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Incorporating Pollution Control Concepts and Technologies into Chemical Engineering Curricula*

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Awareness of pollution control aspects and understanding of unit operations involved in waste treatment technologies is necessary for today's graduating chemical engineers. These can be easily incorporated into the curriculum at undergraduate and graduate levels. Introduction of a separate course on the subject is probably the best approach. When addition of new courses into the curriculum is not possible, courses in mass transfer or separations are the most suitable places to introduce pollution control principles. Courses in material and energy balances, reactor design and process design may also be modified to include environmental concepts. The addition of experiments into the unit operations laboratory that illustrate the environmental aspects can simultaneously expose the students to waste reduction methods and provide them with hands-on experience with the associated separation techniques. This paper details attempts to integrate this material into our undergraduate and graduate curriculum.

INTRODUCTION

CHEMICAL and petroleum processing operations have come under increasing criticism over the last two decades for increasing air pollution and soil/groundwater contamination. This has prompted a stringent regulatory climate for industry with respect to waste disposal. Consequently, many chemical engineers find themselves involved in waste management aspects especially in situations where an end-of-pipe treatment is used as the waste reduction technique. Renovation of industrial waste streams by reverse osmosis or ultrafiltration and air emissions control by activated carbon adsorption are typical examples. Thus, there is a definite need to educate chemical engineering students who will be involved in this area of growing concern.

Although a large number of chemical engineering faculty is involved in environmental research, the majority of BS-level chemical engineers involved in plant design and production have little or no background in environmental pollution control and some of the advanced separation techniques associated with them. Even recent graduates have little or no exposure to this important area. Today's graduates need to be made aware of pollution control issues in order to function effectively as process, design and research engineers. Therefore, the chemical engineering faculty need to examine ways to incorporate waste reduction methods into the chemical engineering curriculum.

INTEGRATION OF POLLUTION CONTROL ASPECTS INTO CURRICULA

The common problems of environmental engineering include:

- predicting the fate and transport of contaminants in the environment;
- soil/groundwater remediation, solid waste and wastewater treatment/disposal/recovery;
- air emissions control;
- design of environmentally benign processes.

Development and implementation of effective solutions to these problems require a knowledge in the areas of transport phenomena, chemical engineering thermodynamics, separation processes, and reaction kinetics. Since these courses are the backbone of the chemical engineering curriculum, the students already have the basic understanding of fundamentals in these subjects. All that is needed is a deliberate attempt on the part of the faculty to incorporate various aspects of pollution prevention and control into these courses. At Cleveland State University, we have attempted to integrate this material especially in our separation courses and in our senior electives/graduate courses to increase the students' exposure to this area of growing importance. We have also initiated efforts to integrate pollution control aspects in other undergraduate courses such as material and energy balances, reactor design, process design and undergraduate laboratories. These efforts are described in detail below.

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UNDERGRADUATE INSTRUCTION

Effective integration of instructional material on environmental technology into the undergraduate curriculum can be accomplished at various levels through both course and laboratory development. The options include integration of environment-related topics in the core chemical engineering courses, introduction of separate elective courses on the subject, and addition of environmental experiments to the laboratory courses. Each of these options is considered in detail below.

Undergraduate courses

Stoichiometry is a prerequisite for solving most environmental engineering problems. Therefore, pollution control concepts can be introduced into the curriculum as early as during the first chemical engineering course in which the students are exposed to material and energy balances. Problems involving steady-state material balances can be designed by taking various waste treatment operations such as stripping of benzene and trichloroethylene from industrial wastewater. The waste treatment system can be presented as a black box into which polluted streams are introduced and processed. The process parameters such as flow rates and compositions of various streams, and removal efficiencies are calculated. Similarly, incinerators may be used in examples that demonstrate excess air concept and combustion calculations. Such an approach allows the students to develop an awareness of and interest in environmental issues while they are learning the basic principles of chemical engineering.

The separations course sequence provides an ideal setting to introduce the waste reduction principles, design and applications. This is especially true when addition of a new course on the subject is not possible within the tightly structured chemical engineering curriculum. Examples demonstrating air stripping and steam stripping of volatile organic pollutants from groundwater or waste streams can be incorporated into classical topics of gas absorption/stripping and distillation. Application criteria for each technique in terms of waste characteristics and composition, effectiveness, and cost can be analyzed. Because industrial wastewater and contaminated groundwater are often multisolute and dilute streams, these examples may be used to explain the simplifying assumptions involved in the theoretical calculations for multicomponent stripping and distillation of dilute aqueous systems. Hence, the students are simultaneously exposed to typical environmental topics and the applications of the associated separation techniques to dilute streams as opposed to highly concentrated chemical process streams.

