlled with a rotameter and valve.

Several visual demonstrations can be made with this apparatus. Since the column is made of plexiglas, students can observe the flow of liquid over the packing. Varying gas and liquid flow rates allows them to observe both gas flooding and liquid flooding, which leads to a discussion of design and operating variables, capacity, and design for flexibility. Adding a small amount of sodium hydroxide and phenolphthalein indicator to the water in the tank makes

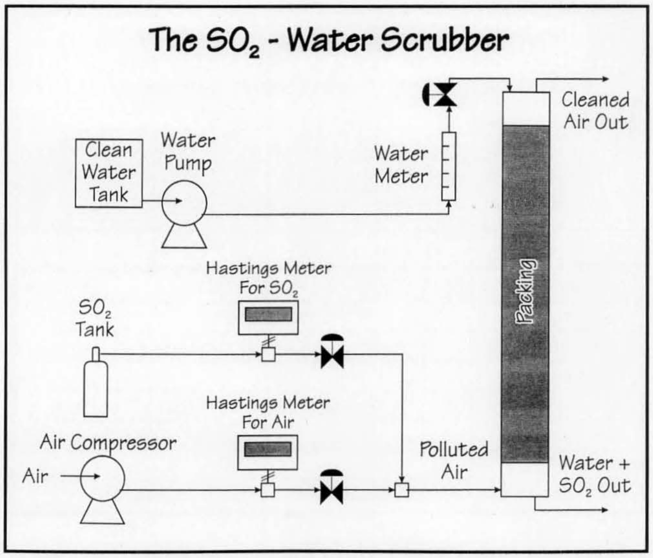

Figure 2. The SO_2 Water Scrubber

the inlet water bright pink. As the water flows down the column and SO_2 is absorbed and reacted, the pink disappears. Varying the gas and liquid flow rates causes the location of the color front to move. Students get a strong visual indication of the progress of the absorption process and see the effect of operating variables on breakthrough.

The bulk of the research, however, was done using plain tap water for scrubbing. In this work, students measured inlet gas and liquid flow rates, and titrated the outlet sample using a standard method.[6] The ideal gas law was invoked to calculate gas molar flow rates, and water volumetric flow rates were converted to molar rates using the density of water. It was then a matter of simple material balances to calculate the percentage SO_2 removal and subsequently to observe the effect of flow rate and inlet gas composition on the removal efficiency.

COMPUTER ACTIVITIES

To complement the laboratory work, students were introduced to chemical process simulation using a commercial package, PRO/II (Simulation Sciences, Inc., Fullerton, CA), running on 486-based PC machines. We pointed out that our own undergraduates learn this and other simulation packages in their senior year, and that many of them subsequently use the same software in industry.

Since setting up a realistic simulation requires extensive background, we had to provide assistance to the students. PRO/II allows the user to specify column and packing type, thermodynamic model for SO_2 solubility, and many other options with which the students were unfamiliar, so we instead used detailed handouts to try to give them a feel for the simulator.

The purpose of the simulation was to re-create as closely as possible the experimental conditions used in the laboratory SO_2 scrubber. Output from the simulation included flow rate and composition of all streams, so students could calculate percentage SO_2 removal. It is a simple matter to adjust flow rates and re-compute stream compositions, and students had a chance to perform numerical experiments similar to the physical experiments carried out in the laboratory.

We discovered that our simulator did not agree well with laboratory results. Experimentally we observed seventy to eighty percent removal of SO_2 from the inlet gas, while the simulator consistently predicted removal in excess of ninety-nine percent. While this was not the desired result, it did prompt class discussion on the potential errors present in both simulation and laboratory work. Possible experimental error, inconsistent technique, and other difficulties in laboratory work became apparent to them. We were also able to point out that setting up a simulation involves many menu selections and assumptions which must be consistent with the experimental setup. Nevertheless, the students could see clearly the iterative process that many practicing chemical engineers must use in the design process: laboratory experimentation over a specified set of operating variables, followed by numerical simulation, followed by careful error analysis and comparison of experiment and simulation, followed by an improved set of experiments.

