



SPRING 1971

Arizona's **RANDOLPH:**

*"...A balanced synthesis of
experiment and theory"*



RELEVANCE: academic research Bankoff

AIR POLLUTION: core courses Grieves

SOVIET EDUCATION: detsky sad to aspirant A & I Myers

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DYNAMICS: without control Friedly

REACTORS: stability experiment Anderson

POLYMERS: flow experiment Rodriguez

DERIVATION: polytropic processes Tiller and Lowry

AIChE: committee reports Andersen & Timmerhaus



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SPRING 1971

Chemical Engineering Education

VOLUME 5, NUMBER 2

SPRING 1971

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CHEMICAL ENGINEERING EDUCATION is published quarterly by the Chemical Engineering Division, American Society for Engineering Education. The publication is edited at the Chemical Engineering Department, University of Florida. Second-class postage is paid at Gainesville, Florida, and at DeLand, Florida. Correspondence regarding editorial matter, circulation and changes of address should be addressed to the Editor at Gainesville, Florida 32601. Advertising rates and information are available from the advertising representatives. Plates and other advertising material may be sent directly to the printer: E. O. Painter Printing Co., P. O. Box 877, DeLeon Springs, Florida 32028. Subscription rate U.S., Canada, and Mexico is \$10 per year to non-members of the ChE Division of ASEE, \$6 per year mailed to members and \$4 per year to ChE faculty in bulk mailing. Individual copies of Vol. 2 and 3 are \$3 each, Copyright © 1971, Chemical Engineering Division of American Society for Engineering Education, Ray Fahien, Editor. The statements and opinions expressed in this periodical are those of the writers and not necessarily those of the ChE Division of the ASEE which body assumes no responsibility for them. Defective copies replaced if notified within 120 days.



ZERO POPULATION GROWTH

We have a lot to do in the next few years if man is to survive. The key problem is overpopulation. The U.S. population is gaining 6,035 daily, 82% babies.

In order to live, we have to obtain certain things from the Earth. In order to have meaningful, happy lives, we have to preserve the quality of our environment. We have already suffered irretrievable losses. No matter what we do now, no matter how wise we are, there will be great future losses.

The **only** long-range solution is population stability achieved by the one or two child family.

Some population-related problems

POLLUTION:

Air: smog, noise, fallout
Water: sewage, thermal, industrial
Land: garbage, litter, junkyards, mining, roads
Biological Systems: pesticides, bioactive chemicals, radioactivity

CROWDING:

Tension
Indifference—cheapening of life
Jams—traffic, airways
Blight—slums
Crime
Congested parks

QUALITY OF LIFE:

Space—hiking, thinking
Quiet
Wilderness—wildlife
Individuality

SHORTAGES:

Minerals
Energy—oil, gas, coal, uranium
Water
Land—open space, forests, agriculture, recreation

FACILITIES:

Food
Housing
Schools—higher education
Hospitals—medical care
Services—fire, police, courts
Cultural
Transportation—highways, mass transit, airports

SOME PREDICTIONS:

296 million in U.S. and 6 to 7 billion on earth by 2,000 A.D.
Without ZPG, mass famine with 25 billion by 2,070 A.D.

Recommended reading on population and environmental problems:

1. **The Population Bomb** by Paul Ehrlich (Sierra Club-Ballantine).
2. **Moment in the Sun** by Robert Rienow and Leona Train Rienow (Sierra Club-Ballantine).
(Above 2 books available from ZPG, postpaid \$1.00 each)
3. **Famine—1975!** by William & Paul Paddock (Little, Brown).
4. **Population, Evolution, and Birth Control**—A Collage of Controversial Ideas, assembled by Garrett Hardin (Freeman).

• ZERO POPULATION GROWTH is a political action organization whose purpose is to bring about population stability in the United States, then in the rest of the world. We will achieve this end by political and educational means.

• ZPG has chapters throughout the United States. These chapters are working units. Many are in college communities.

• Our earth is burdened by 8,292 additional people per hour—all infants.

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RELEVANCE OF ACADEMIC CHEMICAL ENGINEERING RESEARCH

S. G. BANKOFF
Northwestern University
Evanston, Illinois 60201

The word "relevance" has taken on many hues and shades of meanings in recent years, and it has been particularly overused in academic circles. It denotes, however, a valid concept with relation to engineering, which must be relevant to the needs of society if it is to fulfill its mission, and, in fact, if it is properly to remain a professional activity. Chemical engineering has expressed its awareness of societal needs mainly through the chemical industry, which employs engineers to translate the discoveries of science (principally chemistry) into useful products at a price which is attractive to large segments of society. In recent years the role of the chemical engineer has been broadened to include contributions to environmental, health, and food and energy production problems of society at large, but the principal channel for his efforts has been, and remains, the chemical industry. The relations between academic departments of chemical engineering and industry are, therefore, still of prime concern, as discussed recently in the Wilke report.¹ This report makes a number of recommendations of a general nature for strengthening the ties between chemical engineering academia and industry, such as personnel exchange programs, advisory boards, etc., but does not concern itself with the nature of the research bond between the two groups. This bond has become progressively weaker in the past twenty years, for perhaps very understandable reasons.

One factor is the increasing role of technological obsolescence among practicing engineers of all ages, due to the highly scientific and mathematical directions in which engineering research has developed, and the accelerating pace of that development. These are facts which cannot be blinked away, and which call for greatly expanded programs, both on the part of universities and



Professor Bankoff writes: "The relevant part of my autobiography would be that I have spent six years with DuPont and Sinclair before entering teaching, that I and my students have been prolific contributors to the chemical engineering research literature, and that I have been Chairman of the Education and Accreditation Committee of AIChE, as well as AIChE Observer for the Engineering and Accreditation Committee of E.C.P.D. for nearly three years. In 1967, I was a Shell Visiting Professor at Imperial College, London, and a Fulbright Lecturer in Scandinavia and Israel. Purdue named me a Distinguished Engineering Alumnus in 1970. I have four children ranging in age from 10 to 25, and from a student of the violin to a lawyer. I prefer squash, but also play handball (viz. the tournament held at Northwestern during the Chicago AIChE meeting for visiting chemical engineering professors)."

professional societies, for continuing education at all levels, and geared to a variety of needs. Less easy to overcome are management attitudes towards monitoring the academic chemical engineering literature, on the grounds that the cost is not worth the likely return on investment. This is manifested in the opinion, sometimes stated by middle management, that if several of the chemical engineering research journals were to be delayed in publication for two years, little would be lost.

There are, of course, some elements of truth in these assertions, and to that extent they must be treated with serious concern. There is also clearly an atrophy of communication channels, and this cannot help but damage the profession. As an example, there has been a considerable effort in academic circles on chemical reactor design, including stability analysis, optimal design by variational methods, and, most recently, a number of papers on optimal operating policies for decaying-catalyst reactors (which include virtually all real reactors). However, an informal survey of design and computer groups of several

1. Wilke, C. R., *Chem. Eng. Progress* 65, 20 (1969).

. . . one should not lose sight of the fact that academic research should be relevant, not solely to the needs of industry, but basically to those of society, which supports it through tax dollars. The engineer has a responsibility to consider, therefore, the social consequences of his work, and insofar as he can, to guide it in a direction which will add to, rather than subtract from, the sum total of human happiness.

major companies recently turned up the information that this work had had very little impact, if any, on their current operating or design procedures.

Why has this isolation into separate compartments come about? In Europe academic chemical engineering research is much more practically oriented, and this points to a principal element in the present syndrome. It is as true now as in earlier times that he who pays the piper calls the tune, and less than 10% of current chemical engineering research support in American universities is obtained from industry. Professors have oriented their research proposals towards impressing their peers and their colleagues in the funding agencies, and this, in turn, has led to an emphasis on scientific innovativeness, rather than applied research.

Now all this is not necessarily bad. One of the oldest complaints of the man who cannot understand current research is that it is all impractical, which is invariably accompanied by the assertion that the old problems are still important. Historically, there has always been a lag between academic engineering research and practical application, although of late this has become shorter and shorter. Thus, there was an exponential increase in the number of papers devoted to thin-shell theory in the late forties, until in the early fifties the first monococque airplane wing was introduced. More recently, the development of optimal control theory and the design of space vehicle trajectories have proceeded almost simultaneously. Academic engineering research is seldom of lasting value when it addresses itself directly to industrial development or production problems. On the other hand, it should not lose sight of these problems, and, in some sense, it should be motivated by them. One distinction that has been made between the applied mathematician and the theoretical engineer is that the engineer solves specific theoretical problems of an engineering nature, while the applied mathematician tries to generalize these problems by studying their mathematical structure. In the same way, academic chemical engineering research should rarely deal with specific chemical process developments, but instead should be concerned

with basic principles and generalizations of industrial and societal problems. To the extent that this connection is lost, to that extent the research tends to become isolated and sterile.

What can be done to bridge the gap? Clearly, new and more effective means of communication must be set up. One avenue which has not been fully exploited in chemical engineering is the specialist conference, dealing with a particular area of technical interest, and usually lasting several days. These should feature leading contributors, both academic and industrial, to the field, and the program should allow for a thorough review and discussion of current aspects and future goals. The Gordon Research Conferences and the Engineering Foundation Conferences are examples of useful specialist conferences, but the central areas of chemical engineering have rarely been touched. A considerable expansion of these specialized conferences, designed on a regular and periodic basis to attract participants, both academic and industrial, on an international basis, would be most helpful in providing a forum for concerned research and design persons from both sides of the fence to get together in a critical and constructive fashion.

It may also be that a new type of journal or newsletter should be initiated, in order to bring the methods and results of current chemical engineering research to both industrial and academic readers in understandable, uncomplicated language.

Finally, one should not lose sight of the fact that academic research should be relevant, not solely to the needs of industry, but basically to those of society, which supports it through tax dollars. The engineer has a responsibility to consider, therefore, the social consequences of his work, and insofar as he can, to guide it in a direction which will add to, rather than subtract from, the sum total of human happiness.

from our READERS

CORCORAN SPEAKS OUT

Sir: In response to your Editorial (Winter 1971) I must agree with your statement that papers published in *CEE* would not have been published in *CEP*.

The whole rationale of the development of *CEE* was that papers of the type you have been publishing were not being published. Now that you have done this successfully, the obvious conclusion is that these papers should have been published in the past elsewhere. That is not sufficient reason as far as I am personally concerned to discontinue *CEE*.

If everyone agrees that the publishing of the papers of the type you have published is a good idea, either there should be more support from AIChE for the program, or AIChE taking over the program in its present form, or rearrangement of the plans for *CEP* to include papers like the ones you have been presenting. My personal feeling is that *CEP* and *CEE* are complementary and do not interfere with each other.

I hope that there will be an opportunity to continue *CEE* with its present focus. One way to enhance its impact is, like you say, to be sure that all people who are concerned with chemical engineering know that it exists. I do not believe that is the case with many of the industrial engineers at the present time. Those that have seen the magazine, in my opinion, have been very interested in reading it subsequently. We need to get the magazine before those people. That is one of our major problems at the moment.

Wm. H. Corcoran
California Institute of Technology

Editor's note: We appreciate this and similar indications of support that we have received.

MIT SUMMER PROGRAM

Sir: The following is a short announcement of a summer program at Massachusetts Institute of Technology, June 22 through July 1, 1971, on "NEW DEVELOPMENTS IN MODELING, SIMULATION, AND OPTIMIZATION OF CHEMICAL PROCESSES".

This special summer program will present basic principles necessary to understand and apply new techniques for computer-aided design and control of industrial-scale chemical processes. Topics to be covered include steady-state process stimulation, optimization techniques, unsteady-state process simulation, computer-oriented methods for estimation and correlation of physical properties, and comprehensive problem-oriented computing systems for chemical process design. Contact: Director of the Summer Session M. I. T., Room E19-356 Cambridge, Massachusetts 02139.

L. B. Evans
Massachusetts Institute of Technology.

"PRE-BIRDIAN" THROWBACKS

Sir: Since the advent of Transport Phenomena, the chemical engineer has become increasingly aware of the proper use of conservation laws in the lumped and distributed parameter simulation of physical systems. Coupled with the computer revolution, the chemical engineer has, for the first time, really begun to look at the variability in the system parameters as a means of in-

creasing the validity of the simulation. A classic example of this trend is in the use of the temperature variable heat capacity term in the analysis of unsteady-state stirred tank processes. Despite the ready availability of transport-oriented textbooks, we still see some throwbacks to "pre-Birdian" methods of analysis when faced with the problem of what to do with the variable parameter terms. There is hardly a chemical engineering textbook on the market today, with the exception of Aris' new chemical reactor analysis book, which has not in some way erroneously incorporated the variable heat capacity term into the unsteady-state thermal energy balance. Should the variable heat capacity term be inside or outside of the temperature derivative term in the energy balance? We wish to pin-point the origin of the question by referring to an example from Himmelblau and Bischoff, "Process Analysis and Simulation," page 30, Example 2.5-1, 1968. We would like to make it abundantly clear that this example from Himmelblau and Bischoff in no way detracts from their otherwise excellent textbook. Their example 2.5.1, page 30, is only slightly in error. It is the things not said that are of great consequence in the general use of their example problem for variable heat capacity cases. To ease the burden of the presentation, we shall use their nomenclature exclusively and commence our derivation using their equations (a) and (b), page 30, Thus,

$$\frac{dm_t}{dt} = (\rho v S)_{in} \quad (a)$$

$$\frac{dE_t}{dt} = [(\hat{U} + p\hat{V} + \hat{K})\rho v S]_{in} \quad (b)$$

By letting $\hat{K} = 0$, $E_t = U_t$, and $(\rho v S)_{in} = v_i$, equations (a) and (b) become:

$$\frac{dm_t}{dt} = v_i ; m_t(0) = 0 \quad (a^1)$$

$$\frac{dU_t}{dt} = (\hat{U}_i + p\hat{V}_i)v_i ; U_t(0) = U_i \quad (b^1)$$

The initial condition in equation (b¹) reflects the idea that the walls of the tank are radiating at T_i initially. The walls have no heat capacity. Basically, the system equations (a¹) and (b¹) describe the unsteady-state filling of an insulated evacuated tank with helium gas. Equation (a¹) represents the unsteady-state mass balance and equation (b¹) describes the unsteady-state thermal energy balance. The thermodynamic system is the mass of helium gas in the tank at any time. The system boundary is the wetted surface of the tank.

The reference temperatures are rarely needed explicitly in a derivation of this kind. At any time,

$$\frac{dm_t \hat{U}_t}{dt} = v_i \hat{U}_i + v_i p \hat{V}_i \quad (c)$$

Using equation (a¹), we can unfold equation (c) into

$$m_t \frac{d\hat{U}_t}{dt} = v_i (\hat{U}_i - \hat{U}_t) + v_i p \hat{V}_i \quad (d)$$

The term $p \hat{V}_i$ is given for an ideal gas by

$$p \hat{V}_i = \frac{RT_i}{(M.W.)} \quad (e)$$

Therefore, equation (d) becomes

$$m_t \frac{d\hat{U}_t}{dt} = v_i \int_t^i d\hat{U} + v_i \frac{RT_i}{(M.W.)} \quad (f)$$

(Continued on page 66)



*Professor Vincent W. Uhl
discusses chemical engineering
at the University of Virginia.*

"Mr. Jefferson's Academical Village"

"This institution will be based on the illimitable freedom of the human mind. For here we are not afraid to follow truth wherever it may lead, nor to tolerate any error so long as reason is left free to combat it."—T. Jefferson



We are reminded by quotations such as this, and also by the buildings and grounds at the core of the University of Virginia that Thomas Jefferson had a great deal to do with our institution. His "academical village" was founded in 1819; it was his major preoccupation when he retired from public life. Mr. Jefferson designed its first curriculum, recruited faculty, laid out the grounds and served as architect for its buildings. They were designed in a classical, peculiarly American Style, which set the pattern for the buildings to follow. In fact, his neo-classic mode had a profound effect on architecture in the United States in the nineteenth century.

The growth and influence of the University was seriously interrupted by the Civil War; in the twentieth century it regained its leadership and gradually increased its enrollment. At present the student body, including Law and Medicine total about 11,000, a number which might be considered modest particularly for a state university. Many feel that this size is ideal, but the growth is now accelerating toward an estimated size of 18,000 a decade hence.

Many rich, live customs and traditions contribute to provide a unique character. Outstanding is the effective Honor System, which has been student controlled and administered since its inception in 1842. Our legendary "coat and tie" has almost vanished, but most students are still neat in appearance. And there have been drastic changes; beginning this year, we have become, like most state schools, totally co-educational. Needless to say the immediate effect has been pleasant and the engineering students applaud it.

Visitors are impressed by the overall aspect of the university and its location. The buildings and grounds, both the central "academical village" and their considerable extensions, present

a fine environment. This is the result of inspired original planning and conscientious efforts to retain the original beauty. Many of the buildings were designed to present vistas of the beautiful, rolling countryside. In addition, the university is located on the edge of a city of 36,000, cosmopolitan in character yet somewhat isolated. Charlottesville is 115 miles southwest of Washington, and 70 miles west of Richmond in central Virginia; the Blue Ridge mountains are a few miles west. We find that the general resulting atmosphere not only makes for good living, but is also conducive to scholarly discussion and study.

SCHOOL OF ENGINEERING AND APPLIED SCIENCE

Engineering has been offered since 1836. At present about 1350 students are enrolled in the School of Engineering and Applied Science, 350 of whom are doing graduate work. We have the usual major engineering departments, plus Materials Science for only graduate work, and Nuclear Engineering. Biochemical Engineering also deserves mention. Representing a cooperative effort by the Engineering and Medical Schools, it currently has a staff of 13, 23 graduate students, and two postdoctorates; it offers only a doctoral program. Over the years, the School has also set up divisions to offer undergraduate courses of the quality and emphasis needed in Graphics, Applied Mathematics and Humanities; the latter, formed almost 40 years ago under Dr. Joseph Vaughan, is unusual and will be mentioned again. Applied Mathematics now includes Computer Science, and within the last five years has become a degree-granting department offering first a graduate and now also an undergraduate program.

The Engineering School has been conspicuously successful in promoting cooperation between departments, in teaching courses and in interdisciplinary research. This appears to be due somewhat to our moderate size, but it probably results also from the close relationship and good technical awareness that exists between many of our staff and among most departments. Inter-school cooperation, with Medicine, Architecture, and the College of Arts and Sciences has also been good.

