ing real problems.

I suspect it is the elegance and subtlety of the theory which leads so many thermodynamicists to try their hands at writing textbooks. And because there are many good textbooks in the field, we must ask why another.

Modell and Reid answer, and rightly, that there is no advanced level textbook dealing with the applications of thermodynamics in chemical engineering. They seek to close the gap between theory and practice without shortchanging the treatment of relevant theory, and they succeed quite well. The principal medium of their success is the set of problems comprising some 75 examples and nearly 200 problems, none trivial and most derived from broad industrial experience.

The book is well suited to a one-term graduate level course in chemical engineering thermodynamics although there is more material than can be covered in one term. It is equally well suited to the practicing engineer who wishes to upgrade his prowess in dealing with realistic problems. The style of writing is clear and graceful, and difficult areas are dealt with at sufficient length to assume comprehension.

The authors suffer from the disease (endemic to chemical engineers?) of using nonwords like *directionality* and *functionality*, but these are minor lapses in a well-written book which fills a very real need in our literature.

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Professor Leon Lapidus, a member of the Journal Editorial Board, solicited the review for this book.

**Identification and System Parameter Estimation: Parts 1 and 2, Proceedings of the 3rd IFAC Symposium,** The Hague/Delft, The Netherlands, 1973, P. Eykhoff, Editor. North Holland, Amsterdam (1973).

System identification has experienced vigorous growth since its early days when a process was modeled by a first- or second-order transfer function solely by means of graphical techniques. Once the statistical nature of the problem became recognized, many concepts and techniques hitherto hidden in statistics textbooks and journals started being used. Matrix theory and the theory of linear differential equations, under the name "linear systems theory," and optimization theory also provided techniques useful to system identification.

The combination of concepts and techniques from statistics, linear systems theory, and optimization evolved to a large variety of identification techniques many of which have already accumulated a voluminous specialized literature. This is hardly surprising in view of the diverse types of physical processes under consideration, the type, amount and quality of data and the objective of identification. The diverse background and interests of research workers has further added to the proliferation of identification methods. At present the variety of the methods available, and their abstract mathematical formulation are bewildering to the nonspecialist, for example, the research and development engineer or the practical control engineer who are called upon to apply identification. What tests to carry out, what type of model to use, and which identification method to apply are important decisions that he has to make in the presence of many alternatives. The "Identification and System Parameter Estimation" proceedings of the 3rd IFAC Symposium are useful in this respect because they display the state of the art in the field, provide a useful selection of review articles by some of the foremost specialists, and offer a series of papers dealing with specific applications which should be of great value to the practicing engineer. In this review we shall first discuss the theoretical papers contained mainly in Volume II of the proceedings and then the papers dealing with specific applications contained mainly in Volume I.

## GENERAL PAPERS ON THEORY AND APPLICATIONS

As emphasized throughout the proceedings, the type of model (linear or nonlinear, lumped or distributed parameter) used in identification depends on its ultimate utilization. If control (regulation) is the objective, a linear model describing small variations about the steady state is usually sufficient. If the modeling aims at understanding the process for the purpose of design, optimization, etc., then a nonlinear model constructed on the basis of physical laws will be necessary.

### Identification Methods for Linear Lumped Parameter Systems

In spite of the extensive literature available, the identification by means of linear models is still a lively research field, as evidenced by the contents of the proceedings.

*Correlation Techniques.* A review paper by Marchand (p. 591) deals with the identification of linear multivariable systems from frequency response data. The data from sinusoidal testing can be used to obtain the transfer function at a discrete set of frequencies using standard statistical correlation techniques. From such frequency response data, one can obtain either an analytical expression for the transfer function or the coefficients of the differential equations, in both cases by maximum likelihood or least squares fitting. The difficulties of practically producing sinusoidal test signals are well known. An alternative and more convenient test signal that can be used in conjunction with correlation techniques is the pseudo random binary sequence (PRBS) as discussed in the paper by Nougaret et al. (p. 1023). Finally, the application of correlation techniques to a process excited by random inputs is discussed in an interesting and practical paper by Gerdin (p. 759).

*Least Squares—Maximum Likelihood.* Most successful and general among system identification and parameter estimation methods are the closely related least squares, generalized least squares, and maximum likelihood methods. An important paper by Söderström (p. 691) deals with the convergence properties of generalized least squares and provides examples with simulated and plant data. Two other papers, Pandya and Pagurek (p. 701) and Talmon and van den Boom (p. 711), also deal with the estimation of system and noise parameters by generalized least squares. A paper by Merhav and Gabay (p. 745) deals with the effect of modeling error in parameter estimation by least squares or generalized least squares. A paper by Finigan and Rowe (p. 729) is concerned with a modification of instrumental variables, a technique akin to generalized least squares but attempting to avoid the estimation of noise parameters.

Since the methods of generalized least squares and maximum likelihood are statistically optimal and practically workable, they must become better known among chemical engineers interested in process modeling and control. For this purpose we strongly recommend the excellent review of Åström and Eykhoff (*Automatica,* 7, p. 123, 1971).