OTHER ACTIVITIES

We spent most of the time either in the classroom or the laboratory, but for broader exposure we also included several other activities (see Figure 1). ESP students took several field trips, including an all-day trip to a near-by power plant and a coal mine where they were exposed to many of the activities and unit operations associated with electrical power production: open-pit strip mining, land reclamation, rail transportation, solids handling, combustion, steam generation, electrical turbines, cooling towers, scrubbers, electrostatic precipitators, and ancillary control and monitoring equipment.

HISTEP participants were geared more toward curriculum development, so they spent at least an hour each day on teaching methodologies and on developing course plans which incorporated the HISTEP subjects into their classroom instruction. These curriculum activities were coordinated by the Wyoming Center for Teaching and Learning. The teachers were evaluated on the basis of their course plans and received continuing education credit for their participation in the program.

We made extensive use of videotapes during the four-day session. They were not exclusively on acid rain, but were chosen to given the students a broader exposure to issues and possible career paths in chemical engineering.[7] We also showed a department videotape on chemical engineering careers which we use in high school recruiting efforts and gave each of the participants a copy of the tape for later use at their respective schools.

Much of the acid rain unit dealt with experimental chemistry and engineering. While most of the high school teachers found this interesting from a personal standpoint, those whose teaching specialty was mathematics had difficulty finding material to take back to their classrooms. All HISTEP participants had been presented with a student version of TKSolver (Universal Technical systems, Rockford, IL). Therefore we presented the math teachers with an extra problem dealing with the environmental effects of paper and plastic grocery sacks, using a discussion recently presented by Allen and Bakshani.[8] This problem was explored using TKSolver in List Solve mode.

DISCUSSION

Both ESP and the HISTEP classes were run in a very informal atmosphere, and we had ample opportunity to ask the students what they were learning, what they enjoyed, and what they did not like. In addition, a brief, anonymous class evaluation form was filled out by each student at the conclusion of the unit. In this section, we will describe student reactions to the unit and will pass on our impressions of the successes and failures of the program.

Regens and Rycroft[5] present some interesting history of air pollution (see Table 2). Our students were interested to learn, for instance, that air pollution was a problem in imperial Rome, that smoke from wood and coal has been a problem for centuries in Great Britain, and that King Henry once issued an edict calling for decapitation of any who were found "guilty" of burning coal.

An early example of completely misguided government legislation in this area came in 1834, when the British Parliament enacted laws requiring that locomotives must consume their own smoke. (Our students immediately sensed something amiss with this law!) This particular bit of history gave us a good opening for a discussion on the principle of mass conservation and led to the first law of thermodynamics as well.

Because environmental issues are in the news daily, we deliberately tried to provoke class discussion about acid rain and other topics such as recycling, nuclear waste storage, land reclamation, and economic impact of environmental regulation. The "Earth Summit" of 1992 led to a call for holding CO_2 emissions at 1992 levels, so we asked the students what conveniences they would be willing to give up to help meet this goal. Not surprisingly, the "sacrifices" they volunteered were minimal (toaster ovens, curling irons, etc.). The follow-up question, however, did provoke considerable interest and discussion. The question was, "*When* would you be willing to give up the items?" A few altruistic people argued for voluntary conservation, while others said, in effect, "We will conserve when the government forces us to." A third group seemed content to wait for Armageddon. The high school teachers pointed out that when the price of electricity became too high, people would voluntarily reduce consumption (the law of supply and demand, *and* pricing). We considered this sort of discussion to be important because it put some laudable but abstract environmental goals (conserve, reduce) on a very personal basis for the students.

In reviewing the written comments, most students made no mention, pro or con, regarding the class discussions. We estimate that ninety percent of the students actively participated in the discussions, however, and they seemed to enjoy it. Indeed, among the high school teachers it usually required an effort to terminate class discussion and move them on to the laboratory.