CHEMICAL ENGINEERING

Bachelor degrees have been awarded in chemical engineering since 1913. In the early years

Joseph C. Elgin and Lauren B. Hitchcock taught in the department. J. Henry Rushton became chairman in 1937; first Virgil C. Williams and then Darrell E. Mack was his associate. Dr. Rushton was followed by Robert M. Hubbard in 1946. Early during Bob's chairmanship funds for a new building were secured and an exceptionally functional facility with a floor area of 20,000 square feet was completed in 1950. Although it was then commodious, we are now making full use of this building; the remarkable thing is that most of the space is being used for the purpose for which it was originally intended! Also under Dr. Hubbard's leadership the Chemical Engineering Department pioneered in graduate study in the Engineering School introducing a master's program in 1949 and doctoral work in 1956. When Bob Hubbard arrived he was the department. Beginning with Otis L. Updike, who also joined the department in 1946, Bob gradually built a fine teaching staff. This has included John W. Eldridge, who left in 1962 to become Chairman of the Department of Chemical Engineering at the University of Massachusetts, and James H. Gary, now Chairman of Chemical and Petroleum Refinery Engineering at the Colorado School of Mines. In 1963, Bob Hubbard stepped down and Vincent W. Uhl came from Drexel Institute of Technology to assume the chairmanship.

The teaching interests of our present staff of seven embrace the basic subject areas of chemical engineering. Each member teaches graduate and undergraduate courses, in addition to involvement in graduate research. Newcomers to the department are encouraged and aided in developing their own niche and specialty. Some interaction has developed in departmental research; this is evidenced in joint direction of dissertation research, both within and across departmental lines. The staff all have contact with the industrial scene, some from former employment, others from consulting, or both.

UNDERGRADUATE PROGRAM

Our aspiration for our undergraduate students has been stated as **"to develop competence in attacking new engineering problems and in securing optimum solutions to existing problems in chemical and allied fields.** This competence is based on a sound understanding of fundamentals, on familiarity with experimental methods, on general engineering background, and on the de-

veloped power to marshal these elements with proficiency to handle problems, many of which are quite complex". We feel that these goals are largely realized by a bachelor's program within the span of four or five years.* The ingredients supporting this accomplishment are our faculty, the quality and attitude of our students, and the resources—several of which are unique—of the School of Engineering and Applied Science.

Our undergraduate curriculum happens to correspond closely in subject weighting to the current survey average in Barker's report**, with the exception of our greater emphasis on humanities (Table I).

TABLE I. Distribution of Subject Areas for CHE Curricula

	<i>ChE Curricula</i>	
	<i>Barker's Avg.</i>	<i>Univ. of Va.</i>
Communicative skills	5.0	6
Humanities	18.3	21
Subtotal	23.3	27
Mathematics	16.7	16
Chemistry	23.8	26
Physics	9.7	10
Subtotal	50.2	52
Mechanics	5.2	3
Electrical Engineering	3.7	3
Materials	1.4	3
Subtotal	10.3	9
Chemical Eng. (required)	33.8	33
Chemical Eng. (elective)	2.3	6
Subtotal	36.1	39
Graphics	1.4	4
Economics	0.8	0
Technical Electives	6.4	3
Computer	1.2	4
Subtotal	11.8	11
Total semester credit hrs.	131.7	138

One of the unique aspects of our curriculum is a program of four courses, two in the first and two in the last year, taught by our Division of the Humanities. This program is based upon an *interaction of many disciplines, and is intended to challenge the student to face the modern world*

*A five-year program is optional. The student may be enrolled for a minimum of 15 credit hours each semester; more humanities and technical electives are taken.

**Barker, D. H., "Reduction in Hours and Introduction of Common Years into the Chemical Engineering Curricula", Department of Chemical Engineering, Brigham Young University, Provo, Utah. Report received July, 1970.

. . . our students enjoy a high degree of individual attention . . .

from a broad perspective. It is roughly equivalent to two years of college English, but is faster-paced and includes many areas beyond rhetoric and literature. Articulation skills are cultivated effectively in this program. In addition, five elective humanities courses are chosen to develop or enhance knowledge in fields such as economics, psychology, sociology, philosophy, history, religion, and literature. This elective program, planned by the student with his advisor, generally has two areas of emphasis.

Since 1965 the Engineering School has had a core program, extended in 1970 to the first two years. These have been some of the salient guidelines: a maximum of 17 or 18 credit hours per semester; a maximum of six or if possible five required courses per semester; the elimination of *needless* duplication of course material. First year students are introduced to computer programming in the BASIC language, which is then applied to the solution of simple engineering problems followed by a series of short engineering projects. Because of the chemistry requirements of chemical engineering, some exceptions are necessary in the second year from this core curriculum. As part of this core program all students take a minimum four of seven elective courses in the engineering science: mechanics (3 courses), electrical science (2 courses), thermodynamics, and science of materials. All competent departments participate in the planning and teaching of these core courses. Our department participates in teaching the materials science, thermodynamics, computer programming, and engineering problems courses. We have in fact taken a leadership role in the formulation and direction of the core thermodynamics course, and are proud of its thoroughness.

The physical operations are taught from the transport viewpoint; in addition a weekly lecture, which is part of the two-semester chemical engineering laboratory course, emphasizes the relation of the transport theory to experiment and practice. These lectures also introduce new topics for which there are special laboratory exercises. Some aspects of mass transfer operations will now also be considered in a two-semester, third-year course in Equilibrium Processes. This course will bring together stoichiometry, thermodynamics, phase equilibria and stagewise operations. Our conviction is that these topics should be related for effective instruction. Background in industrial chemistry and plant practice is provided by plant inspection trips and a seminar course in the senior year. Here the students learn on their own about some processes and each presents certain ones to the class. The student gets practice in oral reporting and learns how to become the *expert* on a topic. In preparing for these talks the students are guided to and required to use established library searching techniques.

Some (but admittedly limited) flexibility is provided by three technical electives, two of which are taken in a given field such as biomedical engineering, chemistry,

materials science, mathematics, or other areas of chemical engineering. Such areas include equipment design for which there is a course, based on extensive notes by Dr. Hubbard plus selections from Perry. Another popular departmental elective is applied surface chemistry, taught by Dr. John Gainer. It, along with the required kinetics course, reflects the strong inclination of some of the staff to emphasize applied chemistry to our students. All seniors take reaction kinetics, process control, and plant design. The process control course has a balance of hardware emphasis with theory, and makes use of six elaborate teaching aids, modules which demonstrate the modes of control and the characteristics of different devices used to sense and control temperature, flow, and pressure. In the plant design course the elements of technical economics are emphasized, using material developed by Dr. Uhl for his AIChE TODAY SERIES short course. A process design is completed by students working in teams of three on one of the problems first developed by Washington University in cooperation with Monsanto. Generally the seniors also attack the AIChE Student Contest Problem on an individual basis.

We are particularly proud of our two undergraduate laboratory courses, which have been a prime and continuing interest of Dr. Hubbard. Much of the apparatus and equipment is specially designed or modified to facilitate instruction. Many pieces are transparent so that the action can be visually observed. Some experiments are on pilot scale units, relatively heavily instrumented, some with quite sophisticated controls. Recently a pilot plant was completed for the catalytic reaction of methanol and steam to produce hydrogen and carbon monoxide. The unit reaches steady state quickly, the reactants are cheap and available, and the products are disposable. This unit is already proving useful in providing a process experience and in generating raw kinetic data for analysis. Perhaps the outstanding feature of the laboratory is that the equipment *works* smoothly and predictably.

Our students enjoy a high degree of individual attention. This is feasible because our classes are small and possible because our staff are generally on hand and interested. Only staff members are used for lecture courses; graduate students such as NDEA trainees, however, direct problem sessions and occasionally run a section of the laboratories. We are very conscious of, and stress, good teaching. Classrooms in our building are equipped with (or for) the usual teaching aids and we use them, particularly the overhead projector.

Between ten and twenty receive bachelor's degrees in most years. A high proportion go directly to industry. We are pleased with reports which we receive about our recent graduates: "immediately useful", "not bewildered by industry", "know what is expected of them". About a quarter of our students continue their education in chemical or other branches of engineering. Generally a couple of students from each class

continue in other fields such as graduate business, law, or medicine.

Because of the varied teaching and research interests of our faculty we consider we have achieved a good balance, one in which our graduate program effectively complements undergraduate work.

FACULTY INTERESTS

The areas of interest and special research fields of our staff members range broadly over almost the full breadth of process engineering.

Dr. Charles Barron works primarily on problems which involve the integration of chemical reaction theory into the analysis of complex process systems.

Dr. Gainer's original research interest in liquid diffusion, diffusion in polymer solutions and transport through membranes has now been extended to mass transfer in biological systems.

Dr. Robert Hubbard's research interests have been in the fields of continuous ion exchange, extended surface heat transfer, process dynamics and the measurement and control of process variables.

Dr. Donald Kirwan, who recently joined the faculty, has research interests in the general field of unusual separation techniques.

Dr. Lembit Lilleleht's interest lies primarily with the fluid mechanics of multiphase systems.

Dr. Vincent Uhl has long had interests in mixing, heat transfer and technical economics; his current research is concerned with mechanically aided heat transfer.

Dr. Otis Updike has long been interested in computers and their application to chemical engineering problems—initially analog machines, later digital and hybrid.

Despite the breadth of research interest exhibited by our faculty, the areas are effectively complementary, as with process dynamics, fluid mechanics and mass transfer. Some research has involved collaborators from other departments: nuclear engineering, mechanical engineering, materials science, biomedical engineering. We anticipate that this cooperation will grow, in particular in the area of materials science with work on blood clotting. About one-third of the present research is concerned with life processes: the development of blood-mimic fluids, blood flow modeling, diffusion studies in biological fluids, reactions related to the absorption of oxygen in the lungs, enzyme kinetics and protein separation methods.

GRADUATE PROGRAM

In recent years we have built an active community of graduate students which numbers more than twenty, over half of whom are engaged in doctoral work. We very seldom keep our own undergraduates; because we are convinced that students benefit greatly from a change of scene, we insist that they go elsewhere to continue their studies. While we welcome students from other countries, we strive for diversity and balance. Foreign student enrollment is now about 30 percent of the total. We currently graduate about

Our aspiration for our undergraduate students: to develop competence in attacking new engineering problems and in securing optimum solutions to existing problems in chemical and allied fields.

eight masters and four doctoral students each year.

Almost all graduate students are supported financially by fellowships which allow them to devote full time to study and research, or on assistantships for research only. In addition to the usual sources of support such as NSF Fellowships, NDEA Traineeships, industrial fellowships and research grants, we receive a substantial sum each year from the bequest of Christopher Memminger which supports several students each year and departmental research. Mr. Christopher Memminger, the donor, was a graduate of the University of Virginia and founder of the Coronet Phosphate Company.

Our entering masters students normally take courses in fluid mechanics, thermodynamics, reaction kinetics, three elective courses and two courses in mathematics, one of which may be the applied mathematics course taught in the department. Heat transfer courses are taught by members of the Mechanical Engineering, Nuclear Engineering or Chemical Engineering Departments. Although a non-thesis master's program is on the books for engineering, we usually require a thesis for chemical engineering students. We encourage students to complete work for the masters within twelve months and this has been possible in most cases.

Our doctoral program has a traditional emphasis, except for the interdisciplinary atmosphere. A requirement of special interest is selection and development of a proposition in an area different from that of the dissertation to demonstrate ability to do original work. This must be completed in a month, and students are then orally examined on their reported solutions as well as on their general knowledge; this constitutes their comprehensive examination as doctoral candidates. Reading proficiency is required in one foreign language.

We also work with our graduate students to cultivate the ability to organize and present technical matter effectively. Each student speaks several times at our graduate seminars and we encourage them to speak at local and national meetings when practical. We want our graduates to be articulate.

CONTINUING EDUCATION

The department has been continuously aware

of the educational needs of the chemical engineers in the many chemical and process industries in Virginia. For several years we have offered a part-time graduate program; by now this has served the needs of a number of chemical engineers working in nearby plants. To be of broader service, beginning in 1968, we have offered about three short courses each year; each staff member has developed a course in one of his specialties. These have had the extra advantage of increasing our awareness of the problems of industry and improving our contacts with working engineers. It is a program which we hope to continue.

THE FUTURE

For the future, we expect to continue offering a four-year undergraduate program based on a strong background in chemistry (as well as physics and mathematics) in which the student will gain adequate proficiency with analysis, synthesis (from process design), and computation, and cultivate one or more humanistic areas. Research will probably become still more interdisciplinary in character and will grow in its emphasis of living processes. To balance the theory, the graduate program, at least for some students, will continue to emphasize practical engineering.

A SUMMATION

What are some of the marks of our department? Diversity of research interests. Collaboration in research. Research concerned with life processes. Balance between undergraduate and graduate programs. Concern about good teaching. For the undergraduate: stress on fundamentals; sound chemistry background; development of computational prowess; excellent laboratory experiences; promotion of some feel for the practice of engineering. For graduate students: programs with traditional research emphasis; development of creativity, analytical ability, and articulation; conversancy with fundamentals; the power to apply knowledge to practice. In this we feel we are fulfilling this dictum of our founder:

"A University on a plan so broad and liberal and modern as to be worth patronizing with the public support, and to be a temptation to the youth of other states to come and drink of the cup of knowledge and fraternize with us."—**T. Jefferson**

CHALLENGES:

Gulf has enough for your lifetime.

Challenges like making a profit without polluting the air we breathe, or the water we drink, or the land, or the cities we live in.

Challenges such as turning sand into synthetic fuels. Or making our ocean water drinkable. Or developing high efficiency nuclear cells to keep the lights on in the year 2000. The challenge of making a barrel of crude oil work harder to conserve our fossil fuel resources.

And these are only a few of the challenges at Gulf. Meeting them requires top graduates in every technical, scientific, managerial, and marketing field.

If you're the type person who likes to provide answers to make ours a better world, you may want to consider a career with Gulf. For additional information, write Virgil Hanson, Gulf Oil Corporation, P. O. Drawer 2100, Houston, Texas 77001.



This feature article was prepared for CEE by Professor John C. Biery, University of Arizona.

Arizona's

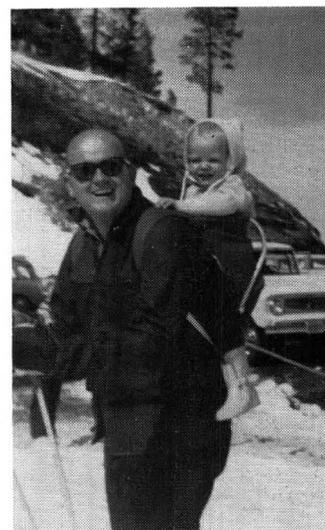
ALAN RANDOLPH

Chemical engineering to Alan Randolph is a profession which requires a balanced synthesis of experimental and theoretical programs. His own research in particulate systems and his professional career are outstanding examples of this view. He feels very strongly about maintaining this balance between theory and experiment for the profession. He says, "Chemical engineering must achieve this balance; otherwise, an ever increasing split within the ranks of chemical engineers will occur. This growing schism, which, unfortunately and unnecessarily, often pits academician versus industrial technologist, is readily observable at our national AIChE meetings."

THEORY AND EXPERIMENTATION IN CRYSTALLIZATION

At the University of Arizona, Alan has developed a program which contains strong elements of experiment and mathematical theory in his study of particle dynamics in crystallization and grinding. For instance, he has two students who have mathematically simulated these two types of particulate processes in a total system simula-

Alan with son David on Mt. Lemmon ski slope near Tucson. 'Skiing is a sometime-thing but you just keep hoping.'



tion using population balance models. Complementary to this program, two other students have experimentally studied crystal nucleation kinetics in a bench-scale crystallizer well-suited for similar industrial studies and more fundamental nucleation mechanisms in realistic crystallization environments by using very sophisticated automatic particle counting techniques representing the current state-of-the-art. Each of these experimental and theoretical programs has assisted the other. The experimental programs are designed to seek basic mechanisms while the simulation programs indicate the mechanisms that are required to predict behavior in large commercial systems that cannot be studied experimentally.

Alan's career has been purposely directed toward the welding of these two elements of Chemical Engineering. After graduating from

Alan's involvement in the overall chemical engineering process on an exciting and interactive level is indicated by the following profiles by two of his graduate students.

"Alan Randolph is a man engrossed in the swirling, growing technology of crystallization. He is smilingly thought of by his graduate students as a generating source for new and innovating concepts which originate from a scrap of paper signed ADR or preferably from a coffee-stained napkin.

Each of his new students is properly initiated by a formal introduction to Mr. Tuffy, Alan's least outspoken graduate student. Mr. Tuffy is a three-foot wooden Kachina make by San Juan Pueblo Indians and represents Alan Randolph's often expressed love for the West. Alan Randolph is truly admired for his dedication and inexhaustible patience." — Eric Nuttall

"Alan Randolph is in some ways similar to the nucleating, growing crystals that he studies. He is constantly generating new twists to old ideas and having his graduate students check them out. Should the graduate student generate a new idea, he must convince Alan of its veracity and often finds him to be the roughest critic. This process draws upon all the student's technical and argumentative talents to produce a clear, concise formulation of that idea. Alan continually admonishes his students to consider the many facets of crystallization. For example, during the winter months he doggedly tells them to 'Think snow!'" — Mike Cise

Chemical engineering to Alan is a profession which requires a balanced synthesis of experimental and theoretical programs. His own research in particulate systems and his professional career are outstanding examples of this view.

the University of Colorado with a BS in 1956, he worked for two years with Shell Chemical. There he became involved with an ammonium sulfate crystallizer that was having crystal-size distribution (CSD) problems and was dynamically unstable. This unstable behavior, poorly understood at the time, was fascinating to him and to others in the group.

In 1958, he entered Iowa State University and obtained an MS and PhD by 1962. After completing an MS by studying entrainment in distillation, he decided that he wanted to study the types of crystallization systems that he previously had encountered, *e.g.* the system with unstable CSD at Shell Chemical. To Dr. Mauri Larson he proposed a program of study which was motivated by an article by W. C. Saeman. This paper analytically described the steady state CSD in a single stage mixed crystallizer. Alan proposed that he study the general dynamic problem of crystal-size distribution using a population density function. In this PhD program, he successfully developed mathematical models to describe the dynamics of CSD in such crystallization systems, and showed the process coupling that could result in an unstable CSD. In addition, he quantitatively evaluated stability limits in terms of system crystal growth and nucleation kinetics. This PhD work resulted in development of a general population balance for a dynamic mixed suspension crystallizer with crystal-size distribution characterized by the population density function.

