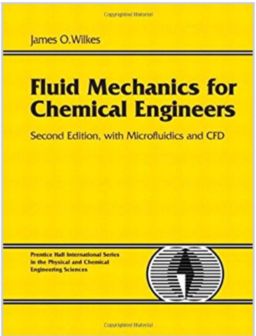

Fluid Mechanics for Chemical Engineers with Microfluidics and CFD (2nd Edition)

By James O. Wilkes

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The Chemical Engineer's Practical Guide to Contemporary Fluid Mechanics

Since most chemical processing applications are conducted either partially or totally in the fluid phase, chemical engineers need a strong understanding of fluid mechanics. Such knowledge is especially valuable for solving problems in the biochemical, chemical, energy, fermentation, materials, mining, petroleum, pharmaceuticals, polymer, and waste-processing industries.

Fluid Mechanics for Chemical Engineers, Second Edition, with Microfluidics and CFD, systematically introduces fluid mechanics from the perspective of the chemical engineer who must understand actual physical behavior and solve real-world problems. Building on a first edition that earned *Choice Magazine*'s Outstanding Academic Title award, this edition has been thoroughly updated to reflect the field's latest advances.

This second edition contains extensive new coverage of both microfluidics and computational fluid dynamics, systematically demonstrating CFD through detailed examples using FlowLab and COMSOL Multiphysics. The chapter on turbulence has been extensively revised to address more complex and realistic challenges, including turbulent mixing and recirculating flows.

Part I offers a clear, succinct, easy-to-follow introduction to macroscopic fluid mechanics, including physical properties; hydrostatics; basic rate laws for mass, energy, and momentum; and the fundamental principles of flow through pumps, pipes, and other equipment. Part II turns to microscopic fluid mechanics, which covers

- Differential equations of fluid mechanics
- Viscous-flow problems, some including polymer processing
- Laplace's equation, irrotational, and porous-media flows
- Nearly unidirectional flows, from boundary layers to lubrication, calendering, and thin-film applications
- Turbulent flows, showing how the k/ε method extends conventional mixing-

length theory
- Bubble motion, two-phase flow, and fluidization
- Non-Newtonian fluids, including inelastic and viscoelastic fluids
- Microfluidics and electrokinetic flow effects including electroosmosis, electrophoresis, streaming potentials, and electroosmotic switching
- Computational fluid mechanics with FlowLab and COMSOL Multiphysics

Fluid Mechanics for Chemical Engineers, Second Edition, with Microfluidics and CFD, includes 83 completely worked practical examples, several of which involve FlowLab and COMSOL Multiphysics. There are also 330 end-of-chapter problems of varying complexity, including several from the University of Cambridge chemical engineering examinations. The author covers all the material needed for the fluid mechanics portion of the Professional Engineer's examination.

The author's Web site, www.engin.umich.edu/~fmche/, provides additional notes on individual chapters, problem-solving tips, errata, and more.

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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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About the Author
James O. Wilkes is Professor Emeritus of Chemical Engineering at the University of Michigan, where he served as department chairman and assistant dean for admissions. From 1989 to 1992, he was an Arthur F. Thurnau Professor. Wilkes coauthored *Applied Numerical Methods* (Wiley, 1969) and *Digital Computing and Numerical Methods* (Wiley, 1973). He received his bachelor s degree from the University of Cambridge and his M.S. and Ph.D. in chemical engineering from the University of Michigan. His research interests involve numerical methods for solving a wide variety of engineering problems.

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Denise Adams:

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