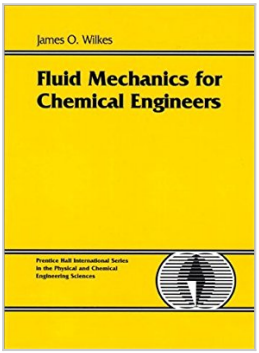

Fluid Mechanics for Chemical Engineers

By James O. Wilkes

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An understanding of fluid mechanics is essential for the chemical engineer because the majority of chemical-processing operations are conducted either partially or totally in the fluid phase. Such knowledge is needed in the biochemical, chemical, energy, fermentation, materials, mining, petroleum, pharmaceuticals, polymer, and waste-processing industries. Written from a chemical engineering perspective, this comprehensive text covers fluid mechanics first from a macroscopic then a microscopic perspective. Fluid Mechanics for Chemical Engineers gives the undergraduate and first-year graduate student a comprehensive overview of this essential topic. Bridging the gap between the physicist and the practitioner, the book provides numerous real-world examples and problems of increasing detail and complexity, including several from the University of Cambridge chemical engineering examinations. It also covers all the material necessary to pass the fluid mechanics portion of the Professional Engineer's exam.

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Fluid Mechanics for Chemical Engineers By James O. Wilkes Bibliography

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Editorial Review

From the Inside Flap
Preface

This text has evolved from a need for a single volume that embraces a wide range of topics in fluid mechanics. The material consists of two parts — four chapters on macroscopic or relatively large-scale phenomena, followed by eight chapters on microscopic or relatively small-scale phenomena.

Throughout, we have tried to keep in mind topics of industrial importance to the chemical engineer.

Part I—Macroscopic fluid mechanics. Chapter 1 is concerned with basic fluid concepts and definitions, and also a discussion of hydrostatics. Chapter 2 covers the three basic rate laws, in the form of mass, energy, and momentum balances. Chapters 3 and 4 deal with fluid flow through pipes and other types of chemical engineering equipment, respectively.

Part II—Microscopic fluid mechanics. Chapter 5 is concerned with the fundamental operations of vector analysis and the development of the basic differential equations that govern fluid flow in general. Chapter 6 presents several examples that show how these basic equations can be solved to give solutions to representative problems in which viscosity is important, including polymer-processing, in rectangular, cylindrical, and spherical coordinates. Chapter 7 treats the broad class of inviscid flow problems known as irrotational flows; the theory also applies to flow in porous media, of importance in petroleum production and the underground storage of natural gas. Chapter 8 analyzes two-dimensional flows in which there is a preferred orientation to the velocity, which occurs in situations such as boundary layers, lubrication, calendering, and thin films. Turbulence and analogies between momentum and energy transport are treated in Chapter 9. Bubble motion, two-phase flow in horizontal and vertical pipes, and fluidization — including the motion of bubbles in fluidized beds — are discussed in Chapter 10. Chapter 11 introduces the concept of non-Newtonian fluids. Finally, Chapter 12 discusses the Matlab PDE Toolbox as an instrument for the numerical solution of problems in fluid mechanics.

In our experience, an undergraduate fluid mechanics course can be based on Part I plus selected parts of Part II. And a graduate course can be based on essentially the whole of Part II, supplemented perhaps by additional material on topics such as approximate methods, stability, and computational fluid mechanics.

There is an average of about five completely worked examples in each chapter. The numerous end-of-chapter problems have been classified roughly as easy (E), moderate (M), or difficult (D). Also, the University of Cambridge has very kindly given permission — graciously endorsed by Prof. J.F. Davidson, F.R.S. — for several of their chemical engineering examination problems to be reproduced in original or modified form, and these have been given the additional designation of “(C).”

The website engin.umich/~fmche is maintained as a “ bulletin board” for giving additional information about Fluid Mechanics for Chemical Engineers — hints for problem solutions, errata, how to contact the authors, etc. — as proves desirable.