ALAN IN THE DESERT

His choice of jobs after leaving Iowa State University indicated that he had developed a sense of direction for his chemical engineering career. Instead of accepting some very tempting positions in groups involved with process control and transport phenomena, he joined American Potash and Chemical Company at Trona, California (located in a rather remote region next to Death Valley in California's Mojave desert). Although Alan at first had some misgivings about the location, he soon learned to love the desert climate and surrounding terrain, and both he and his wife remember the years at Trona as some of the most enjoyable of their life.

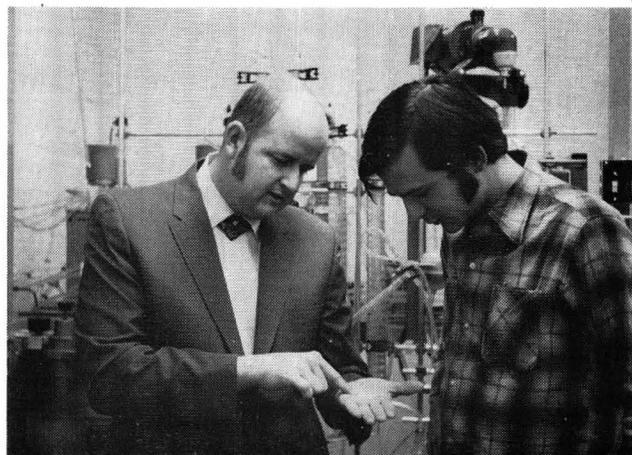
Alan's chief motivation in choosing the Trona

job opportunity was to try out his population balance models on some large-scale industrial crystallizers. These models were successful and became the basis for analyzing size distribution performance for a multitude of crystallizer systems at American Potash. Before leaving, Alan became head of the crystallizer research section.

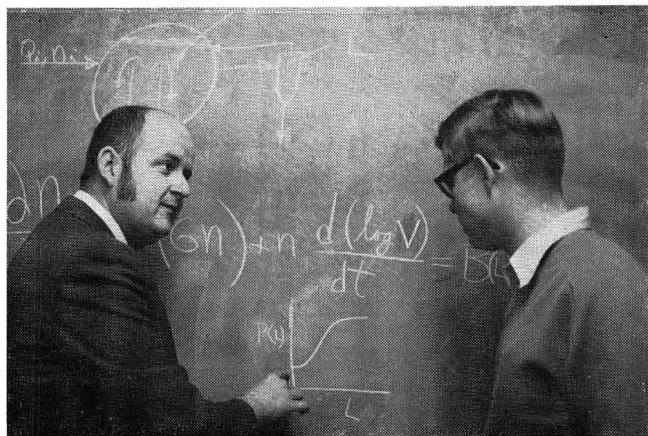
Also, while at American Potash, he realized the population balance models that he was using could be generalized. He published a generalized population continuity equation in particle phase space that could be useful for simulation of multi-dimensional particle distributions in a variety of systems, *e.g.* microbial, macromolecular, catalyst suspension, demographic, etc. Almost simultaneously, Hulbert and Katz also published a paper which developed a generalized particle balance continuity equation and thus confirmed the generality of the population balance approach first applied to the CSD problem.

ALAN IN ACADEMIA

To be able to study fundamentally problems in particle systems and to teach others of his philosophy concerning the balance between theory and experiment, Alan accepted a faculty position in the Chemical Engineering Department of the University of Florida in 1965. His efforts were directed toward understanding the fundamentals of nucleation and growth in crystallization systems and their interaction with process configuration to determine the CSD. Since then, both at



Alan and graduate student Mike Cise examine crystals used as seed in nucleation apparatus.



A fine point in particle classification is discussed with graduate student Eric Nuttall.

Florida and after 1968, at the University of Arizona, he has expanded his interests in particle systems to include grinding, biological and dispersed phase populations.

Alan has found that the two elements of research, experimentation and theoretical formulation, reinforce each other. One element for a time will lead the other, and then their relative positions will reverse. For instance, the theory first indicates what particle dynamics phenomena needs to be measured, *e.g.* nucleation and growth rate kinetics, particle breakage, particle classification, etc. Experimental data are then analyzed using the general CSD theory to back-out and correlate these empirical particle dynamics functions. Then, with numerical values and/or reasonable empiricisms representing such particle kinetics, the mathematical theory is utilized in overall computer simulations to predict the behavior of large complicated systems that cannot be studied directly. In this phase, CSD theory leads experimental kinetics and motivates further refinement of experimental measurements.

From the previous discussion, Alan's involvement in the academic world would appear to be totally one of a researcher. Actually, he has equally involved himself in teaching at both the graduate and undergraduate levels. He teaches such courses as transport phenomena, process control, unit operations, process dynamics, and a special topics course in particulate systems. He has been able to bring to these the same balance that he has displayed in his research. In his area of specialization, together with Dr. Larson of Iowa State University, he has written a book that can be used as a graduate text in courses concerned with crystallization in particular and particulate processes in general.

... no student should go through to the PhD without the awareness of how theoretical models are tested and their necessary relationship to the real world.

This balance between experiment and theory has amplified a similar balance in the Chemical Engineering Department at the University of Arizona. The department has concentrated on teaching computational theory, methods, and techniques by utilizing transport phenomena, unit operations, process control, thermodynamics, etc. The desired end result is a capability to design chemical engineering processes and equipment, and to analyze chemical engineering data to understand a given process. The effective chemical engineer must have a sound grasp of theory plus an appreciation of the experimental process to gain these ends. In this regard, the faculty at the U of A feels strongly that every PhD candidate should have some experience in the planning or execution of an experimental program at least once during his graduate career. Such experience can come at the MS level or in gathering and organizing experimental data taken by others, *e.g.* data made available by an industrial organization or in a previous experimental study by another student. The U of A faculty's main concern in this area is that no student go through to the PhD without awareness of how theoretical models are tested and their necessary relationship to the real world.

LETTERS (con't from p. 57)

It is a well know thermodynamic principle that for a single component, nonreacting, single phase, ideal gas system in a state of quasi-equilibrium, that

$$d\hat{U} = \hat{C}_v(T)dT \quad (g)$$

where $\hat{C}_v(T)$ is the heat capacity at constant volume per unit mass. Usually, $\hat{C}_v(T) = a + bT + cT^2 + \dots$.

Combining equations (f) and (g) yields

$$m_t \hat{C}_v(T) \frac{dT_t}{dt} = w_i \int_{T_t}^{T_i} \hat{C}_v(T)dT + w_i \frac{RT_i}{(M.W.)} \quad (h)$$

At this juncture, it is possible to effect a simplification by letting $\hat{C}_v(T)$ be a constant. Thus,

$$m_t \hat{C}_v \frac{dT_t}{dt} = w_i \hat{C}_v [T_i - T_t] + \frac{w_i RT_i}{(M.W.)} \quad (i)$$

which is the same as equation (b) of Himmelblau and Bischoff.

Now the reoccurring error associated with problems of this kind is simply the fact that $C_v(T)$ is and should remain outside, not inside, of the time derivative term

(Continued on page 71)

Beneath this soft and warm exterior, there lies a heart of plastic.



So far, it's only a valve. Eight-year-old Janet Hernandez has one.

It may not be long before a whole working heart will be made out of plastic.

Men in plastics research at Union Carbide are working on the almost impossible job of designing plastics compatible with the body.

Their most crucial job is making an ultra-thin polypropylene fabric for lining the inside of the heart. A fabric coated with parylene that will allow human tissue to grow into and around it to keep blood from clotting.

A plastic heart isn't the only part of the body we're working on. Maybe someday there will be a little plastic in all of us.

Right now, we've got you surrounded

by our plastics. We were in plastics before most people knew the word. We make more plastics than anyone else. We haven't scratched the surface yet.

Why is a great big company like Union Carbide so concerned about a little bit of plastic for the body?

Because.

Beneath our corporate exterior, there beats a heart.



THE DISCOVERY COMPANY

SEMI-NOTES CAN HELP

Improving the Lecture

ROLAND A. MISCHKE
Virginia Polytechnic Institute
Blacksburg, Virginia 24061

THE PAST FEW YEARS have seen a marked increase in the emphasis on effective teaching and in attempts to understand and to regulate the learning process. Amidst the hardware and software of the effective teaching movement, the lecture stands condemned. The cry goes out that "the lecture is dead."

In its original setting, the lecture format made sense. We can see the medieval scholar standing at his lectern, sharing the fruits of his scholarship, as contained in the handwritten manuscript before him, with his students. But with the invention of the printing press and all of the advances in communication which have taken place in the meantime, should the lecture remain unchanged? Materials are now readily available to students. No longer are they dependent upon the physical presence of the scholar. They can read and study for themselves and interpretations of the original documents are readily available. Textbooks and study guides are produced by the carload. "Modern teaching methods" and "modern technology" are here to assist the student. Why then do we have the usual college lecture—often merely a reading of the textbook to the students—persisting?

WHY IMPROVE THE LECTURE?

If the lecture is indeed dead, why not let it die a peaceful death and then bury it? While this paper does not propose to be a defense of the lecture, I might offer a couple of reasons why the lecture is bound to be around for quite a while yet. If the lecture is to remain with us, then spending time and effort to improve it can be justified.

The lecture will continue to exist because the present educational process is self-perpetuating. The new engineering teachers are the products of the old system and technical competence is still

Despite being attacked as inefficient and outmoded, the lecture continues to be the most commonly used format for teaching. This paper outlines some of the lessons learned in applying a technique for improving the educational value of the lecture by capitalizing upon the student's involvement in note-taking.

Semi-notes do not represent a cure-all for educational ills, but if they are used within their limitations they represent a convenient method of increasing lecture effectiveness. Little additional effort on the part of the instructor is required for their implementation.

deemed to be adequate preparation for college level teaching. By and large, therefore, college teachers will perpetuate the system under which they were taught, because they know of no other. Add to this the fact that classrooms and university facilities have been planned around the lecture approach. Throw in the fact that the lecture is very efficient in the use of the instructor's time—his involvement with the students in minimized, freeing large amounts of his time for "the more important things" which revolve around technical matters. Stir these attitudes and pressures together, and it becomes evident that the lecture is firmly entrenched and will not die easily.

Another reason for the continued existence of the lecture revolves around the fact that the lecture approach is the one with which the students are familiar and the one with which they feel comfortable. Throughout their school years they have been conditioned to believe that learning is something that occurs in a classroom in the presence of someone called a teacher. If the teacher does not show up one day, then that day is lost. Nothing can be learned. Even at the graduate level, where we are dealing with very capable and highly motivated students, this attitude is readily apparent. Try an experiment. Delay your arrival in the classroom for fifteen or twenty minutes. How often will you enter the room to join a discussion of the topic of the day? More than likely you will find the students (if any have waited

*Presented at the 1970 ASEE meeting at Ohio State University.



Roland A. Mischke received his undergraduate degree from Pratt Institute (B.Ch.E. '50) and worked for six years as a design engineer with Chemical Construction Corporation before returning to graduate school. Following the completion of his graduate studies (Ph.D Northwestern '61) he entered the teaching profession. He is currently in his ninth year at Virginia Polytechnic Institute and State University, where he has been involved in the teaching and direction of research in the fields of reaction kinetics, fluid dynamics, thermodynamics and heat transfer. In addition to his teaching responsibilities in the Chemical Engineering Department, he is also Educational Technology Coordinator for the College of Engineering.

around) chatting together and waiting for the "show" to begin. The possibility of learning something in the absence of the instructor never occurred to them—that thought is completely foreign to their upbringing. The lecture, then, has two things going for it. The students want it and the teachers want it.

A third reason for not burying the lecture approach is that we know too little of the learning process to completely dismiss the lecture. Modern approaches to teaching are becoming available in the form of programmed instruction, computer-aided instruction, television (closed circuit and tape), audio-tutorial methods, etc., but we have only incomplete evaluations of the ultimate worth of these methods. Certainly many of these methods are more effective than the lecture in the transmission of facts. But a lecture transmits more than facts. Studying a book with a teacher is more satisfying and more rewarding than studying the book alone. Something else comes across along with the factual information. Simply equating education with factual knowledge could be dangerous. Such a comparison ignores the higher levels of the cognitive skills described by Bloom (1)—those of analysis, synthesis and evaluation. The sign which hangs in my office to remind

me of my job as a teacher says "Education is what is left over after you have forgotten the facts." Education and learning are more than absorbing facts and storing them away as a computer does—to be retrieved and used mechanically upon demand.

The stimulus-response approaches and even the modern day "systems" approaches tend to treat the student as an automaton or mechanism. The basic premise seems to be that a certain stimulus should produce a very predictable response, and much testing and evaluation of teaching methods is done on just such a basis. However, if we accept the concept (von Karman) that "an engineer creates what never was," then creativity—the unique response to a stimulus—is what we need to develop and not stifle. Engineers trained in the traditional manner have been showing some creativity, and until we know more about how to effectively teach creativity and the higher cognitive skills, we should be careful about condemning the lecture.

Whether we like it or not, good or bad, the lecture is going to be around for some time. The lecture may be dead, but there is no reason for it to be deadly.

THE SEMI-NOTES APPROACH

THE ATTENTION SPAN of a listening adult is just about two minutes. That is, we can have a person's undivided attention for only about two minutes. If we fail to interest him (show the relevance of the topic to his needs) in that period of time, then his attention will wander. Therefore, a lecture must involve a student (either mentally or physically) at least once every two minutes if we want to maintain his attention. The usual techniques suggested for effective speaking make use of just such planned involvements of the listener, but we can capitalize on something else in a classroom situation.

Working in our favor is the fact that a student in a classroom is involved in one way in which the usual listener is not—the student is busy taking notes. Looking back over some of the notes that I took in college, I find them to be a pretty disorganized mess. Most of them are undecipherable now (and thinking back over my attempts to review for tests, I'm not so sure that they were decipherable even back then.) Glancing at the notebooks kept by students today I find much the same situation. If we stop to consider just what is required of the student in producing

The lecture will continue to exist because: the present educational process is self-perpetuating; both the students and the teacher want it; we know too little of the learning process to completely dismiss it.

a coherent set of notes, it is no wonder that the results are what they are. A student must listen to material (much of which is new to him), try to follow the logic of the presentation, make value judgments on this logic, sort out the relevant points and organize them into a legible and coherent style. Certainly a formidable task.

Some years ago Zumwalt (2) presented the concept of semi-notes or incomplete notes as an aid to student learning. In this approach the student is presented with the skeleton of a set of notes, and he completes the picture by the addition of his own notes and comments during the course of the lecture.

I have used semi-notes in several chemical engineering courses over the past couple of years, and I would like to share with you my impressions of the advantages and disadvantages of this approach.

IMPACT ON THE STUDENT

From the student's point of view, these notes come as a godsend. For once he can concentrate on what is being said rather than spending a good deal of his effort in organizing a set of notes. At the end of the course, regardless of his ability as a note-taker, he has:

1. **ACCURATE NOTES.** It is sometimes surprising to see how often errors creep into student notes (this in spite of the sterling and crystal clear presentations that we make.) Having a roadmap to follow helps to keep them on the right track, and the distractions from such things as passing trucks, noisy lawnmowers, etc. seem to produce fewer errors when semi-notes are used.
2. **ORGANIZED NOTES.** The notes are coherent and organized around a logical development. This aspect is important when the time for review comes around.
3. **PERSONALIZED NOTES.** Although the skeleton or framework is supplied, much of the material in the completed notes is in the student's own handwriting. He has also had the opportunity to make special notes and markings which will help him to interpret the notes later on.
4. **SIGNIFICANT NOTES.** Not only are the notes coherent, they also contain what the instructor considers important. This is a definite plus value for the student.

IMPACT ON THE INSTRUCTOR

From the instructor's point of view, the use

of semi-notes represents an additional burden. The instructor must cope with:

1. **PREPARATION OF NOTES.** The notes must be prepared and be ready for distribution to the students before the lecture is given. Fortunately, the work that is involved in preparing these notes is not much more than that required to prepare a fairly complete set of notes for lecturing. I have found that by writing in pencil on a Ditto master, the master is prepared for duplication and a projection transparency can easily be Thermofaxed if one is desired.
2. **RIGIDITY OF STYLE.** When following the notes, the lecture presentation is not as free-flowing as it could be. The instructor cannot easily deviate from the pre-determined order of presentation. Perhaps the most frustrating thing I have encountered here is a lack of freedom in the choice of words. The words suggested to fill in the blank spaces in the notes must generally be very close to those in mind when the notes were prepared. If a better way to say something occurs to the instructor in the midst of his presentation, not only must it make sense when coupled with what appears on the handout sheet, it must also fit into the space provided. One soon learns to be careful to consider alternate ways of saying things during the initial preparation of the notes.

IMPACT ON LEARNING

When considered from the pedagogical point of view, semi-notes have strong and weak points. These include:

1. **THE LECTURE MUST BE PLANNED.** This one aspect probably accounts for one of the largest impacts that the use of the notes can provide on the improvement of the lecture. **THE INSTRUCTOR MUST BE PREPARED FOR HIS CLASS.** No off-the-cuff lectures can be made. The lectures become organized, not only within themselves, but between lectures also, because that is the way that they must be under this system.
2. **THE STUDENTS BECOME INVOLVED.** The students must be awake and involved in order to complete the notes. By supplying the connecting thoughts and having the student write in the key thoughts, considerable reinforcement of these key thoughts is provided for the student (he is involved in hearing, seeing and doing—all at the same time.)
3. **THE STUDENTS NEGLECT THE TEXTBOOK.** Because the semi-notes represent the "distilled essence of knowledge" for the course, students will tend to ignore the textbook and await the next "revelation" unless they are forced to interpret the textbook by some sore of assignment which requires a study of the text.

4. THE STUDENTS MAY ACQUIRE A "PSYCHOLOGICAL SET." By just following the organization and development of a topic rather than being involved in such a formulation, they may get into the habit of saying yes . . . that makes sense . . . of course . . . etc. without really understanding the development. They may say, "Yes, I see," when they don't really "see." This process can lead to a false sense of security in the student—and potential disaster at exam time.

