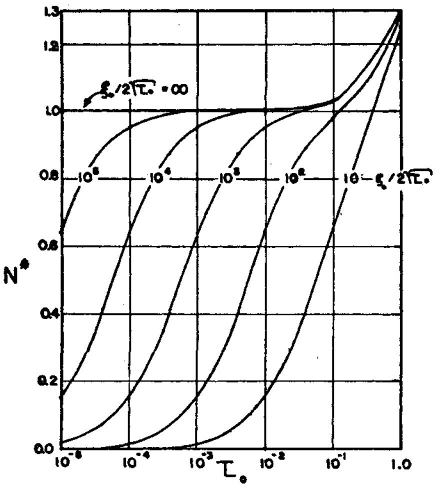

Fig. 1. Higbie model.

$$(N_G)_{avg} = \frac{1}{t_0}\int_0^{\tau_0} N_G\, dt \qquad (5)$$

Then from Equations (3) and (5)

$$(N_G)_{avg} = \frac{c_i(k\mathfrak{D})^{1/2}}{\tau_0}\left\{\left(\tau_0 + \frac{1}{2} - \frac{c_0}{c_i}\right) \cdot \operatorname{erf}\,(\tau_0^{\,1/2}) + \frac{\tau_0^{\,1/2}}{\pi^{1/2}} e^{-\tau_0}\right\} \qquad (6)$$

or

$$N^* = \frac{1}{2}e^{-\tau_0} + \left(\tau_0 + \frac{1}{2} - \frac{c_0}{c_i}\right)\frac{\pi^{1/2}}{4\tau_0} \cdot \operatorname{erf}\,(\tau_0^{\,1/2}) \qquad (7)$$

where

$$N^* = \frac{(N_G)_{avg}}{c_i}\left(\frac{\pi\tau_0}{4D}\right)^{1/2} \qquad (8)$$

Here N^* is the ratio of absorption rate in the presence of chemical reaction to the rate of physical absorption when the tank contains no dissolved gas. Thus this method of estimating mass transfer coefficients is valid only where N^* is one.

Figure 1 shows values of N^* for a wide range of values of $[\xi_0/2t_0^{1/2}]$ and t_0. It can be seen that for high enough values of $[\xi_0/2t_0^{1/2}]$ there is a plateau region, as suggested by Bernard, in which N^* is very nearly unity and independent of the chemical rate constant over a wide range. Such a situation would occur, for example, when (V/A) is large. However if the gas bubbles are concentrated in a small region of the tank, as from a single fine-bubble sparger, for example, Figure 1 could be misleading in that even distribution of bubbles has been assumed in this development.

STATIC FILM MODEL

It is assumed here that the gas bubbles are surrounded by static films, thin compared with the diameter of the bubbles, in which all the resistance to mass transfer is assumed to be concentrated and in which steady state is rapidly established. Film curvature and unsteady state may be taken into account if desired (*6*). Here

$$D\,\frac{\partial^2 c}{\partial x^2} = kc \qquad (8)$$

$$\text{at} \quad x = 0 \qquad c = c_i \qquad (8a)$$

$$\text{at} \quad x = \delta \qquad c = c_l \qquad (8b)$$

where δ is the film thickness. Then

$$\frac{c}{c_i} = \frac{(c_l/c_i)\sinh\xi + \sinh\,(\delta(k/\mathfrak{D})^{1/2} - \xi)}{\sinh\,(\delta(k/\mathfrak{D})^{1/2})}$$

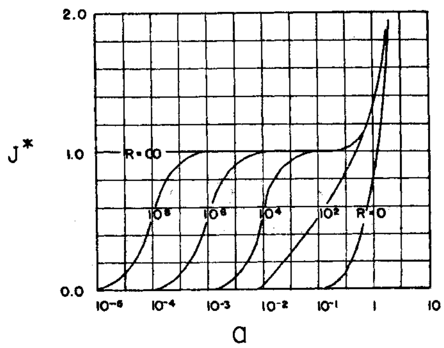

Fig. 2. Film model.

When one determines fluxes through the bubble-solution interface and outer film boundary and equates the rate of absorption through the outer film boundary with the rate of reaction in the bulk of the solution,

$$J^* = \frac{a}{\sinh a}\left[\cosh a - \frac{1}{\cosh a + aR\sinh a}\right] \qquad (9)$$

where

J^* = ratio of rate of absorption to rate of physical absorption to tank containing no dissolved gas

a = $\delta(k/\mathfrak{D})^{1/2}$

R = $V - A\delta/A\delta$ = ratio of volume of solution outside film to that inside film

In Figure 2 J^* is shown as a function of a and R. The behavior here is seen to be qualitatively similar to that for penetration theory model.

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BOOKS

The Properties of Gases and Liquids: Their Estimation and Correlation, Robert C. Reid and Thomas K. Sherwood, McGraw-Hill Book Company, Inc., New York (1958). 386 pages. $10.00.

