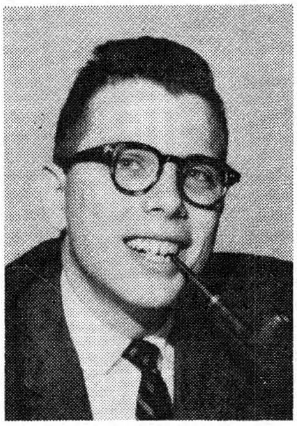
CASE PROBLEMS IN CHEMICAL PROCESS DESIGN AND ENGINEERING

C. JUDSON KING
University of California
Berkeley, California 94720



C. Judson King is Professor of Chemical Engineering at the University of California, Berkeley. His principal teaching and research activities lie in the fields of process synthesis and development, separation processes, food dehydration and mass transfer. He is the author of a new textbook, "Separation Processes," to be published by McGraw-Hill in late 1970. He holds the BE from Yale University and the SM and ScD from MIT. Since 1967 he has been Vice-Chairman of the Berkeley chemical engineering department.

A major challenge to chemical engineering education is the need to develop students' abilities in the *art* of engineering. Present-day curricula concentrate upon analysis and the understanding of physical and chemical phenomena. A chemical engineer must necessarily have a strong background in these areas; yet engineering is inherently an active, problem-solving function, for which analysis and scientific understanding are only the tools. We devote considerable time to developing the tools, but usually spend much too little time developing skills in the integrated use of these tools for the synthesis of new processes and for coping with other real, complex and loosely-structured problem siutations.

Universities can and should provide the training to bring out talents of application and problem-solving in students. Leaving this job to industrial experience runs the risk of these talents never being developed at all, and results in specific methods and customs being passed on from one generation of engineers to the next without the young engineer being encouraged to question and to bring in a fresh approach.

BERKELEY GRADUATE DESIGN PROGRAM

These conclusions have led this department to stress chemical process design and engineering as an important portion of the available graduate program. This portion of the graduate program is under the principal direction of four full-time faculty members: Professors Alan S. Foss, Edward A. Grens II, C. Judson King, and Scott Lynn. Courses are available in Process Simulation in Chemical Process Design, Chemical Process Synthesis, Design and Engineering of Integrated Chemical Process Systems, and related areas. The first three of these courses emphasize not only techniques which are available, but also the application of these techniques in specific chemical processing situations. The fourth course is built around a sequence of short case problems of the sort described below, and the development of these problems is an important aspect of the program. MS and PhD degree requirements are equivalent to the rest of the graduate program, and a thesis is required for each degree. Theses in the process design and engineering program represent original and potentially publishable work in the development and improvement of design concepts and techniques, or of specific processes. Thesis research and the creation of case problem material for use in class are often closely connected. Ties with industry are maintained through short-term (typically one quarter) visitors to the program and through the previous industrial experience of the faculty involved. The program is currently supported by a short-term initiation grant from the Division of Graduate Education in Science of the National Science Foundation.

CASE PROBLEMS

The case problems generated and used in the program are for the most part short enough so that they can be handled through class discussion in a relatively few class periods, with intervening homework assignments. They are not the sort of course-long problem typically taken up in a senior-year design course or in the AIChE Student Contest Problem; instead they are shorter and more qualitative. They are intended to increase the student's abilities in synthesis, in basic process understanding and in coping with open-ended engineering problems. The student must solve the problem himself; he does not read a history of someone else's solution. The problems are similar to those presented by Thomas K. Sherwood in his book, *A Course in Process Design,* and to those presented in *Chemical Engineering Case Problems* published by the *AIChE* Education Projects Committee in 1967.

At Berkeley these case problems are used as the entire subject matter for the aforementioned graduate course and also for a senior-year elective undergraduate course which follows the required senior design course. It is also possible to use one or more of the problems as a portion of a lecture course, for example as a means of tying together and showing application for subject matter at the end of a course.

HOW TO OBTAIN PROBLEMS

Through the grant from the National Science Foundation, these Case Problems are available to faculty of other universities for the cost of Xerox duplication. Each problem consists of a short descriptive introduction with references, a suggested Problem Statement for issuance to the students, and an extensive discussion or "Solution" of the problem for faculty use. This "Solution" constitutes 80 to 90% of the pages involved. The problems may be obtained by college and university faculty members and by those in charge of industrial or governmental training programs. They will not be published in a form such that the "Solutions" are readily available to students, so as to preserve the atmosphere of a new and challenging problem situation in the Classroom. Copies of any or all of the problems listed below may be obtained by sending payment or a purchase order to Professor C. J. King, Department of Chemical Engineering, University of California, Berkeley, California 94720. Checks should be made payable to "Regents of the University of California." Overseas orders should add 60¢ per problem for extra handling and postage.

PROBLEMS AVAILABLE

Announcements of Problems CP-1A, 1B, 2, 3 and 4 were distributed to chemical engineering departments in the U. S. and Canada this past winter. Three additional problems have become available since that time. The full list of problems available as of June, 1970, is as follows:

CP-1A.* **Production of Benzene and Xylenes by Hydrodealkylation.** Process Analysis and Synthesis (King). 29 pages ($1.00).

The aim of this problem is to develop an understanding of a chemical process, starting with a simplified flow sheet. The student is asked to determine reasons for the choice of particular operating conditions which have been given in a brief process description. He then must develop reasonable values for other operating conditions which are not given and must consider the possibility of modifying the basic flow scheme in various ways. Finally, a major elaboration of the process is suggested, and the student is asked to synthesize an ordering of process equipment for the new process.