SUMMARY

Like most things, semi-notes turn out to be a mixed blessing. With careful use and an awareness of their shortcomings they can be a very useful tool in teaching. The main advantages stem from the fact that:

- The instructor must organize his presentation.
- The students must become involved with the presentation.
- The students like the notes and appreciate them.

The major disadvantages of semi-notes seems to lie in presenting to the student a well-organized and seemingly simple explanation. If the student accepts the logic unquestioningly, he may learn little. Learning is an intensely personal experience—the result of a struggle of each individual with himself, and a special effort must be made to get the student involved in that struggle, thereby making the notes as effective as possible.

The role of the teacher is often likened to that of a guide. But what person would pay good money to hire a hunting guide who invariably said, "Come and watch me hunt." A person who hires a guide wants that guide to take him to where the game may be found, to give him some pointers on technique, but not to down the game for him.

Here, then, is the challenge of effective use of semi-notes: to lead the student to and through the subject and not cheat him of the fun of bagging the game himself. Semi-notes will work. They will work well within the framework of the existing lecture format. The challenge is to keep them working for the student and not to let them work against the best interests of his education.

LITERATURE CITED

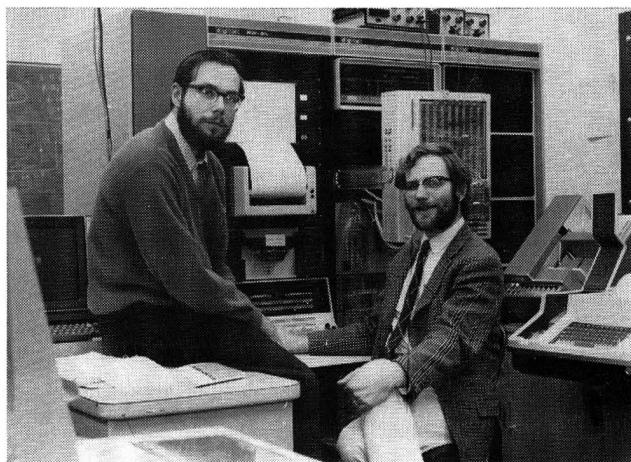
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2. Zumwalt, G. W. "SEMI NOTES: An Aid for the Engineering Lecture," Journal of Engineering Education, 54(5), 182 (1964).

ADDENDUM—WINTER CEE

The following picture and biographies, recently received, are of the authors of "A Facility for Education in Real-Time Computing" CEE, 5, No. 1, p. 30-32 (1971).

James H. Christensen (right) is Assistant Professor of Chemical Engineering, and of Information and Computing Science, at the University of Oklahoma. He received his PhD in Chemical Engineering from the University of Wisconsin in 1967, and was a Ford Foundation Fellow in Engineering Design at Thayer School of Engineering at Dartmouth prior to moving to Oklahoma in July 1968. His main interests are in the application of digital computers to chemical process design, optimization, and control.

Paul M. Vargo (left) received his PhD from Case-Western Reserve University in 1969. During the last 2 years, while a faculty member of the Electrical Engineering School, University of Oklahoma, his activities have included developing a Real-Time Computer System to support education and research activities and initiating a research project exploring Man-Computer Communication.



LETTERS

(Cont'd from p. 66)

in equation (h) even if it is a variable. One usually sees various authors attempt to write, incorrectly, the identity

$$\frac{d[m_t \hat{c}_v(t) T_t]}{dt} = \frac{d(m_t \hat{U}_t)}{dt} \quad (j)$$

using reference temperatures and other gimmicks. The right-hand-side of equation (j) correctly accounts for unsteady-state internal energy changes but the left-hand-side is pure nonsense. To the uninitiated, the l.h.s. of equation (j) is, indeed, tempting.

The stirred-tank, energy design equations on page 4-23 of *Perry's Handbook*, 4th Ed. are in error.

Burton Davidson
Rutgers University

SOVIET EDUCATION: from DETSKY SAD to ASPIRANT

ALAN and IRMGARD MYERS
University of Pennsylvania
Philadelphia, Pa. 19104

IMAGINE AN AMALGAMATION of M.I.T., National Bureau of Standards and Bell Telephone Laboratories in a single organization called the U. S. Academy of Sciences. This hypothetical research conglomerate would be comparable to the Soviet Academy of Sciences. Our visit, for five months of research at the Institute of Physical Chemistry of the Soviet Academy of Sciences in Moscow, gave us an opportunity to observe from the inside the working order of the Russian scientific establishment.

Our plane landed at the Moscow International Airport on a dreary Monday evening last year. We had heard dismal stories about the experiences of others and our excitement was dampened as much by uncertainty as by the rain.

Prepared for a long wait and complicated customs procedures, we were pleased to claim our unopened baggage immediately. Exchange scholars on the US-USSR Academies of Sciences Program are practically free of political interference. The reason is that the Russians have the same selfish motives that we have for keeping open the lines of scientific communication. Within an hour we checked into our new home for the autumn and winter: the 14-story hotel of the Academy of Sciences on Leninsky Prospect near Gorky Park. The apartment, small but well-furnished, had two rooms and a bathroom but no kitchen. Luckily we had packed an electric skillet which became the nucleus of a makeshift kitchen. Borrowing an idea from the Russian housewife, we used the interior of the double window for a refrigerator. Nature did its best to keep the temperature below freezing but occasionally we found in our icebox an unexpected supply of defrosted food. The bathtub turned out to be an all-purpose fixture, serving as laundry tub, bathtub and kitchen sink.

Our Russian colleagues at the Institute of Physical Chemistry loaned us kitchenware and

small appliances and gave us useful shopping tips. Still, for an American woman speaking little Russian, shopping in Moscow was a full-time job. Sign language and a sense of humor helped. More often than not, curious shoppers joined in to guess what the needed item might be. Usually these guessing games ended in laughter and a successful purchase. The Russian people are like Americans, friendly and willing to help. Strangers gave us their seats on buses for our children and often showed concern about our children's clothing. Russian housewives were astonished to see our daughters dressed in a single coat for the cold winter days. In Moscow, woolen or nylon clothing articles are rare and the children wear three or four layers of clothing to keep warm.

The streets of Moscow are literally lined with buses, streetcars and minibuses. The fare is 3 to 5 kopecks (100 kopecks = 1 rouble) and the passengers pay on the honor system by dropping their fare into a machine and dialing their own receipt. The fine for not paying is low, only 40 kopecks, so there is often someone trying to get a free ride.

Stores in Moscow are specialized: bread stores, dairy-product markets and vegetable stores but only a few supermarkets. The stores are well-stocked with staple items such as flour and sugar but few luxury items or out-of-season fruits are available. We quickly grew accustomed to standing in line. A single purchase is a complicated transaction consisting of three steps: 1) find the article and obtain its price at the counter, 2) pay for the article and get a receipt at the nearby cashier's desk and 3) return to the counter and exchange the receipt for the article. This inefficiency is not amusing when you are in a hurry to buy a loaf of bread.

Books are the best shopping bargain in Moscow. The quality of the paper and the printing is substandard but prices are very low. For example, we purchased a hardbound copy of a popular course in physical chemistry (600 pages) for \$1.50. Comparable bargains are available in



Alan L. Myers graduated from the University of Cincinnati with a BSChE '60. In 1964, he received his PhD at the University of California at Berkeley. In 1964 he joined the School of Chemical Engineering at the University of Pennsylvania. Alan Myers has consulted with the Sun Oil Company and Atlantic-Richfield Company. His research is in thermodynamics and surface chemistry. His technical publications give the results of research on adsorption from liquid mixtures, pulsed-adsorption separation methods and sorption in molecular sieves. In 1969-1970 he was awarded a fellowship on the exchange scientist program of the National Academy of Sciences.

fiction. The problem is that it is hard to find copies of books by Bunin or Yevtyshenko, much less Solzhenitsyn. The complete works of the nineteenth century writers (Pushkin, Gogol, etc.) are available in handsome and inexpensive editions.

WE WERE OFTEN invited to Russian homes where we became acquainted with the traditional Russian hospitality. No one we knew owned a house; the apartments were small by our standards. Often the grandparents share a three-room flat with the young family. All of the scientists and engineers whom we met own television sets and refrigerators. **The Russians laugh at our obsession about slimness. Food is not a diversion in an evening of entertainment; it is the main feature. Dinner lasts for hours and hours and it is impossible to eat everything that is served.** The table totters under its load of *zakuski*: cold meats, fish, salads, cheeses, breads and sometimes caviar which, regretfully, is becoming scarce as pollution decimates the sturgeon population of the Caspian Sea. These hors d'oeuvres are delicious but, like a long-distance runner, it is important to maintain restraint at the beginning in order to finish. The next course is borsch (cabbage and beet soup served with sour cream) or another soup accompanied by cabbage-filled cakes. Finally, almost too late to enjoy it, the main course appears and is followed

leisurely by fresh fruit and assortments of cakes and candy. Often, tea is served with a special kind of jam which is eaten before each sip for sweetening. Beverages with the meal include Georgian wine, Armenian cognac and, of course, vodka.

We sampled the Moscow restaurants and found the quality of the food and the service to be occasionally very good but more often mediocre. Tipping is considered somewhat belittling and does not improve the service.

A typical wage in Moscow is 130 roubles (144 dollars at the official exchange rate) per month. Usually husband and wife both work so that the family earns 260 roubles per month. Russian women, with equal pay, drive steamrollers, shovel hot asphalt and are employed as doctors, scientists and directors of collective farms.

A few weeks after we arrived in Moscow, we enrolled our children in the State-run *detsky sad* or kindergarten. The long school day, from 8:30 to 5, allows the Russian mother to work. Younger children of working mothers attend the *detsky yashi* or nursery schools. Our children's class of twenty was cared for by four women. The daily schedule included three meals and a long play period or walk outside, even in the winter. A three-hour nap (yes, three hours) ensures that the children are full of energy when they return home in the late afternoon.

THERE ARE TEN years of school; Russian children enter elementary school one year later and finish high school one year earlier than American children. More time is devoted to physics, mathematics and chemistry in the Russian schools and, in Moscow, over half of the children study English. For Russian teenagers



Moscow State University has an enrollment of 30,000 and is Russia's finest university.

The primary function of Russian universities is teaching . . . the basic research and development is performed by the institutes of the Soviet Academy of Sciences.

the heavy homework assignments provide little spare time for dating and amusements. Even though Russians love, almost idolize, their children, they believe in strict discipline and the nonsense approach that *parents-know-best-what's-good-for-their-children*. The family life is close and the generation gap is not taken very seriously.

The strength of the Soviet curricula in the basic sciences has been well-known since the launching of the first sputnik. Less well-known is the Soviet emphasis upon foreign languages, particularly English. The training begins early, especially for the children of scientists. For example, in 1958, when scientists and engineers began to arrive in Novosibirsk to start the now-famous scientific center in Siberia, one of their first acts was the formation of an English reading circle for their children. Programs like these have achieved impressive results: a large percentage of Russian scientists and engineers speak English and nearly all of them can read technical English.

Higher education in the USSR is divided into two basic types: 1) universities and 2) special educational institutions. The special educational institutions have programs in agriculture, medicine, pedagogy, etc. and include the technical institutes which train the Russian engineers. **The duration of the engineering program is five years. The engineering curricula at the technical institutes contain almost no courses in the humanities and social sciences and there are no elective courses.** As a result, the Russian engineer receives a good but specialized technical education. The Russians complain that their engineers do not receive enough practical experience in the laboratory, a complaint familiar to U. S. educators.

After obtaining a degree at a technical institute or at a university, the student, called an aspirant, may work for the degree of Candidate of Science. There is no formal course work for the Candidate degree, which is based upon research and requires the defense of a thesis. The highest degree is Doctor of Science. It is tempting to equate the Russian degrees of Candidate and Doctor with the U. S. degrees of MS and PhD in the sciences. Actually the Russian degree of



Smolensky Cathedral in Moscow's Novodevichy Convent. In the convent cemetery are the graves of the composer Scriabin and the writers Gogol and Chekhov.

Doctor of Science requires much more work than our PhD degree. For the Soviet doctorate, a typical thesis is based upon a five- or ten-year research program and dozens of publications.

The primary function of Russian universities is teaching. Most of the basic research and development is performed by the institutes of the Soviet Academy of Sciences. This division of teaching and research in the Soviet system contrasts sharply with the U. S. system, where most basic research is done at the universities.

The research activities of the Soviet Academy of Sciences are organized according to disciplines: Institute of Organic Chemistry, Institute of Mathematics, Institute of Geophysics, Institute of Physical Chemistry, etc. Within each institute authority is delegated to senior scientists called academicians, who run research teams consisting of several dozen scientists and technicians. The rank of academician in the Soviet Union is a cherished position which brings with it such privileges as a chauffeur-driven car and virtually unrestricted freedom to travel abroad.

The institutes in Moscow are quite crowded; three scientists may share a small room. Only academicians have private offices. Therefore it was obviously no small sacrifice that I was given a well-equipped private office. Dozens of Russian scientists and engineers at the Institute of Physical chemistry work in the field of surface chemis-



St. Basil's Cathedral in Moscow, built during the reign of Tsar Ivan the Terrible, has domes that resemble peppermint-striped onion bulbs.

try and the desire to learn about their research was the reason for our trip to Moscow. Technical discussions, sometimes in Russian and sometimes in English, began a few days after our arrival. Soon, the routine of daily discussions led to some exchanges of ideas which were eventually published in joint articles.

Besides the lack of space, Russian scientists and engineers are faced with a scarcity of instrumentation and computing facilities. A Russian scientist needing, say, a chromatograph for a routine analysis may have to build it himself. The computers (for example, the BESM 8) are comparable in speed and storage capacity to the latest American models but scientists complain that the demand for computer time greatly exceeds the supply.

The most conspicuous weakness of the Soviet scientific establishment is its technology. I heard a lecture about the U.S. given by a Soviet scientist, who said that the U. S. and Russia are equal in strength of basic research but American technology is superior. He meant that the interlock-

ing and overlapping system of research and development at U. S. universities and industrial research laboratories has no counterpart in Russia. In Russia, the universities teach, the Institutes of the Academy of Sciences do basic research and the industrial organizations do applied research. This clear-cut division of responsibility has obstructed the free exchange of ideas between basic research and applied technology. The Russians are aware of this weakness and are experimenting now with plans for a more equitable distribution of basic research among the institutes, universities and industrial research laboratories.

Our trip to Russia was a rich and rewarding experience. The exchange program sponsored by the U. S. National Academy of Sciences has accomplished the nearly impossible feat of opening the lines of communication between the U. S. and USSR. Unfortunately the number of scientists and engineers exchanged each year is small and it is hoped that agreements negotiated in the future lead to a generous enlargement of the program.



The Kremlin Palace surrounded by the walls and towers of the ancient Kremlin.

ChE news

ASEE LITERATURE

The Relations with Industry Division of ASEE held the 22nd Annual College-Industry Conference at the University of Florida, Gainesville, Florida on February 5-6, 1970. The presentations at that conference are published as Industry-Engineering Education Series I-3, *The Current Campus Scene*. Copies of this 77-page paperback are \$2.00. The booklet contains 13 papers on the problems of the campus, the college-industry relationship, the student adjustment in industry and in gov-

ernment, the response of industry, and challenges to higher education.

The Engineering School Libraries Division of ASEE has published a *Guide to Literature on Chemical Engineering* by V. E. Yagello, Head of Chemistry and Physics Libraries, The Ohio State University. Single copies of the 24 page guide are \$1.00 but 25¢ if 10 or more are ordered).

This literature should be ordered from: Publication Sales, ASEE, Suite 400, One Dupont Circle, Washington, D. C. 20036.

ACKNOWLEDGMENTS

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University of Colorado
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Columbia University
University of Connecticut
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University of New Hampshire
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University of North Dakota
Northwestern University
University of Notre Dame
Nova Scotia Technical College
Ohio University
Ohio State University
University of Oklahoma
Oklahoma State University
Oregon State University

University of Ottawa
University of Pennsylvania
Pennsylvania State University
University of Pittsburgh
Polytechnic Institute of Brooklyn
Princeton University
University of Puerto Rico
Purdue University
University of Quebec
Queen's University
Rensselaer Polytechnic Institute
University of Rhode Island
Rice University
University of Rochester
University of Saskatchewan
South Dakota School of Mines
University of Southern California
State University of N. Y. at Buffalo
University of Tennessee
University of Texas
Texas A & I University
Texas A & M University
Texas Technical University
University of Toledo
University of Toronto
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Wayne State University
University of Washington
University of Waterloo
University of Western Ontario
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University of Wisconsin
Worcester Polytechnic Institute
University of Wyoming
Yale University
University of Windsor



CHEMICAL ENGINEERING DIVISION ACTIVITIES

The annual ASEE meeting will be held June 21-25, 1971 at U.S. Naval Academy, Annapolis, Md. The ChE Program Chairman for the meeting is Professor R. V. Jelinek, Syracuse University, Syracuse, N.Y. 13210. The ChE Division program follows:

TUESDAY, JUNE 22

12:00—Business Luncheon, Executive Committee
1:45—Workshop/Demonstration, W. D. Seider,
presiding
Computer Aids for ChE Education

WEDNESDAY, JUNE 23

10:00—Annual Lectureship Award
12:30—Division Business Meeting
1:45—Symposium/Conference, D. K. Anderson,
presiding
Recruiting High School Students into ChE

Speakers: Lloyd Berg; M. C. Hawley; W. R. Kube; R. S. Schechter
6.30—Annual Division Banquet

THURSDAY, JUNE 24

8:00—Panel Discussion, A. E. Humphrey, presiding.
Departmental Administration
Panel: "How to Put Bioengineering into a ChE Curriculum," K. B. Bischoff and R. L. Dedrick
Panel: "Guiding ChE Departments in Times of Reduced National Funding," W. R. Marshall and L. G. Mayfield.
10:00—Symposium, George Burnet, Chairman
Chemical Engineering Technology Education
"Associate Degree ChE Technology Program," John Kushner.
"Baccalaureate Degree ChE Technology Programs," Jesse DeFore.
"Peaceful Coexistence of Engineering and Technology in the University," M. A. Larson and R. C. Seagrave.
Discussion led by panel of four speakers.

from the STAFF

You will be pleased to learn that, due to the efforts of Professor Stuart Churchill of the University of Pennsylvania, a total of 133 departments of chemical engineering have contributed to the support of CEE in 1971—as compared to 126 in 1970 and about one hundred in 1969. It is also gratifying to note that a large number of departments have increased sizably the number of bulk subscriptions that they have ordered. In addition, Professor John Myers at Santa Barbara and Ed Bartkus at Du Pont have been quite successful in obtaining additional subscriptions from university and industrial libraries. Hence our subscription income for 1971 should be appreciably greater than in 1970. The editors and staff of CEE would like to thank these people and the many departments who have supported us with bulk subscriptions. If your department has not contributed for 1971, you may still order bulk subscriptions and receive back copies of the issues you missed (while they last.)