This excellent book represents the investment of an immense quantity of work which has yielded excellent results. Reid and Sherwood's book is a critical summary of contemporary (1956) methods of calculating the common thermodynamic and transport properties of liquids and gases needed in design. The format of the book will appeal to the design engineer: the basic problems involved in calculating each property are outlined at the beginning of each chapter, then clear and concise descriptions of the selected methods are presented, and finally the best relations for various situations are recommended. In addition numerous sample calculations demonstrate the use of the equations, and an index of best methods for all properties covered is placed most advantageously at the beginning of the book. Thus it is easy to find, to understand, and to use the correlation sought.

The quality of this work stems from the authors' lucid understanding of the subject matter. Although not intended as a treatise upon aspects of physical chemistry, the text gives the reader an understandable, if abbreviated, description of the concepts involved. Hence the blunders which frequently appear in "plug-in" calculations are minimized. Since the decision to use a particular correlation rests upon the accuracy obtained for a given amount of work, statements of the expected accuracy are consistently given. These critical evaluations are based upon a vast body of calculations made by Reid and Sherwood in addition to the trials made by the various original authors. In particular, the authors stress the pitfalls of improper extrapolation of usage. Careful judgment is shown in the methods selected, most calculations being empirical but based upon theoretical considerations. The limitations of the empirical methods presented are emphasized, and tedious and often impractical theoretical methods are wisely avoided. When possible, tables and graphs of parameters appearing in these functions are located adjacent to their description. Thus most methods yield answers from a reasonably short calculation effort.

Reid and Sherwood have covered a vast field in surprisingly few pages, and hence omissions will appear to experts in the various fields covered (particularly the chapter on vapor-liquid equilibria). These limitations are more than compensated for by the general utility of the book; it is a must for design engineers and a necessary reference for students of applied physical chemistry and thermodynamics. The extensive documentation will appeal to researchers, as papers and reviews of particular merit are emphasized. Although the authors state that continued fundamental research and publication of physical properties will make their book needless, this reviewer

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hopes that the success of this work will continue in future (and necessary) editions.

J. H. OLSON

Chemical Reaction Engineering, International Series of Monographs on Chemical Engineering, Vol. I, K. Rietema, editor. Pergamon Press, New York (1957). 200 pages. $12.50.

This volume contains papers presented at the First European Symposium on Chemical Engineering held in Amsterdam in May, 1957, under the auspices of the European Federation of Chemical Engineering. It provides a comprehensive survey of the problems encountered in applying the fundamental concepts of chemical kinetics, heat and mass transfer, and fluid dynamics, especially degree of mixing, to the design of industrial chemical reactors. The papers are predominantly theoretical in nature and all are by authors prominent in the field of applied reaction kinetics. There are a total of thirteen papers, which are divided into five groups: Introductory Papers, Transport Phenomena in Heterogeneous Reactions, Nonuniform Concentration Distributions, Reactor Efficiency and Stability, and Reactor Development.

The first group of papers presents (1) a classification of the various types of chemical-reaction systems and the multitude of reactors in which they are being conducted and (2) brief summaries of classical chemical reaction kinetics and of the treatment of the physical factors present in any practical reactor design.

The second group of papers includes a summary of the general principles of mass transfer through films and within porous solids. Rate data involving both absorption and chemical reaction in a stirred vessel and in a wetted-wall column are presented and analyzed in terms of the separate chemical and physical rate processes.

The third group of papers treats the nature of mixing in continuous agitated vessels from the standpoint of both the scale of mixing and the residence-time distribution. The point is stressed that the performance of continuous tank reactors can be predicted from batch-reaction data and the estimated residence-time distribution only for a first-order reaction unless the mixing is perfect on a molecular scale. The behavior of heterogeneous liquid systems in various types of staged reactor vessels involving both concurrent and countercurrent flow is discussed, and applications to the nitration of benzene and the production of furfurol from xylose are shown.

The fourth group of papers considers the problem of (1) obtaining the maximum yield of a desired product of a complex reaction system by proper control of the temperature gradient and (2) analyzing the performance of autothermal processes, where the exothermic heat of reaction serves to maintain the reaction temperature. A simple and very useful means of establishing the possibility of stable operation of an autothermal system is presented by Dr. van Heerden. The performance of a commercial ammonia oxidation reactor is used to illustrate the principles of treating autothermal processes.

The last group of papers is concerned primarily with the application to commercial reactor design of the principles enumerated earlier, with special emphasis being placed upon the utilization of pilot plant data.

A valuable addition to the literature in chemical-reactor design has been provided by this work though it is not recommended for the uninitiated. An increased amount of research in this important area should result from the ideas presented. The appeal of the book to American engineers is reduced somewhat by the fact that one of the papers is written in French and four of them are written in German.

JOHN M. WOODS

Elements of Water Supply and Waste-Water Disposal. G. M. Fair and J. C. Geyer. John Wiley and Sons, New York (1958). 615 pages. $8.95.

This book, like its predecessor, "Water Supply and Waste-Water Disposal" (Wiley, 1954), is directed to students of civil and sanitary engineering. In this reviewer's opinion, many chemical engineers must be or should be within this category, because of the well-recognized importance of water as a raw material and waste product of the process industries. The two books are essentially similar, but the present edition has been greatly abridged in order to meet the time and financial limitations of undergraduate students (twenty chapters in 615 pages instead of thirty in 973; $8.95 instead of $16.00).

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