I gratefully acknowledge the contributions of my colleague Stacy Bike, who has not only made many constructive suggestions for improvements, but has also written the chapter on non-Newtonian fluids. I very much appreciate the assistance of several other friends and colleagues, including Nitin Anturkar, Brice

Carnahan, Kevin Ellwood, Scott Fogler, Lisa Keyser, Kartic Khilar, Ronald Larson, Donald Nicklin, Margaret Sansom, Michael Solomon, Sandra Swisher, Rasin Tek, and my wife Mary Ann Gibson Wilkes. Also very helpful were Joanne Anzalone, Barbara Cotton, Bernard Goodwin, Robert Weisman and the staff at Prentice Hall, and the many students who have taken my courses. Others are acknowledged in specific literature citations.

The text was composed on a Power Macintosh 8600/200 computer using the TeXtures “typesetting” program. Eleven-point type was used for the majority of the text. Most of the figures were constructed using the MacDraw Pro, Claris-CAD, Excel, and Kaleidagraph applications.

Professor Fox, to whom this book is dedicated, was a Cambridge engineering graduate who worked from 1933—1937 at Imperial Chemical Industries Ltd., Billingham, Yorkshire. Returning to Cambridge, he taught engineering from 1937—1946 before being selected to lead the Department of Chemical Engineering at the University of Cambridge during its formative years after the end of World War II. As a scholar and a gentleman, Fox was a shy but exceptionally brilliant person who had great insight into what was important and who quickly brought the department to a preeminent position. He succeeded in combining an industrial perspective with intellectual rigor. Fox relinquished the leadership of the department in 1959, after he had secured a permanent new building for it (carefully designed in part by himself) before his untimely death in 1964.

Fox was instrumental in bringing Kenneth Denbigh, John Davidson, Peter Danckwerts and others into the department. Danckwerts subsequently wrote an appreciation (P.V. Danckwerts, “Chemical Engineering Comes to Cambridge,” The Cambridge Review, pp. 53—55, 28 February 1983) of Fox's talents, saying, with almost complete accuracy: “Fox instigated no research and published nothing.” How times have changed — today, unless he were known personally, his resume would probably be cast aside and he would stand little chance of being hired, let alone of receiving tenure! However, his lectures, meticulously written handouts, enthusiasm, genius, and friendship were a great inspiration to me, and I have much pleasure in acknowledging his impact on my career.

James O. Wilkes 1 August 1998

From the Back Cover

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An understanding of fluid mechanics is essential for the chemical engineer because the majority of chemical-processing operations are conducted either partially or totally in the fluid phase. Such knowledge is needed in the biochemical, chemical, energy, fermentation, materials, mining, petroleum, pharmaceuticals, polymer, and waste-processing industries. Written from a chemical engineering perspective, this comprehensive text covers fluid mechanics first from a macroscopic then a microscopic perspective. The first part includes physical properties, hydrostatics, and the three basic rate laws for mass, energy, and momentum, together with flow through pumps, pipes, and a wide variety of chemical engineering equipment. The second part covers:

- Differential equations of fluid mechanics.
- Viscous-flow problems.
- Irrotational and porous-medium flows.
- Nearly uni-directional flows, including those in boundary. layers, lubrication, calendering, and thin films
- Turbulence and analogies between heat and momentum transport.

- Bubble motion, two-phase flow, and fluidization.
- Introduction to the concepts of non-Newtonian fluids.
- Use of the Matlab PDE Toolbox for solving some problems in fluid mechanics.

Thorough and clearly written, Chemical Engineering Fluid Mechanics gives the undergraduate and first-year graduate student a comprehensive overview of this essential topic. Bridging the gap between the physicist and the practitioner, the book provides numerous real-world examples and problems of increasing detail and complexity, including several from the University of Cambridge chemical engineering examinations. It also covers all the material necessary to pass the fluid mechanics portion of the Professional Engineer's exam.

About the Author

JAMES O. WILKES is a faculty member of the College of Engineering, University of Michigan. He received his bachelor's degree from the University of Cambridge and a master's and Ph.D. from the University of Michigan. He was awarded a King George VI Memorial Fellowship to the University of Michigan, where he has served as department chairman as well as Assistant Dean for Admissions in the College of Engineering. He was named an Arthur F. Thurnau Professor from 1989 to 1992. His co-authorship of previous books includes Applied Numerical Methods (Wiley, 1969) and Digital Computing and Numerical Methods (Wiley, 1973). His research interests are in polymer processing and computational fluid mechanics.

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