Another way that departments can contribute to the support of CEE—and also benefit their graduate programs—is to advertise in the Fall 1971 special graduate education issue. This issue consists mainly of articles on graduate courses that are written by professors at various

universities and of advertisements placed by departments of chemical engineering describing their graduate programs. Each department is provided with several free copies to distribute to seniors who are interested in graduate work and to some of their graduate students. Last year 51 schools placed advertisements in this issue as compared with 39 schools in 1969. However so far this year we have received indications from only 31 schools that they will advertise in 1971. Since some schools may not have received the letter we sent to department chairmen in early March, we are extending the deadline for receipt of advertising copy to June 1, 1971. With regard to editorial content, we are pleased to announce that we have received a good response to our request for papers on graduate courses. However it may still be possible to add one or two additional papers. If you would like to prepare a paper for this issue, please contact us as soon as possible. Papers that cannot be published in the Fall will be considered for publication in later issues. Our selection of papers is based on the objective of achieving a balance among areas, schools, and authors in a given issue and in preceding ones. R.W.F.

FOR DEPARTMENT CHAIRMEN:

1. We intend to advertise in the Fall Issue of CEE as follows:
Full page (\$150) _____, Half page (\$80) _____,
Quarter page (\$50) _____, Use last year's ad _____.
Note: Rates do not include printer's charges for setup and engraving.
2. We can get our advertising copy to you by _____.
3. School _____

FOR PROFESSORS:

I would be interested in preparing an article on my graduate course by the date indicated. (Manuscripts should be no more than 8 typed double-spaced pages).

Name _____ Date _____

Title of course _____

STABILITY OF REACTION SYSTEMS

JAMES B. ANDERSON*

*Princeton University
Princeton, N. J. 06520*

THIS IS THE first of a series of articles describing the development and operation of several new experiments as part of an undergraduate laboratory course for seniors in chemical engineering. The course was initially offered at Princeton as an elective for seniors in the spring term following a fall lecture course in chemical kinetics and reactor design. Recently, the number of laboratory sessions was reduced and laboratory and lecture courses were combined into a single course required of all students majoring in chemical engineering.

Professor Richard H. Wilhelm provided inspiration and guidance for the successful development of the reactor laboratory. Other members of the faculty—Donald E. Jost, Ronald P. Andres, and James B. Anderson—were directly responsible for development of the experiments and instruction of students. Most of the experiments were designed, built and tested by graduate students of the department serving as teaching assistants.

The laboratory was designed to emphasize reactor properties rather than reaction properties. Four main ideas are illustrated: 1) Modes of operation (batch, CSTR, tubular flow), 2) Regimes of operation (predominance of chemical rates, mass transfer rates and heat transfer rates), 3) Classes of reactions (homogeneous, heterogeneous, biological), 4) Measurements of pertinent physical rate processes. In several of the experiments the coupling of chemical, thermal and diffusional efforts are illustrated. Many of the important experimental techniques for reactor studies are utilized.

Listed in Table I are a total of eleven experiments developed and utilized in the course. A number of the experiments have been used in laboratory courses by other departments and have been described in some detail previously (1, 2). In this series we will consider only those

experiments which are sufficiently new to warrant a full description. The first of these demonstrates thermal effects for an exothermic reaction occurring at the surface of a catalytic wires.

METHANOL OXIDATION ON A PLATINUM WIRE

WHILE THE PHENOMENA of stability of reactor systems are familiar in everyday life (ignition and extinction of matches, etc.), the bridge between theory and practice needs considerable reinforcement before students develop an intuitive feel for stability phenomena in reactor systems. This experiment provides a demonstration of reactor operation in two stable stationary states together with ignition and extinction in a system whose thermal characteristics can be measured. Measurements of the heat generation and removal characteristics are used by students to predict the overall behavior of the system. These predictions are compared with actual behavior observed. In this way the theory of reactor stability is directly related to experimental observations.

The reaction system used stems from self-lighting cigarette lighters in which catalytic wires above an alcohol-saturated pad glow red hot when exposed to the air-alcohol vapors and ignite the alcohol on the pad. In the experiment a helium-oxygen mixture saturated at 0°C with methyl alcohol is passed over a short length of platinum wire in a heated chamber. Since the alcohol concentration is below that for a flammable mixture, reaction occurs only at the wire. Wire temperature is determined from electrical resistance measurements. The heat removal and heat generation characteristics at the wire are determined from measurements of electrical heat input required to maintain various wire temperatures at several chamber temperatures both with and without methanol present. To determine ignition and extinction temperatures for a negligible electrical heat input, the chamber temperature is varied slowly while the wire resistance is monitored. Since the wire does not glow red hot after ignition, all observations must be made by way of the wire resistance.

*Present address: Department of Engineering and Applied Science, Yale University, New Haven, Conn.

Table I. Reactor Laboratory Experiments

1. Batch Reactors: Hydrolysis of Acetic Anhydride.
2. CSTR Systems: Hydrolysis of Acetic Anhydride.
3. Tubular Flow Reactors: Hydrolysis of Acetic Anhydride
4. Gas Chromatography: Analysis of Alcohol-Ketone Mixtures.
5. Heterogeneous Catalysis: Isopropanol Dehydrogenation and Dehydration.
6. Diffusion and Reaction in Catalyst Pellets: TCC Catalyst Regeneration.
7. Stability of Reactor Systems: Methanol Oxidation on a Platinum Wire.
8. Biological Reactions: Kinetics of Yeast Growth.
9. Fluidized Beds: Study of Major Characteristics.
10. Diffusion in Porous Media: Knudsen Flow in Catalyst Pellets.
11. Diffusion in Packed Beds: Dye Tracer Studies.

THEORETICAL BACKGROUND

THE PRESENTLY AVAILABLE theories of the thermal characteristics of reactors have been admirably summarized by Denbigh⁴, Aris⁵, Kramers and Westerterp⁶ and Frank-Kamenetskii⁷. The methanol oxidation system used corresponds in many respects to a CSTR system. Except for end effects the wire temperature is essentially uniform. Reaction occurs at a single temperature and the system need not be considered a distributed-parameter system. A plot of the rate of heat generation by reaction against wire temperature has a sigmoid shape. At lower temperatures the reaction is rate-controlled while at higher temperatures the reaction is diffusion/transport-controlled. Depletion of reactants in the chamber is believed to be negligible under the conditions used. The process of transport of reactants and products is a combination of molecular diffusion with thermal and forced convection. A plot of heat removal rate against wire temperature shows the expected increase with difference between wire temperature and chamber temperature. The heat removal corresponds to that in a CSTR with a heat transfer surface. Heat removal from the wire occurs by radiation in addition to conduction and convection. For the methanol oxidation system the phenomena of multiple steady-states, ignition and extinction by momentary heating or momentary interruption of reaction, and spontaneous ignition and extinction can be explained in terms of the heat generation and heat removal curves. The analysis for this system has a direct parallel in the CSTR. Analysis of the transient behavior of this system is undoubtedly considerably more complicated than that of the CSTR and a direct

The laboratory was designed to emphasize reactor properties rather than reaction properties.

parallel may not exist. Transient behavior is not examined with the present apparatus.

APPARATUS

A schematic diagram of the system and a photograph of the reactor are shown in Figures 1 and 2. The helium-oxygen mixture is supplied from a cylinder, passed through a rotameter and fed to a sparger immersed in methanol at 0°C. The saturated (or partially saturated) gas passes through a coil to the air-jacketed reaction chamber which contains the platinum wire. A by-pass of the sparger is provided. Reactor exit gases are vented within a fume hood. Hot air for the chamber jacket is supplied by a hair-dryer type of heat gun. Resistance of the wire is measured with a commercial Kelvin double bridge circuit. Electrical current for resistance measurements and for heating the wire is supplied by an automobile storage battery and a solid-state control circuit.

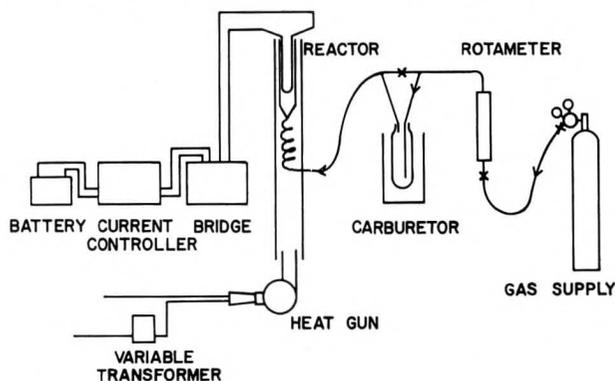


Figure 1. Schematic diagram of apparatus for determination of thermal characteristics of methanol oxidation on a platinum wire.

The 90% helium—10% oxygen mixture is purchased premixed in a conventional cylinder. The gas passes through a pressure regulator, shut-off valve, rubber tubing, control valve, and rotameter to the carburetor. Tygon tubing ($\frac{1}{4}$ -inch I.D.) is used downstream of the rotameter. The carburetor is a 2½-inch I.D., 8-inch long glass cylinder containing methanol in which a fritted-glass sparger is placed. The carburetor is immersed in ice water contained in a 4½-inch I.D. wide-mouth vacuum flask. The carbureted gas passes to the reactor. A carburetor by-pass tube is provided with a pinch clamp.

The reactor chamber is a $\frac{7}{8}$ -inch I.D. glass tube, 6 inches long, contained at the top of a second glass tube (2-inch I.D., 18 inches long) through which hot air from a heat gun is blown. The reactor feed gas passes through a tubing coil within the jacket for preheating prior to entering the reactor. The platinum wire is suspended in a horizontal loop at the center of the reactor. Exhaust gases from the reactor and the jacket are vented at the top of the reactor assembly. The heat capacity of the system is deliberately low so that rapid temperature

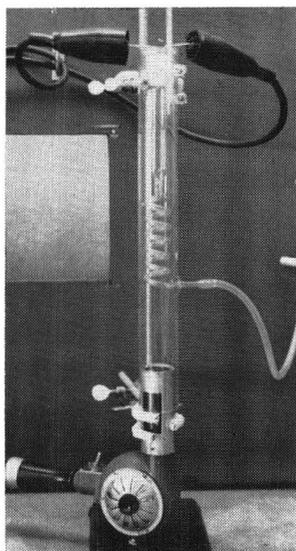


Figure 2. Air-jacketed reaction chamber.

equilibrium can be obtained. The heat gun is wired for control of its heating current with a variable transformer.

The platinum wire (0.003 to 0.005 inch diameter, about 1.5 inches long) is spot welded to two copper rods (3/32-inch diameter, tinned) held by a Teflon plug inserted (loose fit) in the top of the reaction chamber. Holes in the plug allow gas exit and insertion of a thermometer. Since wires are easily melted by overheating, spare assemblies are kept on hand. Spot welding is accomplished with a commercial spot-welding machine common to vacuum tube shops.

A Kelvin double bridge circuit is required for measuring the wire resistance because of the low resistance and the high currents which are used. Since three resistance ratios must be equal for balancing the bridge, a mechanical linkage of two ratios is essential for rapid measurements. With a slightly modified commercial bridge (General Electric, No. 9069199G) resistance measurements are made in a few seconds. The platinum wire and the copper rods (negligible resistance assumed) holding the wire are incorporated in the bridge.

The current control circuit is shown in Figure 3. An automobile storage battery provides sufficient current for more than five hours of experimentation. The circuit provides smooth control of current to the wire (and bridge) with the turn of a single dial. No feedback control is provided. Two ammeters, necessary for determining the power input to the wire, are included in the control box.

For reasons of safety, the reactor assembly and carburetor are located behind Plexiglas shields located within an exhaust hood. Provided the methanol concentration in the helium-oxygen mixtures does not exceed that corresponding to saturation at 0°C, the carbureted gas is not flammable at temperatures below 200°C. With higher methanol concentrations or at higher temperatures, the mixture may be flammable and/or explosive. To minimize the severity of a possible explosion, the volumes of carbureted gas contained in the reactor and in the carburetor are minimized.

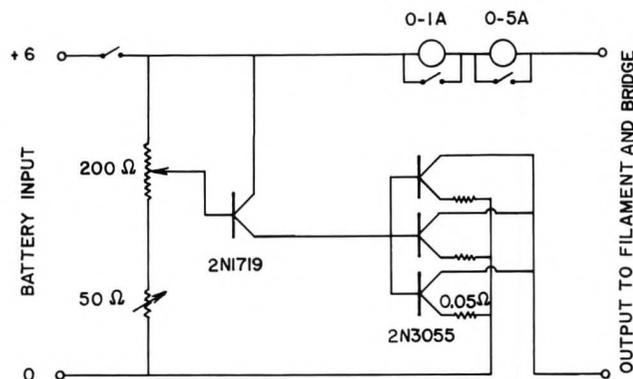


Figure 3. Circuit diagram for current controller.

PROCEDURE

Prior to measurements, the storage battery is charged and the methanol flash is cooled to 0°C. The platinum wire is flashed at a yellow heat in air to remove any contaminants. During experiments occasional flashing at a yellow heat helps to maintain a constant catalytic activity, but also risks melting the wire.

Initial observations of spontaneous ignition and extinction are made in order to check the activity of the wire and set a gas flow rate for which these phenomena are observable with chamber temperatures in the range 25-200°C. Usually flow rates in the range of 10 to 20 percent of full scale on the rotameter are suitable.

With a fixed flow rate and reaction chamber temperature the resistance of the wire is measured for a range of wire currents. Measurements without methanol in the feed give the heat removal-wire temperature curve since the heat removal is equal to the electrical heat input. If it is assumed that the heat removal for a given wire temperature is unaffected by the presence of the methanol, then the heat of reaction can be taken as the difference in electrical heat inputs with and without methanol present.

Measurements of heat removal and heat input by reaction for a range of wire temperatures are taken at several chamber temperatures. It is usually found that heat input by reaction is dependent almost solely on wire temperature and affected only slightly by chamber temperature. The thermal characteristics of the system under normal operating conditions make it impossible to determine the heat input by reaction in the vicinity of the steeply rising portion of the heat input-temperature curve. Interpolation is necessary in this region.

The experiment is concluded with measurements of the chamber temperatures for spontaneous ignition and extinction. These points are located approximately at first, then more accurately by changing chamber temperatures at a slower rate to allow thermal equilibration of the chamber-jacket assembly.

STUDENT PERFORMANCE

Students are in general able to obtain satisfactory results in a 3-hour period. Because the apparatus is simple, only a few minutes are required for examining it and preparing for opera-

tion. Students then seem baffled at the various heat inputs and outputs involved and may spend half an hour discussing these and arguing among themselves over procedures. Once measurements of heat removal and heat release by reaction are underway, data accumulation is rapid. The groups that plot the data immediately are able to gain a full understanding of the thermal characteristics of the system and predict stability behavior on the spot. Other groups may adopt and follow a procedure without fully understanding it and fail to determine the significance of their data until after they leave the laboratory. Questions directed to the students during the laboratory help prevent this situation.

The initial confusion, even for well-prepared students, in relating theory and practice in this experiment indicates the need for the exercise. In the course of the experiment this confusion is usually replaced by understanding and an intuitive feel for this system, and it is hoped, for the stability of reactors in general.

Thermal characteristics determined at the ignition temperature in one experiment are shown in Figure 4. Similar curves were obtained at other temperatures. The ignition and extinction temperatures could be predicted within 20-30°C from the room temperature measurements.

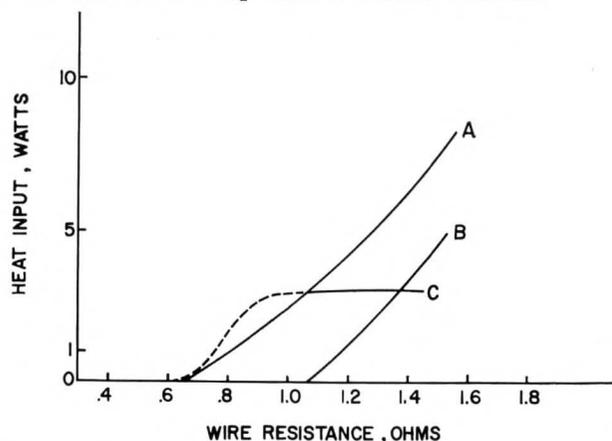


Figure 4. Thermal characteristics of reactor at the ignition temperature (188°C). Curve A—electrical heat input for helium-oxygen flow without methanol. Curve B—electrical heat input with methanol present. Curve C—heat released by methanol oxidation (difference of curves A and B).

DEVELOPMENT OF THE EXPERIMENT

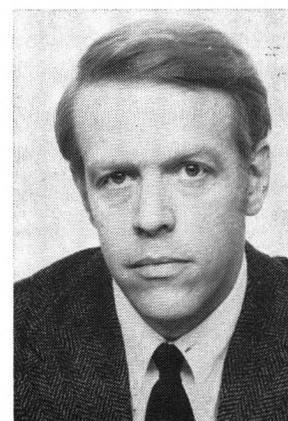
The system was first built for operation with air saturated with methanol at 0°C. The reaction chamber was maintained at room temperature only. Under these conditions reaction at an elevated wire temperature was not sustained without a large electrical heat input. Although meas-

urements of heat removal and heat released by reaction could be made and transitions between stationary operating points were observed, self-ignition and extinction did not occur. The use of a heated reaction chamber, which necessitates the use of a less flammable gas mixture, allows observations of ignition and extinction with a negligible electrical heat input.

Experience indicates that an easily operated, continuously variable current control and an easily operated Kelvin bridge are essential to rapid measurements. In an early version of the apparatus, current was controlled by switching resistors in series with the platinum wire and the bridge lacked mechanical linkage of resistors. Several minutes were required for each measurement in this version.