All students enjoyed the hands-on demonstrations and operation of the scrubber, and most of them listed laboratory activities as their favorite part of the course. It was usually a matter of showing them the basics and then getting out of their way. The mathematics teachers were the exception: while they

TABLE 2
Some History of Air Pollution

- A.D. 61: Senaca (Roman philosopher) wrote of Rome's polluted vistas:
  As soon as I had gotten out of the heavy air of Rome and from the stink of the smoke chimneys thereof, which, being stirred, poured forth whatever pestilential vapors and soot they had enclosed in them, I felt an alteration of my disposition.
- A.D. 1060: Eleanor of Aquitaine, wife of King Henry II of England, moved from Tutbury Castle in Nottingham because of the pollution of wood smoke.
- A.D. 1273: English royalty issued decrees barring the burning of coal in London. The effort was futile, because with the depletion of forests in England (and lack of firewood) people increasingly turned to coal.
  Be it known to all within the sound of my voice, whosoever shall be found guilty of burning coal shall suffer the loss of his head. (King Edward I, ca. 1300)
- A.D. 1578: Elizabeth I is annoyed by coal smoke and complains to Parliament. Coal burning is banned while Parliament is in session.
- A.D. 1661: John Evelyn wrote, "Fumifugium, or the Inconvenience of Aer and Smoak of London Dissipated (together with some Remedies Humbly Proposed)."
- 1772: Second edition of Evelyn's book is published.
- 1819 and afterward: British Parliament issued pollution abatement decrees. Scrubber technology was developed in 19th century. In 1845, Parliament passed a law requiring locomotives to consume their own smoke.
- 1952: A dense fog blanketed London from December 5-8. Fog, mixed with polluted air, caused an estimated four thousand deaths from emphysema, bronchitis, and cardiovascular problems. This led to Britain's first modern clean air legislation.

enjoyed the experiments personally, they expressed concern about the practicality of transferring the hands-on work to their own classrooms.

The booklet of supporting information seemed to be of special value to the high school teachers. Converting the laboratory readings into data for mass balance calculations involved simple algebra, some reaction stoichiometry, ideal gas laws, and knowledge of fluid properties. In addition, we provided a few word problems related to fuel, ash handling, and shipping requirements for a coal-fired power plant. The paper versus plastic bags problem of Allen and Bakshani[8] was also very popular. The teachers appreciated this real-world data and felt that their students would enjoy working on such problems. We believe we were successful in providing some mathematical problems that could be used in high school mathematics, physics, or chemistry classes.

An area that needed more time, according to the students, was computer modeling of the SO_2 absorption process. They would have preferred an opportunity to try the various menu options and run more cases. In retrospect, we see the need for more time to experiment with the computer and to answer questions about its operation.

Another feature of the course that did not go over as well as anticipated was the videotapes. Both high school students and teachers indicated that there were too many videos and that some of them ran too long. We expected that the adults might grow restless watching videotapes, but we were surprised (and rather pleased) to find that high school kids, too, preferred hands-on work to passive viewing.

Our department videotape did generate interest, however—particularly among the teachers. We provided each of them with a copy of the tape to take home, and they indicated they would show it in their classes as a way to introduce students to the field of chemical engineering in general and to our department in particular.

CONCLUSIONS

Judging from the students' verbal and written comments, we believe the unit was a success. Linking chemical engineering principles and practice to an environmental problem proved to be very effective in capturing their interest. The operation of the scrubber, analytical wet chemistry, and lab demonstrations gave a hands-on experience that all of them enjoyed. We were able to bring a strong element of personal and societal values into the discussion, as well as a discussion of technical issues. This helped students appreciate the potential that chemical engineers have to design and develop useful solutions to problems of public interest and concern. The value of the engineer as a literate and articulate advocate for the profession was stressed.

We entered the project with some trepidation. We are accustomed to dealing with students whose chemistry, physics, mathematics, and engineering skills are more developed. In addition, college-age students well into their major are typically motivated by other factors, such as a desire for good grades, fear of failure, desire for a good job, and protecting their large investment of money and time. Our only hold on the participants in this program was to make the course genuinely interesting and challenging.

While we feel that this course was a success, only time will tell if we have achieved our goal of increasing the number of students interested in chemical engineering as a career. We hope to monitor incoming freshmen and transfer students in the future to see if any graduates of ESP join our undergraduate program. Similarly, we hope to find out if high school teachers have been helped in describing chemical engineering careers to their students. In the meantime, we will continue with this and other outreach efforts.

ACKNOWLEDGMENTS

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