Removal of organic contaminants from industrial wastewater or contaminated gas streams may be illustrated while students are studying the principles of adsorption. Classroom examples or homework problems can be created to examine the adsorption/desorption characteristics of a fixed-bed adsorber unit by using an air stream contaminated with a volatile pollutant, for instance 1,1,1-trichloroethane, or a wastewater stream containing an organic pollutant such as ethyl benzene. In an advanced level separations class where the students are exposed to the principles of multicomponent adsorption, more realistic examples simulating multisolute waste streams can be used. While the process parameters and design specifications of adsorption systems are discussed, special considerations regarding the environmental applications, for example the fate of the contaminants upon regeneration or disposal of the spent carbon versus regeneration approach, are incorporated into the subject without much difficulty.

Liquid/liquid extraction and leaching are well established and widely used separation methods in the chemical industry. The current unit operations or mass transfer courses and texts usually devote sufficient time and content for a detailed examination of both subjects. Environmental remediation concepts may easily be integrated into these topics by taking various examples of industrial wastewater treatment and ex-situ soil washing. At the advanced levels, supecritical fluids extraction or supercritical water extraction of organics in soils and sediments may be appropriate illustrations of these emerging separation techniques.

Similarly, renovation of electroplating waste streams and contaminant recovery concepts are discussed simultaneously with reverse osmosis, electrodialysis, and ion exchange. Membrane processes are one of the recent technologies being introduced into the chemical engineering education. Often the instructor does not have sufficient time in a separations course for a detailed study of all membrane processes. However, the fundamentals of reverse osmosis are examined in detail in most schools since it is used by a number of industries for many applications. In addition to desalination, a variety of environmental applications can be used in classroom examples or homework problems for analysis of the influence of feed rate, solute concentration, applied pressure and temperature on the recovery and solute rejection. Principles of ion exchange are usually introduced following adsorption. Although students are not exposed to all of the aspects of ion exchange technology, they receive enough information to allow them to understand how the separation is achieved. Recovery of chromic acid in plating baths can be a generic example for demonstrating metal recovery, water reuse and resulting savings.

Some environment-related issues can be included in the capstone senior process design courses. Individual design problems for liquid and/or gaseous wastes can be assigned. Looking at alternative separation processes for treatment in terms of applicability, effectiveness and economic recovery is emphasized. For instance, a wastewater containing a mixture of organics such as phenol, benzene, and acetone can be used to explore various options for separating them including adsorption, air stripping and steam stripping for a treatment system that will meet all federal standards. Pollution control and the cost of meeting environmental regulations should be included as one of the criteria for process selection and evaluation. Another approach would be to provide the preliminary designs of the required waste processing/recovery units with the design of the chemical process plant. Unless the students were exposed to a comprehensive training in waste removal technologies they may not be able to address some waste streams requiring specialized knowledge, such as biological treatment, chemical precipitation, fixation, etc. However, the design problem can be set up and monitored in a way that the students can offer solutions to the majority or all of the waste disposal/recycling problems through their separations background. This approach would provide an excellent opportunity for the student to gain an understanding of where chemical engineering unit operations can be used for pollution control in addition to their traditional use for separation of chemicals in a process plant.

Some waste treatment subjects can be integrated into the reactor design class as well. In industrial wastewater treatment, activated sludge processes are widely used to remove soluble and insoluble organics and subsequently to convert them into a flocculant microbial suspension that readily settles and permits the use of gravitational solids/liquid separation techniques. The common generic types are plug-flow activated sludge and complete-mix activated sludge. Thus, the same concepts studied during the reactor design course can be applied to activated sludge reactors. Few additional concepts on principles of biological oxidation and related kinetic expressions can be presented to the students with a minimal increase in their academic load. Through exercises or projects on the topic, they can simultaneously develop an understanding of biological wastewater treatment and practice key reactor concepts. Similar exercises may include bioreactors [1] and trickling filters.