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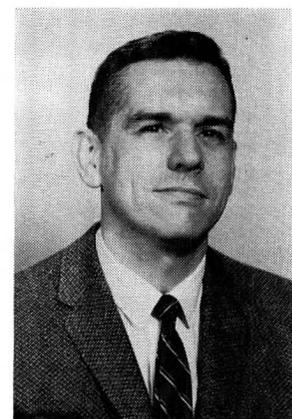
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J. B. ANDERSON is an associate professor of chemical engineering in the Department of Engineering and Applied Science at Yale University. He received his BS from Pennsylvania State University, MS from the University of Illinois and PhD from Princeton University. Professor Anderson taught at Princeton for four years before joining Yale in 1968. His research interests are in the fields of chemical kinetics and chemical reaction engineering.

A Demonstration Experiment In NON-NEWTONIAN FLOW

F. RODRIGUEZ
Cornell University
Ithaca, N. Y. 14850



INTRODUCTION

ALTHOUGH NON-NEWTONIAN FLOW is typical for all solutions and melts of high polymers at high shear rates, it is not an easy phenomenon to demonstrate to a large number of people at once. Other aspects of polymer solution behavior can be illustrated by using extreme examples. Melt elasticity is shown by "Silly Putty" which is readily available, and, in fact, already familiar to most students. Flow birefringence and creep recovery also can be shown.¹ The elasticity of dilute solutions of poly(ethylene oxide) giving rise to an "uphill" flow of a liquid has been packaged as a demonstration experiment (Edmund Scientific Co.). Drag reduction in turbulent flow also is amenable to demonstration. However the non-linear dependence of stress on rate-of-shear (or a viscosity which decreases on increasing stress or rate of shear) usually involves using a rotational apparatus with transducers connected to gauges or recorders so that the results can be seen by a large group at once.

There is one inexpensive type of capillary flow instrument which presents a range of stresses in a single experiment. The variable-head viscometer²⁻⁴ consists essentially of a cylindrical reservoir connected to a capillary tube. When the liquid flows, the reservoir empties in such a way that the logarithm of the height in the reservoir (above the discharge end of the tube) decays linearly with time for a Newtonian liquid. Although this can be used as the basis for a lecture demonstration, there are inherent advantages to using a triangular reservoir connected to a tube as in Fig. 1.

DEMONSTRATION

TO RUN THE experiment one fills the reservoir first with a Newtonian fluid selected to give a flow time of several minutes. Once the clamp is opened, members of the class can call out a signal at equal intervals of time, say 20 seconds. One of the students can mark the liquid level on the front of the reservoir with a crayon on each signal. If the reservoir is about 100 cm high, the experiment is clearly visible to a class of over 100. Next, while the reservoir is being refilled with a second (non-Newtonian) fluid, the points from the first run can be plotted on a paper graph next to the reservoir (as in Fig. 1). It is found that the points lie on a straight line.

The same routine is followed for the second fluid. It should be found that this time the reservoir does not

Ferdinand Rodriguez is a graduate of Case Institute (BS '50; MS '54) and Cornell (Ph.D. '58). He has taught at Cornell since 1958 in the area of polymeric materials and rheology. He has published extensively in this area and a text, *Principles of Polymer Systems* has recently been published. A native of Cleveland, Professor Rodriguez is a lay preacher in the Lutheran Church and also a guitarist.

empty linearly with time. With proper selection, a non-Newtonian fluid can be made to cross over the line for the Newtonian fluid.

EXPLANATION

FOR A FLUID flowing through a capillary tube it can be shown³ that the shear stress and rate of shear (both referred to the wall) are:

Shear stress,

$$\tau_w = \frac{\rho h g_c D}{4L} \quad (1)$$

Rate of shear,

$$\dot{\gamma}_w = \left(\frac{1+3n}{4n} \right) \left(\frac{32Q}{\pi D^3} \right) \quad (2)$$

where ρ is the fluid density, gm/cm³; h is height of fluid in reservoir above the efflux point of the tube, cm; g_c is 981 dynes/gm; D is tube diameter, cm; L is tube length, cm; Q is rate of flow through tube, cm³/sec; and n is $\ln \tau_w / \ln \dot{\gamma}_w$ ($n = 1$ for a Newtonian fluid).

Also, the viscosity (poise) is defined as

$$\eta = \tau_w / \dot{\gamma}_w \quad (3)$$

In the present apparatus, Q can be related to the change of h with time by

$$Q = -A \, dh/dt \quad (4)$$

where A is the cross-sectional area of the reservoir in cm² at a height of h . The reservoir is positioned so that the apex of the triangle is at the same height as the effluent point of the horizontal tube. This,

$$A = \left(\frac{BW}{H} \right) h \quad (5)$$

where B , W , and H are dimensions (in cm) of the reservoir in Fig. 1. Therefore, we have

$$\tau_w = \eta \dot{\gamma}_w \quad (6)$$

$$\frac{\rho h g D}{4L} = \eta \left(\frac{1+3n}{4n} \right) \left(\frac{32}{\pi D^3} \right) \left[- \left(\frac{BW}{H} \right) h \frac{dh}{dt} \right] \quad (7)$$

For a Newtonian liquid all the terms are constant except h , which cancels out, and $n=1$, which is the advantage of the triangular reservoir. Now we have:

$$- \frac{dh}{dt} = \left(\frac{\pi g}{128} \right) \left(\frac{\rho}{\eta} \right) \left(\frac{D^4}{L} \right) \left(\frac{H}{BW} \right) \quad (8)$$

The last three terms on the right are separate functions of the fluid, the tube, and the reservoir. Of course, when dh/dt is constant, h decays linearly with time.

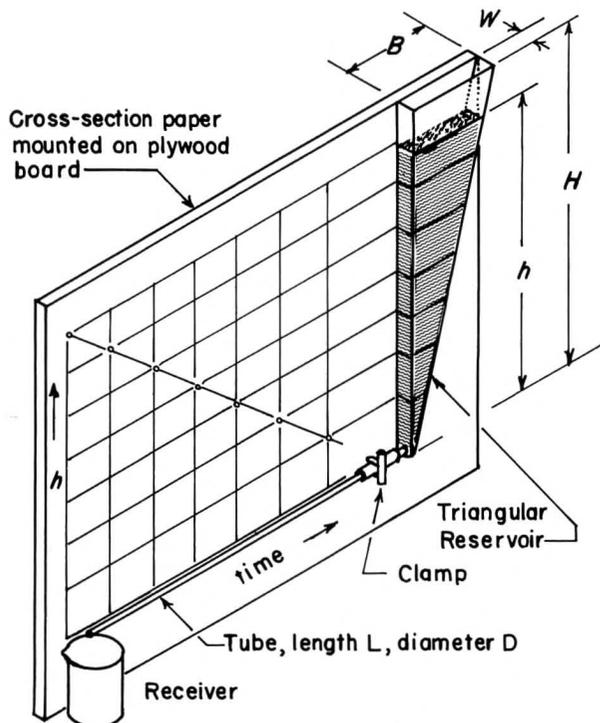


Figure 1. Variable-head viscometer with triangular reservoir.

The analysis of the non-linear plot for the non-Newtonian fluid can be carried out several ways. The easiest is to define an "apparent kinematic viscosity" as

$$(\eta/\rho)_a = \left(\frac{1+3n}{4n} \right) \left(\frac{\tau_w}{\dot{\gamma}_w} \right) \quad (9)$$

Then

$$\left(\frac{\eta}{\rho} \right)_a = \left(- \frac{dt}{dh} \right) \left(\frac{\pi g}{128} \right) \left(\frac{D^4}{L} \right) \left(\frac{H}{BW} \right) \quad (10)$$

The apparent viscosity is inversely proportional to the slope of the h, t plot. Most polymer solutions are "pseudoplastic", that is, the viscosity decreases with increasing shear stress (which is readily calculated from equation 1).

MATERIALS AND APPARATUS DIMENSIONS

THE SUCCESS OF a lecture demonstration is always affected directly by the choice of materials and conditions. A reasonable model made by joining a glass tube

to an acrylic reservoir by rubber tubing has the dimensions: $B = 20$ cm; $W = 1$ cm; $H = 100$ cm; $L = 21.5$ cm; $D = 0.40$ cm.

From equation 8 we learn that

$$-(dh/dt) = \left(\frac{\pi 981}{128} \right) \left[\frac{(0.40)^4}{21.5} \right] \left(\frac{100}{20} \right) \left(\frac{\rho}{\eta} \right) = 0.143 (\rho/\eta) \quad (11)$$

If a reasonable flow time for h going from 90 down to 20 cm is two minutes, then

$$(\eta/\rho) = 0.143 (120/70) = 0.245 \text{ stoke}$$

or about 25 times the viscosity of water. The shear stress is given in dyne/cm² by equation 1 when ρ is in gm/cm³ and h is in cm:

$$\tau_w = \left(\frac{981}{4} \right) \left(\frac{0.4}{21.5} \right) \rho h = 4.56 \rho h \quad (12)$$

Figure 2 shows a non-Newtonian polyacrylamide solution (0.94 wt.%) crossing over the straight line for a poly(vinyl alcohol) (4.0 wt.%) solution. The viscosity of the Newtonian solution is 0.56 stoke since $-dh/dt = 0.254$ cm/sec. When the slope of the other curve is plotted against h (Figure 3) a straight line results. This means that the fluid can be represented by the "power-law" model in this range of stresses.

$$\tau_w = K \dot{\gamma}_w^n \quad (13)$$

From equations 10 and 11 we can derive

$$(\eta/\rho)_a = 0.143 (-dh/dt) \quad (14)$$

This, with equations 12 and 13 (and with $\rho = 1.0$ gm/cm³) can be rearranged to give

$$(-dh/dt) = 0.01\pi (4.56/K)^{1/n} (4n/3n+1) h^{(1-n)/n} \quad (15)$$

From the slope in Figure 3, $n = 0.59$, and from the intercept, $K = 4.73$ dyne, sec.^{0.59}/cm². This is in good agreement with the behavior of this same polymer solution in rotational viscometers⁵.

Most water-soluble polymers that have an intrinsic viscosity less than two will give Newtonian solutions under the conditions of this experiment. In addition to poly(vinyl alcohol), some other materials are hydroxyethyl cellulose, dextran, poly(vinyl pyrrolidone), polyacrylamide, glycerol, and the lower glycols. On the other

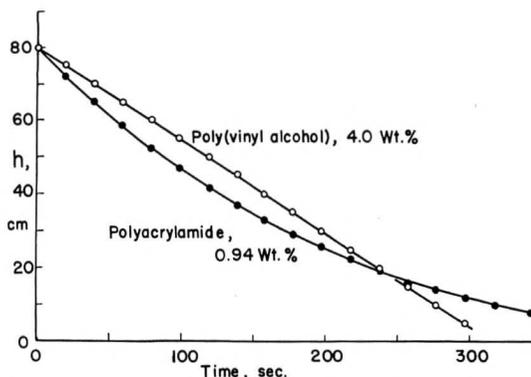


Figure 2. Head decays linearly with time for the Newtonian solution but not for the pseudoplastic solution. Both aqueous solutions were run at 25°C with $L = 21.5$ cm, $D = 0.40$ cm, and $(BW/H) = 0.20$.



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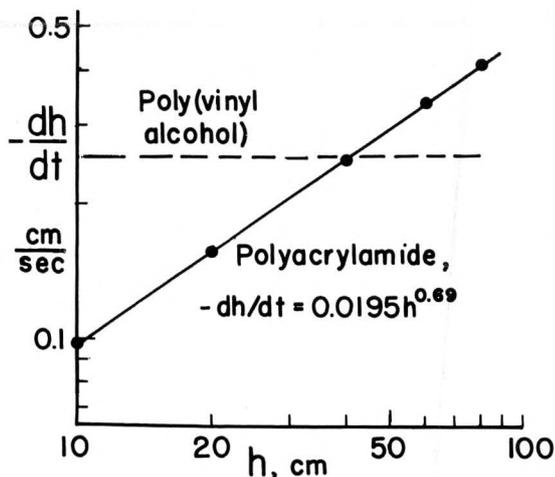


Figure 3. The logarithm of the slope for the non-Newtonian solution taken from Figure 2 increases linearly with $\log h$ corresponding to a power-law model.

hand, a non-linearity for the non-Newtonian material demands a very high molecular weight. Poly(ethylene oxide) is available which performs very well (Polyox FRA, Union Carbide Corp.). The polyacrylamide used here was made by placing a beaker containing a mixture of 50 gm acrylamide, 50 gm water, and 0.001 gm riboflavine-5'-phosphate sodium on the light table of an overhead projector for 10 minutes⁶. The resulting polymer gel dissolved in sufficient water to make a 1 wt.% solution while being gently rocked for one week.

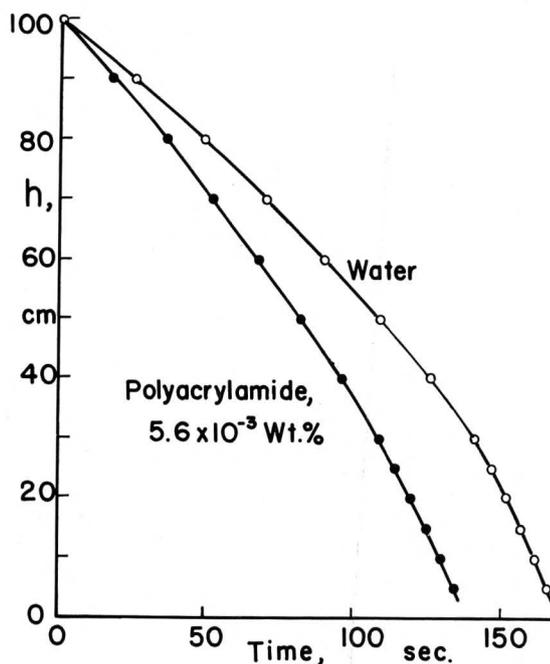


Figure 4. Drag-reduction by a small addition of polymer to water is shown in turbulent flow $N_{re} = 2100$ at about $h = 20$. For this experiment at 25°C , $L = 91.5$ cm, $D = 0.30$ cm, and $(BW/H) = 0.20$.

OTHER EXPERIMENTS

A QUALITATIVE DEMONSTRATION uses two setups in tandem so that both solutions can be run at once. The effect of having the Newtonian fluid flow more slowly than the other at first, but then catching up and passing up the non-Newtonian fluid in tortoise-like fashion illustrates the difference in behavior even without recording the time dependence of head.

The same apparatus can be used for an experiment in turbulent flow. The common parameters are the friction factor, f , and Reynolds number, N_{re} .

$$f = (hDg_c)/(2L\bar{u}^2) \quad (16)$$

$$N_{re} = D\bar{u}\rho/\eta \quad (17)$$

The average velocity, \bar{u} , is given by

$$\bar{u} = (BW/H)(4/\pi)(h/D^2)(-dh/dt) \quad (18)$$

Since f changes slowly with N_{re} , the qualitative prediction of equations 16 and 18 is

$$-dh/dt \propto (1/h)^{1/2} \quad (19)$$

The increase in slope with decreasing h is borne out by experiment (Figure 4) down to the point where laminar flow sets in ($N_{re} = 2100$).

A small amount (56 parts per million) of the poly (acrylamide) will make the reservoir empty even faster due to the well-known phenomenon of drag-reduction^{7,8}. From raw data of head versus time, the student should be able to construct a friction factor, Reynolds number plot. In turbulent flow experiments, end effects must be taken into account to achieve agreement with literature values of friction factors.

In all experiments with this apparatus, temperature control is difficult so that there is an inherent limit to the accuracy obtainable. Two other complications are the drainage error and surface tension. The first is aggravated by fast flows with viscous fluids. The second can be compensated for by first dipping the flow tube in the liquid and then aligning the apex of the triangular reservoir with the meniscus of the liquid in the tube rather than with the effluent point.

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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.

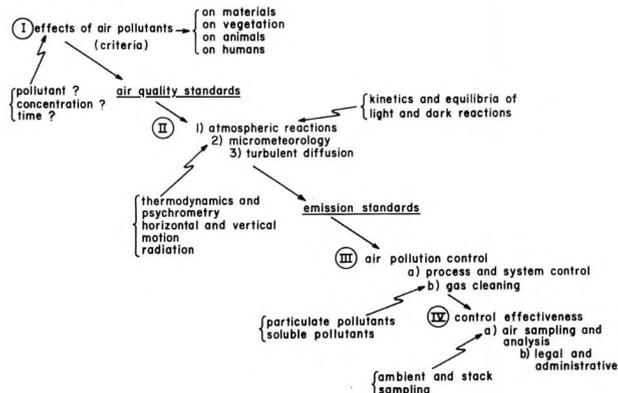


Figure 1. Design for air pollution core courses.

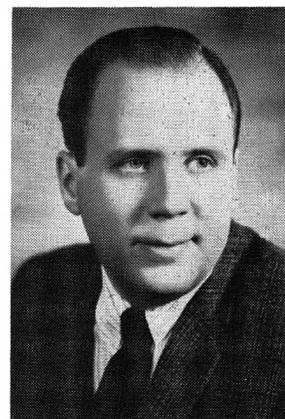
Each of the four numerals in Figure 1 indicates one of the core courses. A specific text is not used in any of the courses, principally because there is no appropriate textbook in the field. In the four courses extensive use is made of A. C. Stern's *Air Pollution* (Academic Press, 1968) which in its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

When compared with other BS degree holders the chemical engineer is best prepared for graduate work in air pollution control engineering.

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

- | | |
|--|--|
| <p>I. Air Pollutant Effects</p> <p>A. Effects of air pollutants on the atmosphere
Alterations to radiation
Effects on weather
Changes in the constituents of the natural atmosphere</p> <p>B. Effects on vegetation and foraging animals
Types of injury to plants, causative agents, conditions of exposure
Ambient and laboratory bioassay
Susceptibility of livestock</p> <p>C. Effects on man
History of acute episodes
Epidemiology
Toxicology</p> <p>D. Effects on materials
General deterioration and specific materials
Economic considerations</p> <p>E. Airborne, waterborne, and solid wastes
Interrelationships of potential and of control
Ultimate disposal</p> <p>II. Reactions and Transport of Pollutants</p> <p>A. Atmospheric chemistry
Basic concepts; kinetics, photochemical reactions, heterogeneous reactions
Inorganic atmospheric reactions; scavenging
Organic reactions; photochemical smog</p> <p>B. Atmospheric thermodynamics and stability; pseudoadiabatic chart
Thermodynamics and psychrometry
Statics, lapse rates, stability
Applications of the pseudoadiabatic chart</p> <p>C. Atmospheric motion
Scales of motion
Wind speed variation
Small scale vertical motion</p> | <p>Air pollution climatology: air patterns, stagnation, and inversions</p> <p>D. Diffusion in the atmosphere
Model of area-source diffusion
Single stack emission; plume characteristics
Models for diffusion</p> <p>E. Atmospheric radiation; energy budget</p> <p>III. Air Pollution Control</p> <p>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</p> <p>B. Removal of particulate pollutants from air streams
Efficiency and selection of collectors
Cyclone separators
Gravity and impingement collectors
Filters
Electrostatic precipitators</p> <p>C. Process and system control
Elimination of emissions
Minimization of emissions
Concentration of air pollutants at the source
Optimization of combustion</p> <p>D. Use of current literature for control problems</p> <p>IV. Effectiveness of Control</p> <p>A. Broad considerations in sampling
Site criteria; sampling network; statistics</p> <p>B. Review of analytical techniques
Radiation instrumentation; electrical; mass spectrometry; chromatography</p> <p>C. Passive effect devices</p> <p>D. Sampling proper
Aerosol sampling; gas sampling absorption, absorption, and condensation.</p> |
|--|--|



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 possible, 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 technology 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.



