M. S. CORE COURSES

ROBERT B. GRIEVES
University of Kentucky,
Lexington, Kentucky 40506

THE MOST APPROPRIATE undergraduate background for graduate work in water pollution control engineering is open to question; both chemical engineering and civil engineering have certain advantages. However, for graduate work in air pollution control engineering, there is virtually no question concerning the most appropriate background. The chemical engineer, with his knowledge of chemistry, engineering thermodynamics, diffusion and mass transfer, process control, and process design is best prepared, in comparison with BS degree holders in the other engineering and physical science disciplines.

At the University of Kentucky, a specialized MS program was initiated two years ago to give advanced training in air pollution and its control. The program is designed to prepare chemical engineers and some mechanical engineers) for employment by municipal, state, or federal (Public Health Service) control agencies, by industries selling in the air pollution control market, and by industries with air pollution problems. At present there are eight full-time graduate students in the program (not including those in the "regular" chemical engineering MS and PhD programs), and eight MS degrees in chemical engineering with specialization in air pollution have been awarded in the past twelve months.

THE MS PROGRAM consists of three parts. First, an acceptable thesis is required on a topic associated with atmospheric pollution and its control. Thesis topics range from research on chemical and physical processes for SO_X and NO_X control to research on the transport of pollutant gases through the human respiratory system. Second, four graduate courses (3 semester hours each) in chemical engineering and mathematics fundamentals are required:

(1) Equilibrium Thermodynamics, (2) Transport Phenomena or Advanced Transport, (3) Engineering Statistics or Applied Calculus II, and (4) Chemical Reactor Design or Advanced Reactor Design, or Process Control or Advanced Process Control.

The third requirement is a series of four courses, constituting the air pollution core. In the core, an effort is made to convey the breadth of the field; however, by utilizing a total of 12 semester hours (one full semester of graduate work) sufficient depth can be achieved in several important facets of the field. A fifth course, taught in mechanical engineering on fuels, combustion, emission evaluation, and stack and automotive sampling is often taken by chemical engineering air pollution students. An air pollution seminar, using both outside and in-house speakers, attempts to alleviate some deficiencies in the area of biological and health aspects.

THE DIAGRAM PRESENTED in Figure 1 is the basis for the air pollution core. The overall approach of the core is first the proper evaluation of the effects of the numerous air pollutants, leading to the establishment of air quality standards; and then a consideration of the reactions and transport of pollutants in the atmosphere, which provides the connection between air quality standards and emission standards. Based on emission standards, the specific problem of air pollution control can be put into perspective, first considering the design of control measures and gas cleaning devices and then the evaluation of the effectiveness of the control.

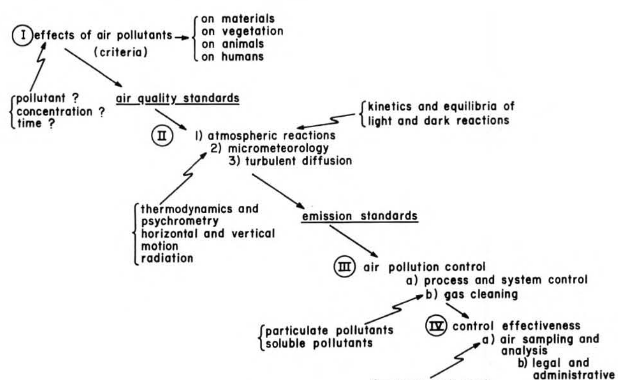

Figure 1. Design for air pollution core courses.

Each of the four numerals in Figure 1 indicates one of the core courses. A specific text is not used in any of the courses, principally because there is no appropriate textbook in the field. In the four courses extensive use is made of A. C. Stern's *Air Pollution* (Academic Press, 1968) which in its three volumes and 2200 pages covers

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the breadth of the field. For the most part, current research papers (Stern has provided an excellent literature review through 1967), government publications including the *Air Quality Criteria* series and the *Control Techniques* series, and handout material on such topics as reaction mechanisms in photochemical smog and design approaches for gas cleaning devices are adequate substitutes for a text. A paper-bound text by W. P. Lowry and R. W. Boubel, *Meteorological Concepts in Air Sanitation* (published by the authors at Oregon State University, 1968), is used for about one third of the course on the reactions and transport of pollutants. Outlines of the four core courses are given in Table 1.

