A Course in

DESIGN OF AIR POLLUTION CONTROL SYSTEMS

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THE COLLEGE OF ENGINEERING at the University of Cincinnati has a program in Environmental Health Engineering which is administered under the Department of Civil Engineering. A curriculum in air pollution control leading to M.S. and Ph.D. degrees, was established three years ago with the support of a training grant from the National Air Pollution Control Administration of the U. S. Department of Health, Education and Welfare. This grant also supports a concurrent program given in the Kettering Laboratory of the Department of Environmental Health of the College of Medicine.

The Engineering program is being presented by a team of three faculty members headed by Dr. John N. Pattison, Research Professor of Environmental Health Engineering. I was invited by Dr. Pattison to present the contributions which the discipline of chemical engineering can bring to bear on the solution of control problems. Third member of the team is Professor Charles W. Gruber who is a mechanical engineer and served for a number of years as the air pollution control officer of the City of Cincinnati.

Dr. Pattison's invitation was accepted enthusiastically for two principal reasons. First, because I have had a long-standing interest in particulate (fluid-solid) systems such as are involved in dust collection. But equally important, I have a firm conviction that chemical engineers have the best background of *any* discipline from which to tackle pollution control problems. There is a great challenge and opportunity for them to use their talents and training in this way. As an educator I feel a real responsibility to bring this to their attention and to provide encouragement, as well as the education, for them to consider a career in the environmental control field. I saw the new Air Pollution Control program as an excellent opportunity to do this.

Dr. William Licht, a graduate of the University of Cincinnati, has been Professor of Chemical Engineering there since 1952. He also served as Head of the Department of Chemical and Metallurgical Engineering from 1952 to 1967. His industrial experience includes a period of employment with the Dow Chemical Company and various consulting assignments. The latter were especially related to work on the drying of refrigerants and gases, and recovery of dust by filtration. His technical publications and patents also disclose the results of research on the properties of azeotropic mixtures, development of dew-point indicators, adsorption in fixed beds, and transport phenomena involved with moving drops. In 1967 he became associated with the air pollution program in the Environmental Health Engineering activities of the College of Engineering, in which he is presently teaching Design of Air Pollution Control Systems. He is also serving as Vice-chairman of the Air Pollution Board of the City of Cincinnati.

AS A FIRST STEP in this direction, a senior level undergraduate elective course "Introduction to Air Pollution Control" was developed at Cincinnati, and also given at Minnesota (as a Visiting Professor in Chemical Engineering) in 1968. This year over half of the 65 students enrolled in the course, now given by Professor Gruber, were chemical engineering seniors.

The students in the graduate program, however, are welcomed with a rather wide variety of backgrounds in several branches of engineering, as well as in chemistry or physics. They also have a variety of career objectives. Some are aiming toward positions in government control agencies, others to industrial engineering work, and still others to the design and research of control methods. Consequently, the courses given, and the program for each student, must involve

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a high degree of flexibility and adaptability.

The principal graduate course which brings the chemical engineering approach into the program is called "Design of Air Pollution Control Systems". It is offered as a second level graduate course following prerequisite courses in Small Particle Technology and in Air Pollution Control Methods. Chemical engineers however usually can enter the course without these formal prerequisites. They find it relatively easy to pick up the necessary material because of the nature of their general background.

Small Particle Technology is essentially a treatment of particle-fluid mechanics. It deals with the motion of aerosol particles under the influence of various forces such as gravitational, inertial, centrifugal, electro-static, diffusional thermophoretic, photophoretic, etc. In particular, motion is studied in the neighborhood of surfaces of various shapes: plane, cylindrical, and spherical. Methods of measuring particle size, and describing size distribution in particulate mixtures are also studied. The text has been Fuchs' "Mechanics of Aerosols" (Macmillan, 1964). Davies' "Aerosol Science" (Academic Press, 1966) is also an appropriate source of material.

AIR POLLUTION CONTROL METHODS is a survey of the various devices available for the collection of particulate matter (cyclones, scrubbers, electrostatic precipitators, filters, etc.) and processes for the collection of gases (absorption, adsorption), or for gas and odor removal by combustion. The principles involved in the operation and successful application of the devices are discussed qualitatively, and from a practical industrial point of view. Field trips and methods of measuring source emission are also included. The reference text is "Air Pollution Engineering Manual" from the U. S. Public Health Service.

With a background equivalent to these two courses assumed, the course in Design presents the mathematical modelling of the collection devices and systems. It is presently given in a two-quarter sequence of three (quarter) credits each i.e. a total of about 60 lectures. However, since it has so far been presented only twice it is still in a state of development. Future plans contemplate expansion of this course to three quarters.

The first quarter begins with a comprehensive check-list of all the factors which might need to be taken into account in designing a control system to meet a given pollutant emission problem. This provides an outline and a motivation for the topics which follow.