John C. Friedly is a native of West Virginia. He was educated at Carnegie Institute of Technology, Pittsburgh and the University of California at Berkeley, receiving a PhD in 1965. He has taught at the University of Rochester and the Johns Hopkins University. Industrial experience includes three years with General Electric Company, as well as consulting activities. He is the author of *Dynamic Behavior of Processes* which will be published by Prentice-Hall in late 1971. Research interests include process dynamics, automatic control, heat transfer, combustion and systems analysis.

These ideas are continually being incorporated into a one semester graduate level course entitled Process Dynamics taught at the University of Rochester. The course has evolved over several years, first being taught by the writer on the informal basis in an industrial environment and then at The Johns Hopkins University. The intent is to present a unified treatment of the unsteady state behavior of processes. Emphasis is on the physical interpretation of the time responses as well as the mathematical methods of analysis. Applications, in the form of examples, are taken from a spectrum of areas.

Students taking the course have a variety of backgrounds. No previous exposure to process dynamics or process control is required and indeed some have had none. The course is normally offered in the Spring semester so all students are expected to have a degree of mathematical maturity. Background in linear algebra, Laplace transforms, and techniques for solution of partial differential equations is built on. In addition to first year and more advanced chemical engineers both mechanical and electrical engineers have enrolled. Full and part time students are included.

No attempt is made to cover applications to process control with any breadth. There is perhaps a bias toward these problems, but no systematic treatment. Students interested in advanced

control concepts are encouraged to take a course in advanced servomechanisms taught in the Electrical Engineering Department or optimal control theory taught in the Mathematics Department at Rochester. The course in Process Dynamics provides sufficient motivation and background material for either. At present no course on control of chemical processes is offered, although one is currently being planned.

TABLE I PRESENTS an outline of the course content. It is divided into three major parts, the first being a rather brief introductory and motivational section. The remainder of the course is divided roughly into equal parts, treating problems described by ordinary differential equa-

Table I. Process Dynamics—Course Content

- I. Motives and Methods of Process Dynamics
 - A. Introduction
Illustrative examples; dynamic versus static behavior
 - B. Dynamic Process Models
Lumped and distributed parameter systems
 - C. Methods of Analysis
Perturbation methods, linearization; linear algebra; Laplace transforms
- II. Lumped Parameter Systems
 - A. Input-Output Representation
Transfer functions; time responses, short and long time expansions; frequency response; linear stability; Nyquist criterion
 - B. State Space Representation
Matrix exponential; eigenvalues, eigenvectors and response modes; modal control; optimal system responses
 - C. Nonlinear Responses
State plane response; perturbation methods; periodic processing; stability in the sense of Lyapunov, Lyapunov functions and system responses
- III. Distributed Parameter Systems
 - A. Linear Constant Coefficient Problems
Wave and diffusion responses; simple time and frequency responses; Riemann representation, the method of characteristics; Laplace transform techniques, short and long time expansions; axial dispersion, Taylor diffusion; stability considerations; optimal responses
 - B. Variable Coefficient and Nonlinear Problems
Local linearization, relation to Riccati equations; some exact solutions; nonlinear problems, flow forcing problem, shockwaves; periodic processing, the parametric pump; application of modified lumped parameter methods of analysis.
 - C. Approximation techniques
Relation between lumped and distributed systems, discretization; method of moments; modal approximation; successive approximations; asymptotic approximations.

tions and those arising from partial differential equation models. These are termed lumped and distributed parameter systems in control jargon.

As an introduction to the subject of process dynamics several diverse examples are discussed qualitatively. It is important to carefully distinguish between the true unsteady state and the quasi-steady and steady states. Only the first is a purely dynamic state in which there is a varying rate of accumulation of mass, energy or momentum. Then typical process models are considered as a basis for the general types of systems to be considered. Since all involve simply applications of conservation equations, models invariably are coupled systems of first order differential equations or first order (in time) partial differential equations.

Although an attempt is made to review or introduce mathematical tools in the context of the applications being considered, some introduction is given to the principal methods of analysis used throughout the course. The application of perturbation methods to general nonlinear equations is discussed to provide experience in obtaining linearized models to analyze. Care is taken to justify linearization not because real processes are linear but because only then can general analysis and interpretation be performed. Consequently most methods of analysis of nonlinear problems extend or build on the linear.

Treatment of lumped parameter systems is begun with a quick review of standard Laplace transform treatment of linear ordinary differential equations. Emphasis is placed on the physical, time domain, responses of these systems. Both long and short time expansions of transforms and their time responses are discussed. Transfer functions and their frequency response are treated only as they represent physical system models and their time response to sinusoidal disturbances. Typical example problems considered in this treatment might include the interpretation of complex viscosities obtained in rheological measurements or the choice of a forcing signal tending to amplify a system response the most.

More time is spent treating the same general N^{th} order system of linear lumped parameter equations from the state space point of view. General solutions are written in terms of the fundamental solution of the adjoint system of equations. The matrix exponential and the system eigenvalues, eigenvectors and response modes are interpreted physically. At each step full compari-

son is made between the same results obtained by general Laplace transform solutions and the state space solution. The problem of feedback control is introduced to illustrate that it is possible to tailor the dynamic response of systems to suit ones need. As a further example of the advantage of using the state space point of view the optimal control problem is considered. Elementary solutions to the variational problem are considered in examples.

Stability of linear systems is also treated from both the frequency response and state space points of view. Careful explanation of the feedback nature of the problem, either inherent or imposed, is included. From a general treatment of the analysis of roots of a characteristic equation the frequency domain methods are derived. In order to convey a physical feeling of the origin of the instability problem, example problems from a wide variety of areas are discussed. Both analysis of multiplicity of steady state solutions and of oscillatory storage and release of system "energy" are discussed physically and demonstrated mathematically.

The growth of a linearly unstable response to the point at which the linear model is no longer valid naturally introduces the analysis of nonlinear systems. The extensive work done on stirred tank reactor analysis can be used to illustrate the methods of classical nonlinear mechanics and the use of Lyapunov functions. Methods of analysis are developed as needed and compared with the limiting cases of linearized models. State plane dynamics and the geometric interpretation of stability in the sense of Lyapunov are rather easily presented after the linear canonical state space concept is grasped.

Although much of the material on lumped parameter systems is available in a variety of suggested textbook references, a conscious effort is made to use papers available in the literature for examples. It is felt that in this way the student is given a better feeling that these are indeed relevant problems of current research interest. In addition the point of view is made as broad as possible. Table II includes representative suggested references. Currently lecture notes are also distributed to the student to provide a unifying summary of the literature.

BECAUSE OF THE importance of partial differential equation models in chemical engineering an attempt is made to spend nearly half a semester on distributed systems. The nature

of distributed systems dictates that examples from research papers be used much more than general analysis. In contrast to lumped systems there are no adequate textbooks available with a systematic treatment of distributed parameter systems. The use of current research papers is not only advisable but necessary.

Table II. Representative References

- I. Motives and Methods
 - A. Himmelblau and Bischoff, *Process Analysis and Simulation*; Bird, et al, *Transport Phenomena*
 - B. Collins, *Mathematical Methods for Physicists and Engineers*; Amundson, *Mathematical Methods in Chemical Engineering*.
- II. Lumped Parameter Eystems
 - A. Coughanowr and Koppel, *Process Systems Analysis and Control*; Campbell, *Process Dynamics*; Aris, *Introduction to the Analysis of Chemical Reactors*.
 - B. DeRusso et al, *State Variables for Engineers*; Rosenbrock, CEP 58, No. 9, 43, (1962); Lapidus and Luus, *Optimal Control of Engineering Process*
 - C. G. Davis, *Introduction to Nonlinear Differential and Integral Equations*; Minorsky, *Nonlinear Oscillations*; Douglas and Rippin, *Chem. Eng. Sci.* 21, 305, (1966); Horn and Lin, *I/EC Proc. Des. and Dev.* 66, 21, (1967); Lasalle and Lefschetz, *Stability by Liapunov's Direct Method*; Berger and Perlmutter, *AICHE J.* 10, 233 (1964); Gurel and Lapidus, *I/EC* 61, No. 3, 30, (1969)
- III. Distributed Parameter Systems
 - A. Gould, *Chemical Process Control*; Koppel, *Introduction to Control Theory*; Courant and Hilbert, *Methods of Mathematical Physics*, vol. II, Chap. V., Taylor, *Proc. Roy. Soc.* A219, 186, (1953); Hsu and Gilbert, *AICHE J.* 8, 593, (1962); Yang, *J. Heat Trans.* 86, 133, (1964); Carslaw and Jaeger, *Conduction of Heat in Solids*
 - B. Bilous and Amundson, *AICHE J.* 2, 117 (1956); Crider and Foss *AICHE J.* 14, 77 (1968); Stermole and Larson, *I/EC Fund.* 2, 62 (1963); Koppel, *I/EC Fund.* 1, 131 (1962); Hart and McClure, *J. Chem. Phys.* 32, 1501, (1959); Orcutt and Lamb, *Proc. 1st IFAC Congress*, vol. 4, p. 274; Wilhelm et al, *I/ES Fund.* 7, 337, (1968)
 - C. Rosenbrock, and Storey, *Numerical Computation for Chemical Engineers*; Paynter and Takahashi, *Trans. ASME* 78, 749 (1956); Gould, *Chemical Process Control*; Schone, *Proc. 3rd IFAC Congress*, p. 10, b. 1.

Dynamic distributed parameter systems are classified naturally as either hyperbolic or parabolic. Flow problems are most frequently simplified to the extent that they belong in the former class. After first looking at some simple examples of transformed solutions to distributed systems, the striking contrasts with lumped parameter results are drawn. Complex transcendental

transforms, infinite series time responses, and delays are the rule rather than being nonexistent.

It is felt that a useful introduction to the types of linear responses expected from hyperbolic systems can be gained using the time domain Riemann representatives for the solution. The Rie- to the adoint system of equations and serves the same function as the matrix exponential in the standard state space analysis. The analogous interpretation of the Lagrange multipliers or adjoint variables of the calculus of variations problem ties these three subjects together neatly.

Fig. 1 illustrates the utility of the Riemann representation as applied to the simple counter-flow double pipe heat exchanger. The solution at any position and time $M(\zeta, \tau)$ is written as a linear functional of the initial and boundary conditions given between the points P and Q, connected with M by the characteristic lines PM and QP. The natural appearance of delays and their relation to domains of dependence and influence can be readily interpreted graphically and physically. From this, appearance of reflected waves can be easily explained. Since the responses to all hyperbolic systems can be interpreted in terms of system waves, this conceptual aid has a great deal of utility.

Once the expected wave behavior is understood thoroughly, it is a much more straightforward task to obtain and interpret solutions for hyperbolic systems both in the time and frequency domains. Recurring resonance phenomena in frequency responses of these systems is easily explained. Methods of expanding and inverting transforms of hyperbolic systems can be tailored to the physical interpretation. Short time (high frequency) solutions emphasize the wave behavior; long time (Heaviside expansion) solutions emphasize approach to steady state and stability. Interpretation of time delays is straightforward once they are expected. The effect of time delays on stability can be readily explained on physical grounds.

Problems arising with parabolic partial differential equations are contrasted with hyperbolic, wave problems as well as lumped parameter problems. The $t-z$ diagram of Fig. 1 can also be used to qualitatively interpret diffusion responses but with characteristics which are horizontal, corresponding to infinite wave velocities. The Riemann representation naturally reduces to the Green's function solution. No delays are encountered. For these problems also both short and

long time solutions prove to be useful in interpreting the results. Typical example problems treated in parabolic systems illustrate that real systems, whether by virtue of Taylor diffusion, axial dispersion or whatever means, never achieve the ideal limiting behavior of hyperbolic systems. A physical interpretation of the effect of superimposing a small amount of diffusion into a purely wave response is then given.

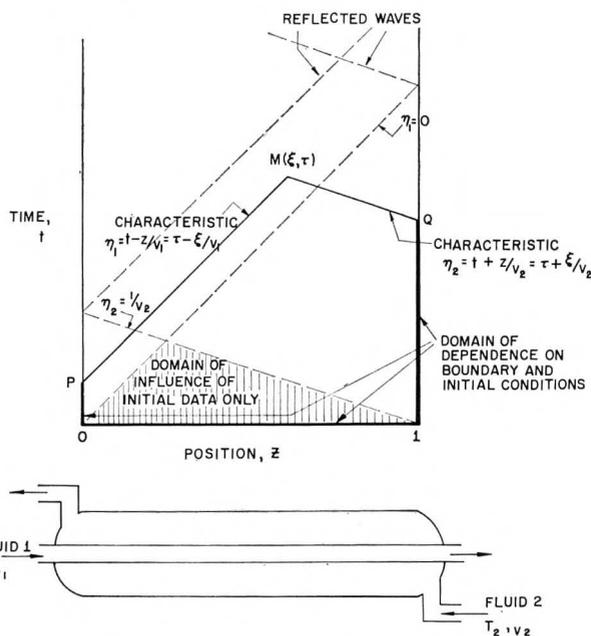


Fig. 1. Domains of dependence on initial and boundary data—double pipe heat exchanger.

The above problems all arise from linear constant coefficient distributed parameter models. Much can be said in general about variable coefficients and nonlinear problems. The former are treated by first transforming and making the change of variable to the corresponding Riccati equation. This illustrates the very real problem that although linear and transformable, distributed parameter systems do not always even yield transfer functions, let alone meaningful expressions for time responses. Several well known problems which can be solved are illustrated and discussed in terms of their peculiar characteristics. Strictly nonlinear or semilinear problems are treated in much less detail. Examples of solutions by the method of characteristics and perturbation techniques are discussed. The parametric pumping concept is a useful illustration.

In view of the general complexity of distributed parameter problems when solvable and the real possibility that some linear problems cannot be solved, approximation methods are

Rather than following one wag's assessment that, having lost control, one teaches process dynamics; it is useful to teach process dynamics, without control.

given special emphasis here. Available techniques such as quantization, the method of moments, modal approximation, successive approximations and asymptotic approximations are all introduced. Typical sample problems are used to illustrate the low frequency applicability of the first three and the high frequency utility of the last two. The value of the approximations are judged in terms of their utility in frequency response, time response as well as the general physical interpretation of responses.

IN VIEW OF THE expressed intention of applying process dynamics to as broad a spectrum of applications as possible the course content is evolving gradually as better and more diverse illustrations become available. Problems given as assignments are chosen to reflect the breadth of application. To the extent possible students are permitted a wide degree of choice of examination problems and term paper topics so that special interests can be accommodated. One interested in control problems can specialize his applications just as one interested in reactor design and technology. Perhaps this breadth of interest is reflected by the following selected term paper titles: 'Noninteracting Control of Distillation Columns,' 'Analysis of the Filtration of a Puff of Cigarette Smoke,' 'Relation between Singular Perturbations and System Simplification,' 'Analysis of an Electro-hydraulic Valve,' 'Thermal Regulation in the Human Body,' and 'Physical Interpretation of the Oscillatory Stability Criterion in a Stirred Tank Reactor.'

Process dynamics is a subject of infinite variety. Like transport phenomena it consists of a core of fundamentals applicable to diverse situations. Dynamics is not synonymous with control. "Processes" maybe interpreted as a piece of equipment in a plant, a single molecule, or the human body. The underlying principles of process dynamics are common to all applications. A combination of a unified treatment of these fundamentals and illustrative examples of applications in a range of fields is the intent of this course. Rather than following one wag's assessment that, having lost control, one teaches process dynamics; it is useful to teach process dynamics, without control.

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CHEMICAL PLANT SIMULATION An Introduction to Computer-Aided Steady-State Process Analysis by C.M. Crowe, A.E. Hamielec, T. W. Hoffman, A.I. Johnson, and D.R. Woods, all of McMaster University, and P.T. Shannon of Dartmouth College. Describes and illustrates the strategy of simulation to answer technical questions about non-linear processes with realistic objectives and industrial data and restraints. Demonstrates the technique with the sulfuric acid plant, and discusses other experiments such as those which involve pulp and paper processing, alkylation of hydrocarbons, the Bayer process for the production of alumina, business systems and various petrochemical processes. May 1971 330 pp. \$16.95 (12868-6)

PROCESSES AND SYSTEMS IN INDUSTRIAL CHEMISTRY by Herman P. Meissner, Massachusetts Institute of Technology. Focuses on the definition and quantitative study of factors determining the form of processes involving chemical transformations. Similarities between flow sheet patterns are indicated, depending on whether the reactions occurring are homogeneous gas phase, gas-solid, gas-liquid and the like. Problem emphasis is on the synthesis and technical screening of process alternatives, with consideration given to the total operation rather than only to the reactor and its design. January 1971 386 pp. \$14.95 (72332-0)

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AIChE ANNUAL REPORTS: EDUCATION PROJECTS COMMITTEE



Various AIChE Committees concerned with educational matters have furnished CEE reports of their activities.

L. BRYCE ANDERSEN, *Chairman*

The 20th edition of the Committee's widely distributed publication, CHEMICAL ENGINEERING FACULTIES, has been published at the University of Texas under the guidance of David Himmelblau. The directory, which lists faculties and other information about chemical engineering departments in the United States, Canada, Great Britain, and Australia, is published in cooperation with the national office of AIChE. Copies are supplied to academic departments and to Committee members. They are also available for sale through the AIChE national office.