*Other Techniques.* The proceedings include contributions to several other techniques, for example, the stochastic approximation technique, which however are of less general interest and need not be discussed here.

### System Order Determination, Canonical Structures, and Order Reduction

An important part of system identification is the determination of system order. This problem has received attention only during the last few years and the proceedings include some of the most important references available to date. For example, the papers of Unbehaven and Göhring (p. 917) and van den Boom and ven den Enden (p. 929) compare several tests of order determination in a series of problems with simulated data. Most work on order determination, including the above two papers, deal with linear systems, while a paper by Woodside (p. 987) treats the problem for nonlinear systems.

The aforementioned papers focus on single-input, single-output systems. A multiple-input/output system can be represented by a class of equivalent time-domain representations (consisting of matrices), posing the problem of a canonical representation. This problem is addressed by the theoretical papers of Bingulac and Djorović (p. 995), Furuta (p. 939), and Guidorzi (p. 943). Another related problem, that of system representation by a model of lower order, is treated in an interesting paper by Isermann (p. 1081).

#### Nonlinear Systems

The proceedings include several papers on identification of nonlinear systems. Among these we note a paper by Godfrey and Briggs (p. 809) dealing with a class of systems with direction-dependent response and including applications to a pilot-scale chemical reactor and a steam generation unit. The test signals used were pseudo random binary sequences (PRBS) and the identification was performed by generalized least squares. The interesting papers of Jackson and Rippin (p. 827) and Sutek and Varga (p. 839) apply PRBS to nonlinear system identification.

#### Distributed Parameter Systems

Among several papers on distributed parameter systems, we note that of Pillo et al. (p. 687) applying a simple identification algorithm known as the epsilon method. Many of the other papers presented are of mathematical interest but do not seem to contain material of immediate value to the practicing engineer.

#### Design of Test Signals

The accuracy of parameter estimates depends on the input signals used in process testing, whence the problem of choosing optimum test signals. However, the optimum test signal depends on the system parameters, hence some type of *a priori* knowledge about the system or some iterative procedure are required. A paper by Goodwyn and Payne (p. 1005) defines optimal test signals characterized by their spectral properties and discusses the realization of these signals. The definition of optimality of test signals is treated by Kevicsky and Bányász (p. 1011) via the covariance matrix of parameter estimates while the paper of van den Bos (p. 1015) is concerned with the choice of optimal periodic test signals, for example, PRBS of optimal length and bandwidth. Other interesting papers on test signal design include that of Smith (p. 1027) dealing with recursive identification (filtering) and that of Sawaragi and Katsuya (p. 1035) using a game theoretic approach to test input selection.

At this point it is appropriate to emphasize the attractive properties of pseudo random binary sequences in generating data for system identification. The proceedings contain several papers discussing the properties of PRBS signals, for example, the papers of van den Bos (p. 1015) and Nougaret et al. (p. 1023). Applications of PRBS signals are given in the papers of Söderström (p. 691) and Godfrey and Briggs (p. 809).

#### Applicability of Identification and Comparison of Various Methods

Following the papers on estimation methods, test signals, etc., the proceedings include a series of papers devoted to a discussion of the practical applicability of identification and the comparison of various methods. The short papers of Godfrey (p. 1071), Goodwin (p. 1073), Bohlin (p. 1074), Clarke (p. 1075), and Godfrey and Goodwyn (p. 1077) contain brief and lucid qualitative discussions on various practical aspects of identification that should be of great interest to chemical engineers. The papers of Isermann et al. (p. 1081, 1103) and of Baeyens and Jacquet (p. 1107) should also be of value to the engineer for his detailed comparisons of various identification methods.

## SPECIFIC APPLICATIONS AND CASE STUDIES

The first volume of the proceedings contains primarily applications of identification in specific processes, either commercial or experimental (pilot plants). Relatively few papers deal with chemical, petrochemical or refining processes, probably due to the secrecy surrounding the industry. However, many of the applications to power plants, glass furnaces, paper processes, etc. should be of value to the chemical engineer working in the chemical or petrochemical industry.

#### Chemical Processes

A very important survey on identification in chemical, metallurgical, cement and glass processes is presented by Gustavson (p. 67). The survey discusses many specific applications and contains a critical discussion of problems important in practical identification, including limitations in the data, measurement problems, the effect of noise, choice of input signals, etc. This survey is a must for the chemical engineer interested in applications. A case study of distillation processes by Foulard and Bornard (p. 167) is of practical interest for its detailed coverage of various aspects of applying system identification. Other papers of interest are Riffaud and Magistry (p. 285) dealing with a bauxite digestion process, Parnaby et al. (p. 299) comparing different models for plastics extrusion systems and Argentesi et al. (p. 317) modeling an aquatic ecological system. All these papers treat real data from commercial or pilot plant units. A paper by McGreavy and Vago (p. 307) applies nonlinear filtering to the on-line identification of deactivation parameters and activity profiles in a fixed bed reactor. In the last two papers (p. 317, 307) the purpose of identification is to increase the knowledge about the process and to provide a model for optimization, while most previous papers were concerned with providing a linear model for control.