TABLE I. CORE COURSE OUTLINES

I. **Air Pollutant Effects**
- A. Effects of air pollutants on the atmosphere
  - Alterations to radiation
  - Effects on weather
  - Changes in the constituents of the natural atmosphere
- B. Effects on vegetation and foraging animals
  - Types of injury to plants, causative agents, conditions of exposure
  - Ambient and laboratory bioassay
  - Susceptibility of livestock
- C. Effects on man
  - History of acute episodes
  - Epidemiology
  - Toxicology
- D. Effects on materials
  - General deterioration and specific materials
  - Economic considerations
- E. Airborne, waterborne, and solid wastes
  - Interrelationships of potential and of control
  - Ultimate disposal

II. **Reactions and Transport of Pollutants**
- A. Atmospheric chemistry
  - Basic concepts; kinetics, photochemical reactions, heterogeneous reactions
  - Inorganic atmospheric reactions; scavenging
  - Organic reactions; photochemical smog
- B. Atmospheric thermodynamics and stability; pseudoadiabatic chart
  - Thermodynamics and psychrometry
  - Statics, lapse rates, stability
  - Applications of the pseudoadiabatic chart
- C. Atmospheric motion
  - Scales of motion
  - Wind speed variation
  - Small scale vertical motion
  - Air pollution climatology: air patterns, stagnation, and inversions
- D. Diffusion in the atmosphere
  - Model of area-source diffusion
  - Single stack emission; plume characteristics
  - Models for diffusion
- E. Atmospheric radiation; energy budget

III. **Air Pollution Control**
- A. Removal of soluble pollutants from air streams
  - Application of principles of mass transfer
  - Engineering considerations of absorber design
  - adsorption applications; the adsorption process; design
- B. Removal of particulate pollutants from air streams
  - Efficiency and selection of collectors
  - Cyclone separators
  - Gravity and impingement collectors
  - Filters
  - Electrostatic precipitators
- C. Process and system control
  - Elimination of emissions
  - Minimization of emissions
  - Concentration of air pollutants at the source
  - Optimization of combustion
- D. Use of current literature for control problems

IV. **Effectiveness of Control**
- A. Broad considerations in sampling
  - Site criteria; sampling network; statistics
- B. Review of analytical techniques
  - Radiation instrumentation; electrical; mass spectrometry; chromatography
- C. Passive effect devices
- D. Sampling proper
  - Aerosol sampling; gas sampling absorption, absorption, and condensation.

Robert B. Grieves is Professor and Chairman of the Department of Chemical Engineering at the University of Kentucky and is director of a graduate training program in air pollution control. He received MS and PhD degrees in chemical engineering at Northwestern and has taught at Northwestern and at the Illinois Institute of Technology. His interests include membrane transport, foam separation, and air and water pollution control technology.

E. Analysis of particulates
Physical; inorganic chemical; organic chemical
F. Odor in ambient air
G. Analysis for gaseous pollutants
Inorganic gases; organic gases
H. Legal and administrative aspects

Students specializing in air pollution are studying a problem and the approaches to its solution. Consequently, two potential dangers must be carefully watched and avoided: first, that the core program can become too broad and too qualitative. To overcome this danger, fundamentals are stressed whenever possible, for example in considering atmospheric photochemistry or atmospheric diffusion, and engineering design is introduced whenever passible, for example in gas cleaning. The second concern is that the problem and the approaches to its solution change very rapidly. To overcome this danger, the only answer is the use of the latest research and development publications in the field.

ChE classroom

PROCESS DYNAMICS, Without Control

JOHN C. FRIEDLY
University of Rochester
Rochester, N. Y. 14627

Process dynamics has traditionally been closely associated with the field of process control. Indeed it was a natural marriage. Control systems by their very nature modify the unsteady state response of a process. However, process dynamics need not be so restricted in application. Clearly such diverse problems as dynamic measurement of rheological properties, batch processing, molecular excitation and relaxation, periodic operation of processes and the onset of hydrodynamic instabilities all have a common foundation in process dynamics. Problems in stability, for example, arise not only in analysis of control systems, but also in thermodynamics, boiling heat transfer, reactor analysis and hydrodynamics, among others.

There is a need then for a common fundamental discipline concerned with unsteady state problem is engineering. Presentation of dynamic ideas may come in a rather natural context in control system analysis. It is the writer's experience that more difficulties arise when presented in other surroundings. Chemical engineers have been traditionally steeped in steady state concepts. From the period when analytical description of processes became feasible, continuous steady state operation was the ideal. Only recently has this accepted norm been challenged. Periodic operation of processes can prove to be optimum in some economic sense. So ingrained is the steady state concept though, it is often difficult to get across the idea that a process cycle is not necessarily a repeating sequence of different steady states. This could be remedied by proper exposure to the fundamental concepts of process dynamics.

THE NEED FOR A fundamental understanding of process dynamics, divorced from specific fields of application, increases each year. Engineers are being called on to contribute their techology to important social problems. Blind application of traditional chemical engineering techniques to problems in biomedical and environmental engineering, for example, might prove disastrous. It is perhaps clear that processes occurring in the human body vary continually with time. The steady state concept may be virtually nonexistent there. Application of steady state analysis to environmental problems may be more insidious. A large lake, for example, may respond to changes with a time constant on the order of months rather than minutes. Changes with time may be so slow that the natural temptation would be to assume that a quasi-steady state prevails. Serious errors may result in trying to use steady state models to describe observed data.

The basic ideas of process dynamics must be incorporated into any chemical engineer's education. It is the writer's opinion that process dynamics should be taught in a core of fundamentals. Process control is an application of these fundamentals, but only one of a variety of applications. To a certain degree process dynamics is to process control as transport phenomena is to diffusional operations.