We then take up the modelling of particulate collection devices. The objective of the models is twofold: to predict the efficiency of collection as a function of system parameters, and to predict the pressure drop, hence energy requirements for operation. The order of topics is arranged according to increasing complexity of the system of collecting forces involved, as follows:

Collection on surfaces
- **— Gravity settling chambers (gravitational)**
- **— Electrostatic precipitators (electrostatic)**
- **— Cyclones (centrifugal, and gravitational)**

Aerodynamic capture
- **— General principles**
- **— Filters (inertial, diffusional, electrostatic)**
- **— Scrubbers (inertial, gravitational)**

The "classical" models for most of these devices are rather unsophisticated and oversimplified. They tend to assume plug flow, for example, and to ignore boundary layer effects, as well as turbulence. They always assume that when the path of a particle is such as to bring it into collision with a surface it will be collected or captured on that surface.

It is not surprising to find that the degree to which the models succeed in representing actual performance is poor. Attempts are made to develop more sophisticated models by taking into account such concepts as turbulent mixing of dust in gas streams, velocity distributions, residence time distributions, and boundary layer behavior. These are all concepts drawn from various standard chemical engineering operations which seem to be transferable to the particulate collection problem. Research projects are under way in this connection.

THE SECOND QUARTER is largely devoted to the collection of gases and to the chemical aspects of emission control. Gaseous collection is considered first by a continuation of the study of scrubbers used as gas absorbers, and of gas absorption design in general. This is followed by fixed-bed adsorption. Combustion calculations are then reviewed and extended to the complex systems encountered in stack or exhaust gases containing oxides of sulfur and oxides of nitrogen. The role of the thermodynamics and kinetics of the reactions involved in the formation of these pollutants is explored. Special effects relating to the psychrometry of these stack gases are also presented. Finally, we examine specific control methods which are now being developed for certain gases.

At various appropriate points in the course the basic concepts of system and equipment design optimization are introduced and applied to the air pollution control system. Generalizations relating to costs and economic aspects of control systems are likewise brought in. It would be desirable to give a more thorough treatment of these matters. This is one motivation for lengthening the course to three quarters. It would also be desirable to present computer simulation of control devices.

The method of instruction involves asking the students to solve a number of problems specially devised for the course. Some of these are numerical illustrations of the use of the models or design methods. Others, however, are open-ended design problems in which judgment and ingenuity may be exercised and alternative solutions considered. The effect of a particular system parameter is illustrated by having different members of the class do the same calculation with each using a different value of the specified parameter, and then pooling the results into one overall picture.

There really is no text which is quite appropriate for this course as it is now conceived. The one used thus far has been "Industrial Gas Cleaning" by Strauss (Pergamon, 1966). Material has also been drawn from Stern's "Air Pollution", especially Vol. III of the 2nd edition (Academic Press, 1968). Much use is made also of original literature references. There is a lot of interest in these problems today, and new work is appearing with increasing frequency.

It is hoped that chemical engineering students will find increasing interest in dealing with air pollution problems, especially through the approach taken by such a course as this. Many of the concepts which are familiar to them in reactor design and in transport phenomena, can be transferred immediately with very fruitful results. Every effort is made to show them, and all students, that the pollution problem is not only serious enough to demand their attention as concerned citizens, but also challenging and sophisticated enough to captivate their intellectual interest at the highest level of professional competence. This applies not only to the present, but certainly even more so to the future developments in research and design.

ChE problems for teachers

Submitted by Professor R. M. Felder, North Carolina State University at Raleigh.

A graduate student in your seminar on existential reaction engineering bursts into your office, barely giving you time to cover Playboy with Chemical Engineering Progress, and announces that he has formulated a proof of man's nonexistence based on the known effects of diffusion in tubular reactors. All thoughts of the Playmate of the Month are forgotten as visions of publications, promotions, awards and enduring fame dance in your head. (You would, of course, acknowledge helpful discussions with the student in a footnote somewhere.) You casually express an interest, and the student promptly erases the irreplaceable notes on your blackboard and offers the following demonstration:

Consider a laminar flow tubular reactor in which a single first-order reaction occurs. Now

1. Radial diffusion brings the reactor closer to plug flow, and therefore increases conversion. On the other hand
2. Axial diffusion brings the reactor closer to a stirred tank, and therefore decreases conversion. But
3. Radial diffusion can be represented as axial diffusion using the Taylor model. Therefore
4. Radial diffusion both increases conversion [from (1)] and decreases conversion [from (2) and (3)]. The only way this can be the case, however, is if
5. Radial diffusion does not affect conversion at all. But we all know that it does, and consequently
6. Radial diffusion does not exist. Moreover, by applying a coorrdinate transformation which maps the radius onto the axis and vice versa, it can easily be shown that axial diffusion also does not exist. In short,
7. There is no such thing as diffusion in tubular reactors. But everyone knows there is, and therefore
8. Tubular reactors do not exist. But I am certain beyond all possible doubt that tubular reactors exist, which can only mean that
9. I do not exist. Q.E.D.

Sadly, you realize that you might just as well have kept your thoughts on Miss October, and that any enduring fame you get will have to come from your process to manufacture sand from glass (patent applied for). Meanwhile it's almost time for lunch, so you decide to ignore the student's philosophical fallacies and simply advise him where his engineering analysis [Steps 1-4] falls down. What do you tell him?