#### Power Systems

A survey of identification applications by Baeyens and Jacquet (p. 1107) should be of interest to chemical engineers in spite of its emphasis on power systems. It reviews literature and discusses such important topics as choice of model and identification method, effect of noise, choice of test signals, etc. A case study of a pilot scale boiling rig by Clarke et al. (p. 355) provides all the details of identification in an actual application. The use of normal operating data in the identification of power generator dynamics is treated in a paper of Lindahl and Ljung (p. 367) and an important case study of Olsson (p. 375) deals with the identification of the dynamics of a nuclear reactor using real data. In most case studies of power systems, PRBS test signals were used, evidently with very good results. There seems to be no reason why this type of test signal should not be just as useful in chemical identification.

#### Other Processes

Two case studies in glass manufacturing processes are given by Rao et al. (p. 1151) emphasizing simple transfer function models, PRBS signals, and least squares estimation. A paper by Richalet (p. 109) on the identification of a glass furnace presents some useful ideas for dealing with a complex and ill-understood process. A sophisticated application of identification of a paper production process is given by Gentil et al. (p. 473). In addition to considering rather carefully questions of noise correlation and test signals, the authors provide a comparison of the results obtained by different methods, namely least squares, generalized least squares, maximum likelihood, and instrumental variables.

**Aircraft and Transportation Systems**

Several papers in the proceedings deal with the identification of aircraft dynamics including a survey by Rault (p. 49), a number of sophisticated case studies by Mehra and Tyler (p. 117), and an interesting application to ship dynamics by Åström and Källström (p. 415).

**Biological and Economic Systems**

A short survey of identification of biological systems is given by Bekey (p. 1123), and several other papers deal with specific systems such as the metabolic, the immune, the lungs, and the cardiovascular. Finally, there are three applications to economic models.

## ADAPTIVE CONTROL

Although the IFAC Symposium was devoted to system identification and parameter estimation, it included a limited number of contributions to the closely related subject of adaptive control. Among these we may mention a paper of Peterka and Åström (p. 535) treating the design of self-adjusting regulators using an on-line identification technique, and a paper by Nikiforuk et al. (p. 555) on the control of a nonlinear plant of unknown structure. Finally, Ku and Athans (p. 571) consider a feedforward-feedback suboptimal control for a linear system with randomly varying parameters.

## CONCLUDING REMARKS

The proceedings contain material that should be of considerable interest to chemical engineers. The survey papers, especially those which compare various identification methods, give a much needed perspective about what methods are available, how they differ from each other, and under which conditions one method is more suitable than others. One cannot escape the conclusion that further research or applications by chemical engineers should not concentrate in further development of methods but should be focused on a critical evaluation of various assumptions required in applying various methods to specific processes. For example, the statistical nature of random dynamic or measurement errors deserves careful consideration. The design of test signals that do not seriously disturb normal operation, yet provide an adequate excitation, is another. Among various specific applications presented, we recommend a careful study of those directed to power systems because of the serious effort made to utilize theory in a critical way. However, it must also be emphasized that most of this admittedly impressive work deals with linear models required for regulatory control. The modeling of complex nonlinear processes such as a catalytic cracking unit, with the objective of process design and optimization remains a virtually untouched area that will hopefully be taken up in all seriousness by chemical engineers.

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**The McGraw-Hill Dictionary of Scientific and Technical Terms,** Daniel N. Lapedes, Editor-in-Chief, McGraw-Hill Book Company, New York (1974). $39.50

How does one review a scientific dictionary? Especially one with almost 100,000 definitions and 2,800 illustrations? Spot checking of chemical engineering terms, for example *Marangoni effect, bag filter, Sherwood number,* yielded positive results. The definitions were brief but well-written. *Drag reduction* was not included, but even a book of this size cannot be expected to be all-inclusive.

In fact, the dictionary is a fascinating book in which to browse and learn. Most scientific and engineering fields are covered and my vocabulary was expanded to include *bra vector, Robin Hood's wind, free gold,* among many.

I invited my friends to supply me with terms from their fields and the results were excellent in all cases but one. An orinthologist was outspokenly critical since birds seem to have been somewhat neglected. To make matters worse, worms seem to be well represented (try *Rhynchocoela*). Her retort was, what is a worm without a robin?

The book will be invaluable for libraries and for all companies which must deal with the technical or scientific community. For individuals, it would be a delightful addition to the bookshelf—and in many cases, of real value.

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*(Continued from page 207)*

industrial people such as Dr. Weekman. To allow the editor to print more of such articles, AIChE should give the *Journal* more pages per year.

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# ERRATA

In the last column of Table 2b of the article "Computational Methods for Cylindrical Catalyst Particles", [*AIChE J.*, **19**, 969 (1973)], 0.3682 should be 0.2682.

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In "Bisphenol A Synthesis: Kinetics of the Phenol-Acetate Condensation Reaction Catalyzed by Sulfonic Acid Resin" [**20**, 933 (1974)] by R. A. Reinecker and B. C. Gates, in Equation (4) and on the left-hand sides of Equations (5) to (7), the variable $C$ should be replaced by $\theta$, with $\theta$ defined as the fraction of sites occupied.

B. C. GATES