A Course in

WASTEWATER ENGINEERING FOR CHEMICAL ENGINEERS

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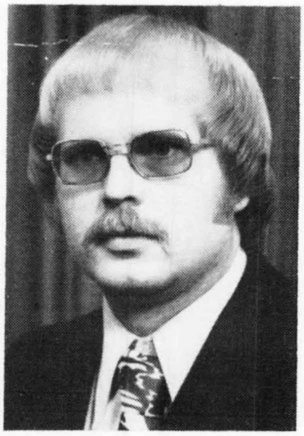
IN THE PAST FIVE YEARS, the areas of research and development interest for chemical engineers have expanded to include environmental topics. To see this, one has only to look at advertisements for industrial positions in our trade journals or at the listings of active research areas in graduate programs in the fall issue of this journal. Yet, coverage of wastewater topics in most chemical engineering programs is limited to a few specific examples introduced by instructors with experience in the field.

This paper describes "Wastewater Engineering," a graduate course oriented for the specific needs and backgrounds of chemical engineers. It evolved under the somewhat unusual circumstances that in the 1965-1970 period there were no active teaching or research programs in Environmental Engineering (or, as it was known then, Sanitary Engineering) at Case Western Reserve University. This vacant niche in the ecology of the School of Engineering has been occupied by a Graduate Chemical Engineering Wastewater Program built around the subject course and a complementary program on Water Resources in the Systems Engineering Department. Further development of "Wastewater Engineering" was fostered by hiring of faculty with specific background in the field and by a training grant (jointly administered between Chemical Engineering and Systems Engineering) from the U. S. Environmental Protection Agency, Office of Manpower and Training.

The graduate chemical engineering course on wastewater originated in response to a wide appeal for environmentally oriented courses. Many others enrolled besides chemical engineering graduate students, including undergraduates (mainly chemical engineers), graduate students in other fields and part-time students already employed in industry. The initial offerings in 1969 and 1970 were as a seminar or special-topics course. This was followed in 1971 by a structured course devoted principally to wastewater analyses and treatment technology. That course also dealt with water quality criteria and air pollution topics, hence its title "Environmental Quality: Measurement and Improvement." At the time, it was the only substantial environmental course, graduate or undergraduate, available in the engineering school.

"Wastewater Engineering," the present graduate course, was first taught in 1973. Now, an undergraduate course on wastewater or an introductory Sanitary Engineering course is a prerequisite. We assume that the students are familiar with water quality criteria, units of



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Peter B. Melnyk received his B.S., M.S. and Ph.D. (1974) from McMaster University. His technical experience includes work with the Ontario Pulp and Paper Company and Pollutech Advisory Services. He has participated in the Association of Professional Engineers of Ontario, the Pollution Control Association of Ontario and the Water Pollution Control Federation. He is presently an assistant professor of chemical engineering at Case Western Reserve University. (RIGHT) measurement, wastewater analyses and the common schemes for municipal wastewater treatment.

The discussion here covers both the lecture topics and associated laboratory experiments. Because adequate references have been provided, we only list the lecture topics and discuss the reasons for their selection. In the lectures, Chemical Engineering methods applied to wastewater technology take away some of the mystique. Still, empirical methods play a large part in characterizing wastewaters and their treatment. Hence, the laboratory is an important complement to the lectures. Since no published laboratory manual is available, we have consolidated our experience over the last few years by providing details on the objectives and suggestions for carrying out the experiments. Finally, we touch briefly on the relationship of "Wastewater Engineering" to other courses in our program.

COURSE CONTENT

TABLE 1 LISTS THE SPECIFIC topics covered. Each topic is presented starting with fundamental considerations and proceeding to rational methods for design specification or process analysis. Comprehensive problems are assigned, based on actual wastewater treatment experience whenever possible. Table 1 includes recommended texts. Locating suitable books was a problem, since environmental engineering texts generally devote considerable coverage to fundamental physical chemistry, transport phenomena and reaction kinetics.

