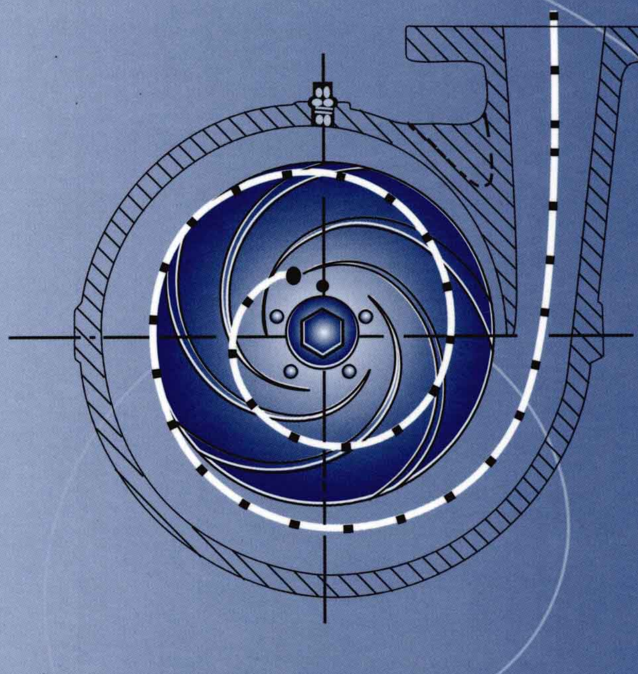
Chemical Engineering Fluid Mechanics

Second Edition, Revised and Expanded



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MARCEL DEKKER, INC. NEW YORK • BASEL

ISBN: 0-8247-0444-4

This book is printed on acid-free paper.

Headquarters
Marcel Dekker, Inc.
270 Madison Avenue, New York, NY 10016
tel: 212-696-9000; fax: 212-685-4540

Eastern Hemisphere Distribution
Marcel Dekker AG
Hutgasse 4, Postfach 812, CH-4001 Basel, Switzerland
tel: 41-61-261-8482; fax: 41-61-261-8896

World Wide Web
http://www.dekker.com

The publisher offers discounts on this book when ordered in bulk quantities. For more information, write to Special Sales/Professional Marketing at the headquarters address above.

Current printing (last digit):
10 9 8 7 6 5 4 3 2

PRINTED IN THE UNITED STATES OF AMERICA

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Preface

The objectives of this book are twofold: (1) for the student, to show how the fundamental principles underlying the behavior of fluids (with emphasis on one-dimensional macroscopic balances) can be applied in an organized and systematic manner to the solution of practical engineering problems, and (2) for the practicing engineer, to provide a ready reference of current information and basic methods for the analysis of a variety of problems encountered in practical engineering situations.

The scope of coverage includes internal flows of Newtonian and non-Newtonian incompressible fluids, adiabatic and isothermal compressible flows (up to sonic or choking conditions), two-phase (gas–liquid, solid–liquid, and gas–solid) flows, external flows (e.g., drag), and flow in porous media. Applications include dimensional analysis and scale-up, piping systems with fittings for Newtonian and non-Newtonian fluids (for unknown driving force, unknown flow rate, unknown diameter, or most economical diameter), compressible pipe flows up to choked flow, flow measurement and control, pumps, compressors, fluid-particle separation methods (e.g., centrifugal, sedimentation, filtration), packed columns, fluidized beds, sedimentation, solids transport in slurry and pneumatic flow, and frozen and flashing two-phase gas–liquid flows. The treatment is from the viewpoint of the process engineer, who is concerned with equipment operation, performance, sizing, and selection, as opposed to the details of mechanical design or the details of flow patterns in such situations.

For the student, this is a basic text for a first-level course in process engineering fluid mechanics, which emphasizes the systematic application of fundamental principles (e.g., macroscopic mass, energy, and momentum balances and economics) to the analysis of a variety of fluid problems of a practical nature. Methods of analysis of many of these operations have been taken from the recent technical literature, and have not previously been available in textbooks. This book includes numerous problems that illustrate these applications at the end of each chapter.

For the practicing engineer, this book serves as a useful reference for the working equations that govern many applications of practical interest, as well as a source for basic principles needed to analyze other fluid systems not covered explicitly in the book. The objective here is not to provide a mindless set of recipes for rote application, however, but to demonstrate an organized approach to problem analysis beginning with basic principles and ending with results of very practical applicability.

Chemical Engineering Fluid Mechanics is based on notes that I have complied and continually revised while teaching the junior-level fluid mechanics course for chemical engineering students at Texas A&M University over the last 30 years. It has been my experience that, when being introduced to a new subject, students learn best by starting with simple special cases that they can easily relate to physically, and then progressing to more generalized formulations and more complex problems. That is the philosophy adopted in this book. It will certainly be criticized by some, since it is contrary to the usual procedure followed by most textbooks, in which the basic principles are presented first in the most general and mathematical form (e.g., the divergence theorem, Reynolds transport theorem, Navier Stokes equations, etc.), and the special cases are then derived from these. Esoterically, it is very appealing to progress from the general to the specific, rather than vice versa. However, having taught from both perspectives, it is my observation that most beginning students do not gain an appreciation or understanding from the very general, mathematically complex, theoretical vector expressions until they have gained a certain physical feel for how fluids behave, and the laws governing their behavior, in special situations to which they can easily relate. They also understand and appreciate the principles much better if they see how they can be applied to the analysis of practical and useful situations, with results that actually work in practice. That is why the multi-dimensional vector generalizations of the basic conservations laws have been eschewed in favor of the simpler component and one-dimensional form of these laws.

