

JOURNAL REVIEW

Five Decades of Transport Phenomena

R. Byron Bird

Dept. of Chemical and Biological Engineering, University of Wisconsin, Madison, WI 53705

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Surveying the progress made in transport phenomena in the past half-century is an impossible task. Fully half of the publications in the chemical engineering journals have something to do with transport phenomena, and, in addition, there are many other disciplines where transport phenomena arise. In this summary we try to give the flavor of the developments by citing typical textbooks, review articles, and research publications—but the choices are often capricious. To some extent we try to put the emphasis on works that involve two or more of the transport mechanisms.

In reviewing the *AIChE Journal* for the last 50 years, the author must confess to having a feeling of nostalgia as he came across names like Allan Colburn, Olaf Hougen, W. R. ("Bob") Marshall, R. L. ("Bob") Pigford, T. K. ("Tom") Sherwood, and R. H. ("Dick") Wilhelm; he had to pause and contemplate the many contributions of these fine people. We have indeed profited in many ways from the contributions and wisdom of our predecessors.

[Note: The references in §1 are numbered. In subsequent sections the references are labeled with lowercase letters. If a reference is made to another section, both the section and letter are given; thus, 1.6f means "reference f" of §1.6.]

§1. The Status of Transport Phenomena Fifty Years Ago

The subject of transport phenomena is a very old one,¹ with some of the topics dating back several centuries. By 1955, much of the theory for homogeneous fluid mixtures had been developed. The equations of change were well known from continuum mechanics, and because of the development of the thermodynamics of irreversible processes during the two preceding decades,²⁻⁴ the linear expressions for the fluxes as functions of the driving forces were also well understood. Consequently, the existence of the cross effects (thermal diffusion, the diffusion-thermo effect, and the relations among the multicomponent diffusivities) had been firmly established.

In addition, the Chapman-Enskog kinetic theory of dilute

monatomic gases had been presented in great detail by Chapman and Cowling⁵ for pure gases and binary mixtures. The analogous kinetic theory for multicomponent mixtures had also been worked out by Curtiss and Hirschfelder⁶ and calculations based on the theory had been made for the Lennard-Jones 6-12 potential.⁷ Some work had also been done on the kinetic theory of polyatomic molecules, loaded spheres, rough spheres, and rigid ovaloids. A beginning had been made on the kinetic theory of monatomic liquids.⁸ These molecular theories give flux expressions that are consistent with those obtained from the thermodynamics of irreversible processes.

Also, a number of analytical solutions of the equations of change were available. In fluid dynamics, the field of inviscid flow had been well developed, and, for viscous Newtonian flow, there were many analytical solutions that were useful in engineering and the applied sciences. For heat conduction, there was the first edition of Carslaw and Jaeger's excellent compilation of thousands of solutions of the heat-conduction equation.⁹ For heat conduction, convection, and radiation, there was the book by Gröber and Erk,¹⁰ as well as several others. For diffusion, the situation was rather bleak, since that subject was newer than fluid dynamics and heat transfer, and is more difficult. There were books by Joshi¹² and Barrer¹³ on diffusion in solids, and for liquids and gases, the Eucken-Jakob treatise¹⁴ provided some guidance. But these references were incomplete inasmuch as the distinctions among the reference frames for the mass and molar fluxes were not made clear, and the nature of the driving forces for diffusion was not carefully discussed. In addition, the heat generated by viscous dissipation was usually omitted from the energy equation.

As far as turbulent flows are concerned, considerable effort had been expended to provide an understanding of this very difficult subject. The status of this topic as of 50 years ago was pretty well summarized by Prandtl¹⁵ and Schlichting,¹⁶ who considered both isothermal and nonisothermal systems.

The macroscopic balances were part of the everyday tools of the civil, mechanical, aeronautical, and chemical engineers. These balances could be found in many handbooks, although the origins of some of the equations were difficult to trace, and often the assumptions inherent in them were not given or had been forgotten. Actually, it was probably this part of the subject

R. B. Bird's e-mail address is bird@engr.wisc.edu.

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Journal Review Five Decades Of Transport Phenomena:

Decoding **Journal Review Five Decades Of Transport Phenomena**: Revealing the Captivating Potential of Verbal Expression

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