"Wastewater Engineering," as a course for specialists in the field, concentrates on the widely used minimum-operating-cost "workhorse" processes, which can remove many pollutants together. Biological treatment heads the list of these topics, as the unit process of choice for removal of biodegradable organic pollutants from municipal or industrial wastewaters. It is difficult to conceive of other treatments which could be economically competitive to biological treatment. Sedimentation also is stressed, as an integral part of biological waste treatment processes and, in its own right, as the unit operation of choice for removal of settleable pollutants. Precipitation is widely used in municipal and industrial wastewater treatment for removal of inorganic pollutants by conversion to insoluble forms and sedimentation or other liquid-solid separations. Oxidation-reduction processes are used principally in in-

TABLE 1

Topics In Wastewater Engineering

Topics	Textbooks
1. Biological Waste Treatment (15 lectures)	Busch[1]
a. Basic microbiology.	
b. Stoichiometric and kinetic relations of mixed cultures, including both organic and inorganic substrates.	Weber,[2] Ch. 11
c. Biodegradability and respirometric measurements.	
d. Biological treatment process configurations, including auxiliary facilities for aeration, mixing, and sedimentation.	
e. New developments including unsteady-state analysis, use of purified oxygen, rotating fixed-surface growth, etc.	
2. Sedimentation, Clarification and Thickening (9 lectures)	Weber,[2]
a. Flow regimes for gravity settling, including free-falling particles, hindered settling and zone settling.	Ch. 3, 12
b. Solids flux concepts and design methods.	
c. Differentiation between requirements for clarification vs. those for thickening.	
d. Integration of sedimentation vessel design with the biological treatment reactors.	
e. Tube-settler operation.	
3. Precipitation (9 lectures)	
a. Physical chemistry of ionic equilibria.	Weber,[2] Ch. 2
b. Effect of complexing agents.	Stumm and Morgan[3] Ch. 5, 8, 10
c. Use of pH-solubility diagrams.	
d. Statistical approaches for application of laboratory or pilot data to design.	
4. Oxidation-Reduction (6 lectures)	Weber,[2]
a. Stoichiometry for common oxidants and reducing agents.	Ch. 8 Stumm and Morgan,[3] Ch. 7
b. Reaction rate concepts.	
c. Oxidation-Reduction Potential and relations to electrochemical processes.	

dustrial wastewater treatment, to change inorganic pollutants either directly into innocuous forms (e. g., conversion of cyanides to CO_2 by chlorine oxidation) or into another form more tractable for treatment by conventional processes (e. g., reduction of chromates to trivalent chromium ions prior to precipitation of the insoluble $Cr(OH)_3$).

LABORATORY PROGRAM

FOUR EXPERIMENTS ARE OFFERED with "Wastewater Engineering" on Biological Waste Treatment, Biological Respirometry, Sedimentation and Thickening, and Precipitation Processes. They have been selected and developed, based on the following criteria:

- **The experiments must complement and relate directly to the course material.**
- **They must be realistic in the sense that data obtained from the experiment can be applied to design problems discussed in class.**
- **It is important that the experiments are carried out in a manner that allows students to participate and, thus, obtain "hands on" experience.**
- **The experiments should be organized into laboratory sessions no longer than about three hours.**
- **The students should be able to operate all necessary equipment without extensive training.**

BIOLOGICAL TREATMENT

This experiment provides students with the opportunity to measure the reaction rates and stoichiometry of the bio-oxidation of a particular waste. They obtain the data by monitoring changes in organic substrate and suspended solids concentrations occurring for a mixed culture in a batch reactor. This permits the experiment to be completed in one laboratory period. A continuous reactor at steady state would provide only a single rate measurement during the same time span.

Careful preparation is needed beforehand to assure that the rates measured in this experiment approximate those of a full scale system. The mixed culture must be acclimated to the waste and mode of operation, and the average bacteria floc size should be similar to those found in full scale systems. Both acclimatization and classification of flocs by size can best be carried out in a continuous system in which bacteria are recycled.* These steps require a separate reactor and consume more time and attention than the experiment itself. For example, during acclimatization care must be taken to avoid filamentous growth on the walls of small reactor vessels. Such growth represents an active bacteria population which is significant on the laboratory scale but negligible in full-scale operation.

The Total Organic Carbon (TOC) or Total Carbon analyzers are the most efficient means of measuring substrate concentrations. Indeed, this experiment would not be feasible if we had to use the difficult, inaccurate and time-consuming B. O. D. or C. O. D. tests. Suspended solids (a measure of bacterial culture concentration) are monitored gravimetrically.

Students calculate yield factors and rate constants for substrate oxidation directly from the data obtained here. Usually the change in microbial mass during the batch experiment is not large enough to obtain a good estimate of the culture's specific growth rate. This can be better determined from measurements of sludge wasted in a continuous system (i e., either full- or bench-scale). With this additional information, students are able to: 1) select the operating level of bacteria and specify the hydraulic residence time, 2) specify sludge waste rate, and 3) determine theoretical aeration requirements for a full scale reactor.

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BIOLOGICAL RESPIROMETRY

EXPERIMENTS IN RESPIROMETRY illustrate a number of points pertinent to biological waste treatment. A sample of waste is seeded with bacterial culture and then isolated in a stirred container with air or oxygen in the gas cap. Pressure changes resulting from the absorption of evolved carbon dioxide and uptake of oxygen by the culture indicate the extent of oxidation. Inexpensive, direct-reading apparatus is available commercially. (Hach Chemical Co. Model 2173), as well as more elaborate electrolytic equipment which log the data automatically.