It is also important to maintain a balanced perspective between fundamental, or theoretical, and empirical information, for the practicing engineer must use both to be effective. It has been said that all the tools of mathematics and physics in the world are not sufficient to calculate how much water will flow in a given time from a kitchen tap when it is opened. However, by proper formulation and utilization of certain experimental observations, this is a routine problem for the engineer. The engineer must be able to solve certain problems by direct application of theoretical principles only (e.g., laminar flow in uniform conduits), others by utilizing hypothetical models that account for a limited understanding of the basic flow phenomena by incorporation of empirical parameters (e.g., :turbulent flow in conduits and fittings), and still other problems in which important information is purely empirical (e.g., pump efficiencies, two-phase flow in packed columns). In many of these problems (of all types), application of dimensional analysis (or the principle of "conservation of dimensions") for generalizing the results of specific analysis, guiding experimental design, and scaling up both theoretical and experimental results can be a very powerful tool.

This second edition of the book includes a new chapter on two-phase flow, which deals with solid–liquid, solid–gas, and frozen and flashing liquid–gas systems, as well as revised, updated, and extended material throughout each chapter. For example, the method for selecting the proper control valve trim to use with a given piping configuration is presented and illustrated by example in Chapter 10. The section on cyclone separators has been completely revised and updated, and new material has been incorporated in a revision of the material on particles in non-Newtonian fluids. Changes have made throughout the book in an attempt to improve the clarity and utility of the presentation wherever possible. For example, the equations for compressible flow in pipes have been reformulated in terms of variables that are easier to evaluate and represent in dimensionless form.

It is the aim of this book to provide a useful introduction to the simplified form of basic governing equations and an illustration of a consistent method of applying these to the analysis of a variety of practical flow problems. Hopefully, the reader will use this as a starting point to delve more deeply into the limitless expanse of the world of fluid mechanics.

Ron Darby

Unit Conversion Factors

Dimension	*Equivalent Units*
Mass	1 kg = 1000 g = 0.001 metric ton (tonne) = 2.20461 lb_m = 35.27392 oz
	1 lb_m = 453.593 g = 0.453593 kg = 5 × 10^{-4} ton = 16 oz
Force	1 N = 1 kg m/s^2 = 10^5 dyn = 10^5 g cm/s^2 = 0.22418 lb_f
	1 lb_f = 32.174 lb_m ft/s^2 = 4.4482 N = 4.4482 × 10^5 dyn
Length	1 m = 100 cm = 10^6 μm = 10^{10} Å = 39.37 in. = 3.2808 ft = 1.0936 yd = 0.0006214 mi
	1 ft = 12 in. = 1/3 yd = 0.3048 m = 30.48 cm
Volume	1 m^3 = 1000 liters = 10^6 cm^3 = 35.3145 ft^3 = 264.17 gal
	1 ft^3 = 1728 in.^{3} = 7.4805 gal = 0.028317 m^3 = 28.317 liters = 28,317 cm^3
Pressure	1 atm = 1.01325 × 10^5 N/m^2 (Pa) = 1.01325 bar = 1.01325 × 10^6 dyn/cm^2 = 760 mm Hg @ 0°C (torr) = 10.333 m H_2O @ 4°C = 33.9 ft H_2O @ 4°C = 29.921 in. Hg @ 0°C = 14.696 lb_f/in.^{2} (psi)
Energy	1 J = 1 N m = 10^7 erg = 10^7 dyn cm = 2.667 × 10^{-7} kWh = 0.23901 cal = 0.7376 ft lb_f = 9.486 × 10^{-4} Btu [550 ft lb_f/(hp s)]
Power	1 W = 1 J/s = 0.23901 cal/s = 0.7376 ft lb_f/s = 9.486 × 10^{-4} Btu/s = 1 × 10^{-3} kW = 1.341 × 10^{-3} hp
Flow Rate	1 m^3/s = 35.3145 ft^3/s = 264.17 gal/s = 1.585 × 10^4 gal/min = 10^6 cm^3/s
	1 gpm = 6.309 × 10^{-5} m^3/s = 2.228 × 10^{-3} ft^3/s = 63.09 cm^3/s

Example: The factor to convert Pa to psi is 14.696 psi/(1.01325 × 10^5 Pa)

Some values of the gas constant: R = 8.314 × 10^3 kg m^2/(s^2 kg mol K)
= 8.314 × 10^7 g cm^2/(s^2 g mol K)
= 82.05 cm^3 atm/(g mol K)
= 1.987 cal/(g mol K) or Btu/(lb mol °R)
= 1545 ft lb_f/(lb mol °R)
= 10.73 ft^3 psi/(lb mol °R)
= 0.730 ft^3 atm/(lb mol °R)

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