The introduction of a separate course on pollution control/prevention technologies would be the ideal option. However, many chemical engineering departments do not have the flexibility to add a new required course on the subject due to the tightly structured nature of their undergraduate curriculum. In our program at Cleveland State University we have recently added graduate courses on air, water and soil decontamination which are also open to the senior level undergraduate students to fulfill their technical elective requirement. These courses have been highly popular as indicated by high enrollment. Almost all of the graduating seniors for the past two years were enrolled in one of the environmental courses. Several of them selected both of their electives in this area. These courses have also attracted undergraduate students from chemistry and biology as well as from other departments in the college.

Undergraduate laboratories

Senior level unit operations laboratory provides another opportunity to integrate pollution control principles, design and applications. Experiments can be designed to demonstrate environmental applications of separation techniques that are already being taught in mass transfer or separations courses. This can provide the student with an understanding of the basic principles and design of pollution control systems as well as an appreciation for the applications of the involved separation method.

An experiment in air pollution control using activated carbon adsorption would be an appropriate unit operation for chemical engineering instructional laboratories. The objectives of the experiment would be to demonstrate the removal of volatile organic compounds from contaminated air or industrial exhaust streams and to study the adsorption column dynamics. Such experimentation could be performed in two consecutive modes. First, an air stream contaminated with a typical volatile organic pollutant vapor would be used to study the adsorption/desorption characteristics of a fixed bed adsorber unit. With air being the non-adsorbing gas, the process would illustrate single component adsorption. This would permit students to examine and analyze the basic parameters involved in an adsorptive separation. Since contaminant vapors usually exist as mixtures in the air or in industrial exhaust streams, the second portion of the experiment would target removal of mixtures of contaminants from air streams. An air stream containing two or three pollutant compounds would be introduced to the adsorption unit. The effectiveness of contaminant removal would be quantified from the exit stream composition which could be determined by using an appropriate analytical instrument, for example a gas chromatograph. This part would demonstrate that removal of mixed pollutants by adsorption vary and is different than removal of a single pollutant. The experiment would allow the students to gain hands-on experience with an air pollution control technique that is widely used in industry while they are studying the principles of single/multicomponent adsorption. Many chemical engineering instruction laboratories include fixed-bed adsorption systems in their curriculum. These units are usually used to demonstrate chemical separation processes such as helium/nitrogen separation on molecular sieves. The existing units can be modified, without much difficulty, to conduct experiments for environmental applications.

In a similar manner, liquid phase adsorption or ion exchange experiments can be performed to illustrate renovation of industrial waste streams. Phenol adsorption on activated carbon and removal of copper using ion exchange resins are good examples.

Experiments in pressure driven membrane processes such as reverse osmosis or ultrafiltration may be used as generic examples to demonstrate to the students the industrial wastewater purification and contaminant recovery concepts. Reverse osmosis is one of the major methods for purifying wastewater of toxic chemicals. It separates pure water from its contaminants rather than removing pollutants from water. Thus, while the purified water can be further used in manufacturing, the concentrated contaminant chemicals can be recycled or used in other processes. Consequently, reverse osmosis has a wide spectrum of applications for the treatment of industrial discharges. Recovery of metals and metal salts from plating wastes, removal of sulfates from acid mine drainage, concentration and recovery of hydrocarbon pollutants from waste streams, cleaning water from black liquor in paper industry [2–4] are some examples.

Pilot or bench-scale reverse osmosis units can be used to effectively illustrate several waste reduction applications. Design criteria, specifications and considerations for a pilot-scale reverse osmosis system for instructional laboratories are outlined in detail by Slater and Paccione [2, 3]. A typical experiment could be carried out in two consecutive modes. First, the basic principles of reverse osmosis separation technology would be emphasized by using an aqueous solution of a single contaminant. This would allow the students to examine the major characteristics of the separation process including solute rejection and permeate production. The second portion of the experiment would emphasize the removal of mixture of contaminants from industrial effluent streams. A simulated aqueous process stream contaminated with multisolutes would be fed to the reverse osmosis unit and varying levels of species rejection would be measured. Different runs could also be conducted using different membranes in order to investigate the rejection of pollutants by different membrane types. This part would demonstrate that rejection of contaminant species vary and is different for different membranes. Students would be exposed to industrial wastewater purification and material recovery concepts, while they are evaluating the effectiveness of reverse osmosis technology in terms of multisolute recovery and membrane materials.