The Design subcommittee is sponsoring a full day symposium on "Educational Programs in Process Design" at the annual meeting in Chicago. The subcommittee is chaired by Howard E. Turner of duPont and C. Judson King of the University of California at Berkeley. Dr. King is also responsible for developing a Design Education Workshop as part of the 1972 Summer School for Chemical Engineering Faculty being planned by the Chemical Engineering Division of ASEE.

The chairman of the subcommittee on Undergraduate Curricula, Clyde W. Balch, has carried out a survey on undergraduate design education. The results of this survey will be reported at the session mentioned in the previous paragraph.

The subcommittee on One-Day Schools held a session on "Chemical Engineering in the Pharmaceutical Industry" at Merck and Company in Rahway, New Jersey. Sixty-seven faculty members from 14 academic departments attended. While one-day schools continue to be successful in the Middle Atlantic area, attempts to generate

such schools in other parts of the country have failed.

The subcommittee on Graduate Study, C. Michael Mohr Chairman, has prepared a questionnaire for a survey on outcomes of doctoral programs. It is hoped to complete the survey in the year ahead.

The subcommittee on Films has been reorganized with Robert M. Hubbard as chairman. He is presently active in the development of films for educational purposes and is trying to establish contact with other interested persons in chemical engineering.

The new subcommittee on Cooperative Education has proposed a number of possible directions for action. The chairman, W. H. Tucker, will lead a discussion at the Education Projects Committee meeting in Chicago.

The subcommittee on Chemical Engineering Laboratory Experiments, W. H. Tucker, chairman, has been working with Professor B. E. Lauer on a new volume of laboratory experiments. A further survey of colleges is being contemplated, as is some coordination with the workshop on laboratories to be held at the 1972 ASEE Summer School for Chemical Engineering Faculty.

The chairman of the Programmed Learning subcommittee, Charles E. Wales, recommends disbanding the subcommittee because very few chemical engineers are writing programmed instruction. He feels that this activity can be more adequately handled by the ERM Division of ASEE.

C. Judson King, University of California at Berkeley, became chairman of the Committee January 1, 1971.

CONTINUING EDUCATION COMMITTEE

K. D. TIMMERHAUS *Chairman*

Engineering not only serves man but has assumed a deep responsibility for the effect of its contributions on society. For the graduate of a well grounded engineering program, continuing engineering studies

will be essential in order to remain informed and to retain the ability to make appropriate decisions in this rapidly advancing technological society. The engineer must assume the responsibility for maintaining his competence at the maximum level, but industry, government, universities and professional societies must

**provide opportunities for continuing education. on-
tinuing engineering studies are a national obligation
of the entire engineering profession to the progress of
mankind.****

Similar thoughts by a forward looking national AIChE leadership motivated the initiation of the AIChE Continuing Education Committee in 1963 under the capable leadership of W. R. Marshall, Jr. From a modest beginning of two programs the AIChE Continuing Education Program has now grown to the point where some fifty programs are annually scheduled in convenient locations across the country to provide assistance to chemical engineers with their continuing education programs.

THE PRESENT AIChE Continuing Education Program involves four different types of programs. The Today Series is a tutorial short course designed to update chemical engineers who have not had the opportunity to become familiar with material which is now part of the undergraduate chemical engineering curriculum but was not so ten or fifteen years ago. The AIChE Advanced Seminar is a short course intended for the chemical engineer familiar in a specific area of chemical engineering but desiring to learn what is going on in the research frontiers of the area. The Management Seminars are designed for chemical engineers who are adequately trained technically but are now experiencing the need to become more acquainted with the latest management techniques. Finally, the AIChE Continuing Education Workshop individually involves the participating chemical engineer with both experts in a certain field and others interested in the same field. This latter technique has been successfully employed for subjects like pollution, management, computer use, etc.

During the past four years the Committee has, with the gracious assistance of many dedicated chemical engineering lecturers, developed thirty-eight different Today Series, six AIChE Advanced Seminars and four Management Seminars. (At least six more programs are currently being considered by the Committee for 1971.) During 1970, the Committee sponsored a total of thirty-four Today Series, three AIChE Advanced Seminars, three Management Seminars and one Workshop. All but three of the forty-eight programs were two-day programs. These programs have been

**E. Weber, President of The Polytechnic Institute of Brooklyn, presented at ASEE Continuing Engineering Studies Conference, Dec. 12-13, 1966, Chicago, Ill.

scheduled principally at AIChE meetings. However, the more popular programs have also been scheduled at other locations across the country often with the support of the local AIChE section. The list of programs developed by the Committee includes such topics as mathematical modeling, simulation, optimization, strategy in process engineering, prediction of design data, automatic control, transport phenomena, reaction engineering, catalysis, statistics, statistical design, technical economics, heat transfer, distillation, polymer processing, instrumentation surface phenomena, air pollution control, water quality control, legal aspects in engineering, etc. Printed lecture notes for some of these programs are available from the New York AIChE office at nominal cost to local AIChE sections desiring to present these programs to their members.

To more clearly ascertain the specific needs of chemical engineers in local AIChE sections the Committee has recently formed a subcommittee which will poll and interview key representatives of local sections. This survey will be similar to the one undertaken by the South Texas section in 1963. However, this survey will go beyond determining the short course developments desired by various individuals in that it will try to assess what programs should be made available on the national AIChE level and what programs should be made available on the local section level. In addition, the Committee will seek to determine what types of programs and media are best suited for individuals of large sections, small sections, large companies, small companies, etc. Greater emphasis will also be placed on locating key personnel in the various local sections who can serve as focal points for that section's continuing education program.

IN LINE WITH TRYING to develop different types of continuing education programs, for the varied interests of chemical engineers, the Committee with the kind assistance of the Union Carbide Corporation has just arranged to develop a three hour video-tape presentation on "Fundamentals of Heat Transfer." This program is a shortened version of a Today Series by the same name which has been well received by attendees of the two-day course. In attempting this video-tape program, the Committee felt that it should explore the reactions of local section members and individuals pursuing a variety of continuing education programs to determine if this media would not only fill a need but also be accepted as an ad-

junct to their educational programs. Plans call for making this video-tape available on a minimal rental fee basis with an accompanying survey of all viewers of the tape. From comments of the viewers, the Committee should be able to determine whether a series of video-tape presentations should be developed of the more popular programs in the Today Series.

Because of the gradually increasing need for continuing education by all chemical engineers, the Committee has formulated a ten-point program to guide it in its future operations. These are:

- Constantly upgrade both present and future continuing education programs.
- Increase the quantity of published material from various continuing education programs.
- Develop better techniques for determining the continuing education needs of AIChE members.
- Develop new programs which fill these continuing education needs of AIChE members.
- Assist local AIChE sections with development of their own continuing education programs.
- Increase acceptance of the continuing education concept by industry.
- Further the cooperation with continuing education programs of educational institutions.
- Develop closer working relationships with other professional societies having continuing education programs of interest to AIChE members.
- Continue the exploration of new media to provide continuing programs in a more convenient and usable form for AIChE members.
- Extend the publicity coverage of both AIChE and non AIChE continuing education programs of interest to AIChE members.

Available manpower in the New York AIChE Office is directly related to the number of continuing education programs that the Committee sponsors. This number, during the past two years, has been established at approximately fifty. The Committee is, therefore, planning no more than this number on a national level for both 1971 and 1972. Greater emphasis will be placed on having the local AIChE sections develop their own continuing education programs with assistance from the Committee. The nucleus of available programs is now sufficient to give the local AIChE sections a wide variety of choices to satisfy their continuing education needs. However, as noted above, the Committee will continue to develop additional quality programs to meet the ever changing needs of the AIChE membership.

The Education Projects Committee carries on projects oriented toward chemical engineering education. Suggestions for projects come from

various sources. The new activities are initiated only if an interested person can be found to serve as chairman of a new subcommittee. The projects develop at various rates and subcommittees disappear when projects are completed and no further work is proposed.

ChE book reviews

Material and Energy Balance Computations.

E. J. Henley and E. M. Rosen. John Wiley & Sons, Inc. (1969), pp xxx + 577, \$14.95.

Henley and Rosen have undertaken a major task in this book, that of combining the "new stoichiometry" with the presentation of those chemical and physical principles and manual calculation methods usually taught in a beginning chemical engineering course. The "new stoichiometry" consists of linear algebra, numerical methods and machine computations plus some changes in the traditional ways of formulating the approaches to problem solutions.

A major judgment is that, to quote from the Preface, "We recognize that there is more material in this book than can be successfully incorporated in even a one-year course." It is this reviewer's opinion that critical deletion of material would have better served the authors' aim of a text emphasizing the new stoichiometry. To cite only one example, the longest chapter in the book is that on thermodynamics. Most of this chapter deals with the second law and related functions, material not essential to most material and energy balances.

The authors' correctly point out that by selecting six of the nine chapters an instructor may use the text as a classical stoichiometry book. In this regard, the treatment of some topics is judged to be less successful than that of some other basic texts. One example is that major bugaboo of the beginning course, units and dimensions. The section on units and dimensions dwells more upon what units are not than what they are, tending to obscure rather than clarify their nature and use. Another example is that the presentations and applications of the laws of conservation of mass and energy do not emphasize the value of a general (i.e. a word) statement of these equations as a framework for setting up the specific equations for a particular problem. Still another example is that there is only a very brief treatment of the unsteady-state.

The book is very inclusive in the treatment of the chemical and physical principles that determine the behavior of substances in chemical processes. There is much material on phase equilibrium and material and energy balances in staged systems. The book is liberally supplied with examples, problems and data tables.

The more likely reason for selecting this book would be the desire to emphasize the new stoichiometry. The three unique chapters, then, are of special interest. Of these, Chapter 5 deals with "The Solution of Equations." In this chapter, methods for solving sets of linear and non-linear equations are presented. The methods are applied to given equations, not to process problems in this chapter. Especially worthy of note is that an appendix includes complete FORTRAN IV program listings for four of the methods discussed. They are: GMST, Gram-Schmidt method of constructing orthogonal vectors for sets of linear equations; GELG, Gaussian elimination method for solving a set of linear equations; ROOT, finds the root of a one-dimensional, non-linear equation; and, BSOLVE, Marquardt's method to solve a set of non-linear equations. Each program includes the solution to an example problem from the text. This chapter could be useful in many contexts for it presents in a reasonably clear and concise form several useful algebraic-equation-solving techniques.

Chapter 8 emphasizes developing solution algorithms for certain process calculations, namely flash vaporization and equilibrium-extent-of-reaction in both homogeneous and heterogeneous systems. This chapter requires a rather thorough understanding of the principles of phase-and chemical-equilibria. A number of excellent examples of problem formulation and algorithm development are included.

Chapter 9 emphasizes process material and energy balances by computer process simulation. The building-block approach is clearly presented. The contents of the building-blocks tend to be somewhat obscure. Indeed an example illustrating the individual block calculations includes a reactor where conversion is kinetically determined. The equations cannot be very meaningful to a student, for nothing in the book has prepared him for a non-equilibrium chemical reactor.

Chapter 9 presents and compares direct substitution, the quasi-Newton method and an extension of Nagiev's method of split-fractions for handling recycle loops. It represents a reasonably good introduction to the rapidly developing field

of computer process simulation and design. The level of chapters 8 and 9 would seem to be above that of a first course, but they contain valuable material for chemical engineering curriculum.

In summary, this book could be used as a traditional stoichiometry book. It offers a very thorough treatment of the physical and chemical bases of material and energy balances, though in this reviewer's opinion the treatment of some topics lacks clarity. It offers material unique in this type of book in the way of the mathematics and the use of a digital computer for solving sets of equations, the development of algorithms for certain complex process operations, and an introduction to computer simulation of chemical processes. This new material is welcome in textbook form, though much of it appears to be above the level of the typical first course.

This book is sufficiently important that all teachers of chemical engineering undergraduate courses should examine it. They might choose to use portions of it in several courses.

Ronald E. West
University of Colorado

ChE problems for teachers

Simplified Approach to POLYTROPIC PROCESSES

FRANK M. TILLER AND FRED LOWRY
University of Houston
Houston, Texas 77004

Q. Derive expressions for polytropic processes.

A. Little attention is given to developing new techniques for teaching elementary concepts in thermodynamics in comparison to emphasis on advanced research. When new methods can be found which simplify and afford clearer presentation of basic principles, the student can proceed more rapidly and confidently to advanced aspects of the subject. The authors believe that one of the surest methods for providing more time and better understanding of advanced topics arises from improving approaches to the simpler topics of thermodynamics.

We have explored a new way of deriving the well-known expression $pV^n = \text{constant}$, which is straightforward in approach and appealing to the student. The proposed method can be restricted to processes, or it may be broadened to include irreversible effects. The instructor can take up the simpler reversible case or go into more depth by treating lost work. While more explanation is required when friction effects are included, a broader understanding is produced; and an introduction to irreversibility is commenced.

In the simpler reversible case, the method consists of assuming that the polytropic specific heat for an ideal gas is constant and then deriving the expression $pV^n = \text{constant}$. This procedure is the reverse of that which is usually encountered in textbooks, where it is first assumed that the expression $pV^n = \text{constant}$ is valid; and then the polytropic specific heat is shown to be constant. In many texts, derivation of $pV^k = \text{constant}$ for a reversible adiabatic process is the first step toward the more general expression. In the proposed method, the

more general $pV^n = \text{constant}$ is derived, and it is then demonstrated that $n = k$ is a special case.

In the second case involving lost work, it is possible to introduce the concept of a quasi-equilibrium process with friction, and then derive a more general expression of the form $pV^{n_i} = \text{constant}$. The exponent n_i reduces successively to n for a reversible operation and then to k for the added constraint of adiabaticity.

In the reversible case, the first law of thermodynamics

$$d'Q = dU + d'W \quad (1)$$

becomes

$$NCdT = NC_v dT + pdv \quad (2)$$

with the assumptions of an ideal gas constant specific heat, and reversibility. Introducing irreversibility, it is possible to say

$$d'W = d'W_r + d'L_w = (1 \pm r)pV \quad (3)$$

Various postulates concerning friction are possible. For our purposes, we assume that the lost work is proportional to the reversible work, because that assumption leads to the answer we want in the form $pV^{n_i} = \text{constant}$. The sign prefixing the factor r is dependent upon whether the process involves expansion or compression of the gas as demonstrated in Figure 1.

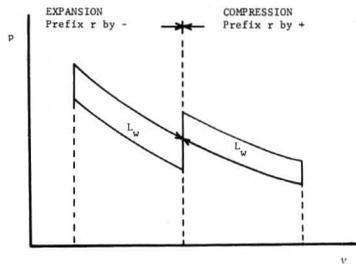


FIGURE 1

For the irreversible case, the first law becomes

$$NC_i dT = NC_v dT + (1 \pm r)pdv \quad (4)$$

where C_i is an irreversible specific heat. Utilizing $pV = NRT$, the differential dT can be eliminated from Equations (2 and (4) to give

$$\frac{dp}{p} = - \left(\frac{C_p - C}{C_v - C} \right) \frac{dv}{v} \quad (5)$$

$$\text{or } \frac{dp}{p} = - \left[\left(\frac{C_p - C_i}{C_v - C_i} \right) \pm r \left(\frac{C_p - C_v}{C_v - C_i} \right) \right] \frac{dv}{v} \quad (6)$$

whose solutions are, respectively,

$$pV^n = \text{Constant} \quad pV^{n_i} = \text{Constant} \quad (7a,b)$$

$$\text{where } n = \frac{C_p - C}{C_v - C} \quad \text{and } n_i = \left(\frac{C_p - C_i}{C_v - C_i} \right) \pm r \left(\frac{C_p - C_v}{C_v - C_i} \right)$$

Various thermodynamic relations for irreversible processes can similarly be developed for expansion and for compression.

IT IS POSSIBLE to derive a series of equations for Q , W , ΔU , ΔS , and pVT relationships based on Equation (7a,b). For example, the irreversible specific heat is given by

$$C_i = C_v - \left(\frac{1 - r}{n_i - 1} \right) R \quad (8a)$$

for expansion and

$$C_i = C_v - \left(\frac{1 + r}{n_i - 1} \right) R \quad (8b)$$

for compression. The isobaric specific heat with $n_i = 0$ becomes

$$C_{pi} = C_v - (1 \pm r)R = C_p \mp rR \quad (9)$$

For $r = 1$, corresponding to complete irreversibility in an isobaric expansion,

$$C_{pi} = C_p - R = C_v \quad (10)$$

For an adiabatic process, the pV relation is

$$pV^{k \pm r(k-1)} = \text{Constant} \quad (11)$$

When $r = 1$, the process corresponds to an unrestrained expansion, and the exponent in (11) becomes unity as expected.

The entropy change offers a good opportunity to show that $dS \neq dQ_i/T$. The first law can be written as

$$d'Q_i = dU + (1 \pm r)pdv \quad (12a)$$

$$= dU + pdv \pm rpdv \quad (12b)$$

where Q_i is used to emphasize that the heat transfer occurs in an irreversible operation. The quantity $dU + pdv$ can be replaced by TdS , thereby leading to

$$dS = \frac{d'Q_i}{dT} - \frac{d'L_w}{dT} = NC_i \frac{dT}{T} - (\pm r) \frac{pdv}{T} \quad (13)$$

Substituting $NR/V = p/T$ leads to

$$\Delta S = NC_i \ln(T_2/T_1) - (\pm r)NR \ln(V_2/V_1) \quad (14)$$

For an adiabatic process, (14) reduces to

$$\Delta S = rNR \ln V_2/V_1 \quad (15)$$

for an expansion.

It is possible to have an isentropic expansion which is not reversibly adiabatic. By placing $\Delta S = 0$ in (14), manipulation leads to

$$\left(\frac{T_2}{T_1} \right)^{C_i} = \left(\frac{V_1}{V_2} \right)^{rR} \quad (16)$$

as the condition for an isentropic process.

Nomenclature

C	Reversible polytropic specific heat
C_i	Irreversible polytropic specific heat
C_p	Reversible specific heat at constant pressure
C_{pi}	Irreversible specific heat at constant pressure
C_v	Specific heat at constant volume
k	Adiabatic exponent
L_w	Lost work
n	Reversible polytropic exponent
n_i	Irreversible polytropic exponent
p	Pressure
Q	Heat transferred
Q_i	Heat transferred in irreversible process
r	Irreversibility factor
R	Universal gas constant
S	Entropy
T	Temperature
U	Internal energy
V	Volume
W	Work
W_r	Reversible work



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