CP-1B. **Simulation of a Hydrodealkylation Plant.** Process Simulation (Alesandrini, King and Foss). 34 pages ($1.00).

This problem is designed to give the student some understanding and familiarity with the requirements of a plant simulation on a computer. The student is asked first to generate a list of independent variables for a moderately complex chemical process. He then must select a sub-group of these variables upon which to base the simulation and present a block diagram of his approach to the solution of the heat and mass balances throughout the process. The selection of independent variables so as to eliminate iterative calculations connected with recycles is stressed.

CP-2.* **Continuous Drying of Air.** Trouble-Shooting (King). 41 pages ($1.25).

This problem involves the analysis of operating data for a fixed-bed, continuous air drying unit. The student is given a smattering of information on the current performance of the unit. On the basis of this he must design an appropriate and discriminating performance test. The results are real data, obtained from a past test on an actual, operating dryer system. From the data the student is asked to identify the source or sources of malfunction and to suggest ways of improving the operation of the unit.

(Continued on page 135)

*CP-1A,-2 appeared in "Chemical Engineering Case Problems," AIChE, New York (1967).

Analog and digital computers are needed in today's curriculum because we emphasize more sophisticated math techniques as the key to comprehension and learning.

Of equal importance from an instructional standpoint in the fact that this exercise, of an interdisciplinary nature, is a very practical industrial problem that any professional engineer might encounter. It follows therefore that the problem is completed when an interpretation of the mathematical solution invokes a practical engineering decision. We have found with this problem as with others which we have developed, that this "practical flavor" or realistic aspect has been an important factor in eliciting a most favorable response from among our students. As a follow-up to the problem presented here it was interesting for our students to discover that similar mathematics were reported by T. Wood[3], who investigated first order irreversible chemical kinetics in a series connected well-mixed and tubular reactor system.

REFERENCES

1. Barnes, B. G., R. E. Fuchs, and R. A. Somsen, TAPPI, **50**, 72A (1967).
2. The analog computer solution: Simulation, **Vol. X**, No. 4, 157 (April 1968).
3. Wood, T., Nature, **191**, 589 (1961).

KING: CASE PROBLEMS

(Continued from page 125)

CP-3. **Removal of Water Vapor in Freeze-Drying.** Process Synthesis (Kumar and King). 89 pages ($2.75).

This problem requires that the student generate and give a rough, evaluative screening to different approaches to the removal of water vapor which is being continually generated in a vacuum chamber, in this case a freeze-drying process. Initial attention is given to the conception of various techniques for removing water vapor. Then preliminary analyses are made of the proposed schemes to check the feasibility of each process, to gauge its requirements in terms of materials and energy, and to determine the merits and drawbacks of the proposal.

CP-4 **Desalination by Reverse Osmosis.** Process Synthesis and Optimization (Thompson and King). 60 pages ($2.00).

The student is presented with the basic physical concepts underlying reverse osmosis and is given some indication of the difficulties which may arise and the factors to be compromised in a reverse osmosis desalination process. The principal problem is to determine the best configuration of a reverse osmosis unit so as to achieve minimum energy consumption. The student must recognize the mechanisms by which design parameters influence pressure drop and water flux. He must ascertain which decisions can be made on the basis of qualitative or common sense thinking rather than through the optimization of formal mathematical equations. Finally, he can determine optimum values of the remaining decision variables through either mapping or a formal optimization procedure.

CP-5. **Sulfate Removal from Brackish Water.** Process Synthesis (Forrester and Lynn). 50 pages ($1.50).

This problem concerns the synthesis of a process which removes sulfate from a brackish water supply and which permits the recovery of both the potable water and its previous mineral content. The student is given several existing processes with which to work and is asked to combine them in the best way. Several different elements of process engineering are involved, including development of process flow sheets and mass balances, consideration of the heat requirements of different processing sequences, thermodynamics of reactions in aqueous solution, and consideration of pollution potentials during a process design.

CP-6. **An Evolutionary Problem in Process Simulation.** Process Simulation (Grens). about 55 pages ($1.75).

In this problem a number of basic aspects of process simulation are incorporated in a series of computer implemented projects, which evolve from basic equilibrium vaporization calculations to simulation of a process with material and enthalpy recycle loops. The problem is based upon a hydrocarbon absorber-stripper system, with absorber and stripper each having only one stage. First the student is asked to develop efficient procedures for equilibrium flash computations. Then he must develop simulations for the absorber-stripper system, with alternative convergence techniques being used and compared. Finally interstream heat exchange is added to the problem, and simulations of the dual loop system (material and thermal recycle loops) using both direct substitution and convergence accelerating techniques are sought. Development of efficient modular simulation programs is stressed throughout.

CP-7. **Removal of Inerts from Ammonia Synthesis Gas.** Process Synthesis and Analysis (Alesandrini, Sherwood and Lynn). about 60 pages ($1.75).

The purge of methane and argon from ammonia synthesis recycle gases causes a substantial simultaneous loss of hydrogen and nitrogen. This problem pursues the question of somehow obtaining a partial or complete separation of methane and argon from the other gases, by taking advantage of the unusual vapor-liquid equilibrium behavior of the system of these gases mixed with ammonia. Successively better process modifications are developed and are explored through energy and mass balances, followed by preliminary equipment sizing and economic evaluation. A computer calculation of the behavior of an absorber-stripper may be included at the discretion of the instructor.