A variety of other experiments focusing on wastewater renovation in different industries could be conducted. Two good examples on applications of reverse osmosis in the textile and electrochemical industries are outlined in the current literature [4, 5].

GRADUATE INSTRUCTION

The easiest and the most logical place to incorporate environmental issues into the graduate instruction would be the research component of the graduate curriculum. A number of chemical engineering faculty, throughout the country, is already working on several environment-related research projects. Transport and fate of contaminants in the subsurface, soil decontamination, physical/chemical/biological treatment methods, air pollution control are the general areas of concentration. However, availability and variety of graduate research topics in a program depend on the faculty research interests. Furthermore, graduate research projects are often effectively instructive only to the students who wish to be specialized in the area of a particular research. Many chemical engineering graduate students who choose to be specialized in non-environmental areas express interest to acquire knowledge in pollution control technology. Introduction of waste reduction concepts through the graduate courses can serve the needs of a much larger audience.

Subsurface contaminant transport concepts can be integrated into a transport phenomena course. Examples or term projects involving simple advection/dispersion models for non-reactive dissolved pollutants in the saturated zone can be used to illustrate applications of Darcy's Law and transient and multidimensional transport fundamentals. At a more advanced level, mathematical models for transport of reactive species in the unsaturated zone may be included to demonstrate multiphase transport in porous media.

Some graduate programs offer a graduate course on separations or more specialized courses devoted to one or few advanced separation techniques, such as Fundamentals of Adsorption or Membrane Technology. Such courses would be ideal places to include pollution control methods. Unlike the undergraduate chemical engineering programs, most graduate programs have enough flexibility to include highly specialized courses in their curriculum. Thus, the introduction of separate graduate courses on environment-related topics may be feasible. This is also the best option for a sufficiently detailed presentation of the instructional material.

At the Cleveland State University, we offer three separate courses for graduate students and seniors on the topics of Principles of Air Pollution Control, Industrial Wastewater Treatment, and Environmental Remediation. These three courses cover the majority of the environmental areas that come under the working umbrella of chemical engineering. They have been received with enthusiasm by both the graduate and the undergraduate students as demonstrated by high enrollments in these courses.

The first course introduces the application of engineering principles to the analysis and prevention of air pollution. The course content includes discussion of common air pollutants, their adverse effect on environment, their sources, atmospheric chemistry and their transport in atmosphere, techniques of air sampling and analysis, air quality standards, and methods of air pollution abatement with an emphasis on process engineering and design for air pollution control. In the second course, principles of industrial wastewater treatment are introduced. The course begins with an overview of sources and characteristics of industrial wastewaters. Following a brief introduction on the regulatory issues, the design and operating parameters of wastewater treatment processes and the equipment are studied. The course outline includes pre- and primary treatment, coagulation and precipitation, aeration, biological wastewater treatment processes, adsorption, ion exchange, membrane methods, chemical oxidation, sludge handling, and new developments in wastewater recovery/reuse. The objective of the third course is to introduce the students to the traditional and developmental techniques for removal and/or destruction of hazardous wastes at contaminated sites. The course addresses soil and groundwater remediation. During the first one-third of the course, legislation, sampling and analytical methods, fate and transport of contaminants, and environmental toxicology are studied. The rest of the course time is devoted to the analysis and design of remediation systems including soil-vapor extraction, physicochemical methods, stabilization and solidification, bioremediation, and land disposal. Case studies are utilized throughout the course.

CONCLUSIONS

The integration of pollution control methods into the chemical engineering curriculum is important in today's environment. It can be accomplished in many ways at both undergraduate and graduate levels. Modification of existing courses, offering separate courses, and introduction of environmental experiments are some of the available options. The separations course sequence is the most suitable place to introduce environmental topics into the undergraduate curriculum. Examples can be created for classroom demonstrations or homework problems to show the environmental applications of the unit processes that are being taught in the mass transfer/separations courses. Stoichiometry, reactor design, and process design courses may also be modified to include some waste reduction content. If feasible, the addition of a separate pollution control course into the curriculum is the best option. Unit operations laboratory can easily be modified by the introduction of environmental experiments. This can expose the students to the typical pollution control methods while they are gaining hands-on experience with the related separation techniques. Separate graduate courses can provide detailed instruction on environment-related topics. These courses may also serve to satisfy a large student audience.

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