*For experiments involving industrial wastes, a commercially available bench scale reactor-settler is recommended. (Cole Parmer: Bio-Oxidation Reactor). A more expedient approach is to use samples of a waste (e. g., primary effluent) and culture (activated sludge return) obtained from a local treatment plant.

This experiment takes a number of days to run, 3-6 days for carbonaceous oxidation only and up to 10 days for nitrification. Students are organized into teams to carry out monitoring around the clock over the desired period.

Tests carried out simultaneously on a number of containers demonstrate the effects of bacterial seeding, stirring, substrate concentration, etc. on the shape of the uptake curves. This experiment illustrates the relationships among B. O. D., C. O. D. and T. O. C. The students complete this study with a comparison of the observed uptake curves to the ideal characteristics proposed in the lectures.

SETTLING MODES

Students observe the characteristics of hindered and zone settling modes, and measure the rates of settling at each condition. The major apparatus is simply a 6" I. D. x 7 ft. high plexiglass column which is equipped with sampling ports. The batch settling tests are carried out with actual wastewater samples, (e. g., primary influent and aeration "mixed liquor"). An investigation of each condition occupies one laboratory period.

The settling rates are determined from changes in suspended-solids concentration profiles during settling. In hindered settling studies, the concentrations are measured directly. In zone-settling studies, the concentration is estimated indirectly from the sludge blanket height. Graphical methods introduced in the lectures are used to calculate the rates from these profiles. This permits students to specify the basin areas required in continuous operations. Comparative studies with and without flocculation aids would illustrate their effects on the design specifications.

PRECIPITATION PROCESS

A precipitation process of considerable local interest is removal of phosphates. Both stages of precipitation, nucleation and flocculation, can be readily investigated in a simple batch reactor in which mixing is controlled, (i. e., a jar test).

Stirring equipment designed especially for this experiment is available commercially (Phipps & Bird Stirrer). Students investigate the effects the following variables on treatment efficiency:

- **Wastewater composition (e. g., solution pH, alkalinity, particulate concentration, and initial phosphorous concentration),**
- **Ratio of ortho- to poly-phosphates,**
- **Type and dosage of precipitant (e. g., lime, alum or ferric salts),**
- **Type and dosage of flocculant aids (e. g., anionic and cationic polymer), and**
- **Turbulence level (i. e., mixing intensity).**

Though each test can be completed in 30 minutes, a large number of tests are required. The present state of the art is empirical, and thus the effects of the above variables must be determined for each particular waste. Also, as the composition of a waste usually varies with time, there is a further problem of determining chemical dosage which results in the desired removal over a specified percentage of the time.

Both problems require that the students apply statistical techniques discussed in class. An efficient approach to experimental design permits the relative importance of independent variables to be sorted out in a minimum number of tests. The problem of specifying suitable levels of the chemical dosage is solved by a frequency-of-occurrence analysis. Because each problem requires at least 8-10 tests to be carried out, the chemical analysis must be efficient. For example, an automated system (Technicon Autoanalyzer II) is used here to carry out phosphorus measurements.

RELATION TO OTHER COURSES

"Wastewater Engineering" is one of three graduate chemical engineering courses which deal primarily with wastewater topics. "Separation Science" deals in part with the more costly selective membrane and packed-column processes, which find application for industrial wastewater treatment either to meet stringent effluent quality requirements or for recovery byproducts. "Colloidal Systems" deals with fundamental considerations on coagulation and flocculation and on the nature of turbidity. This adds to understanding of sedimentation and precipitation processes.

These three, plus courses on "water Resources" and on "Legal, Economic and Political Aspects of Water Pollution" available through Systems Engineering provide a core program for chemical engineers specializing in wastewater. Added to traditional chemical engineering graduate courses in thermodynamics, transport phenamena and chemical reaction engineering, this provides a unique background for professional careers in development and design of treatment facilities for industrial wastewaters or for advanced municipal wastewater treatment. A measure of our success with this program is that all of our graduate students who have completed it to date are active in the area.□

REFERENCES

[1]Busch, A. W., *Aerobic Biological Treatment of Wastewaters*, Oligodynamics Press, Houston, 1971.

[2]Weber, W. J., editor, *Physiochemical Processes for Water Quality Control*, Wiley, New York, 1972.

[3]Stumm, W. and Morgan, *Aquatic Chemistry*, Wiley, New York, 1970.