FLUID MECHANICS AND UNIT OPERATIONS

David S. Azbel
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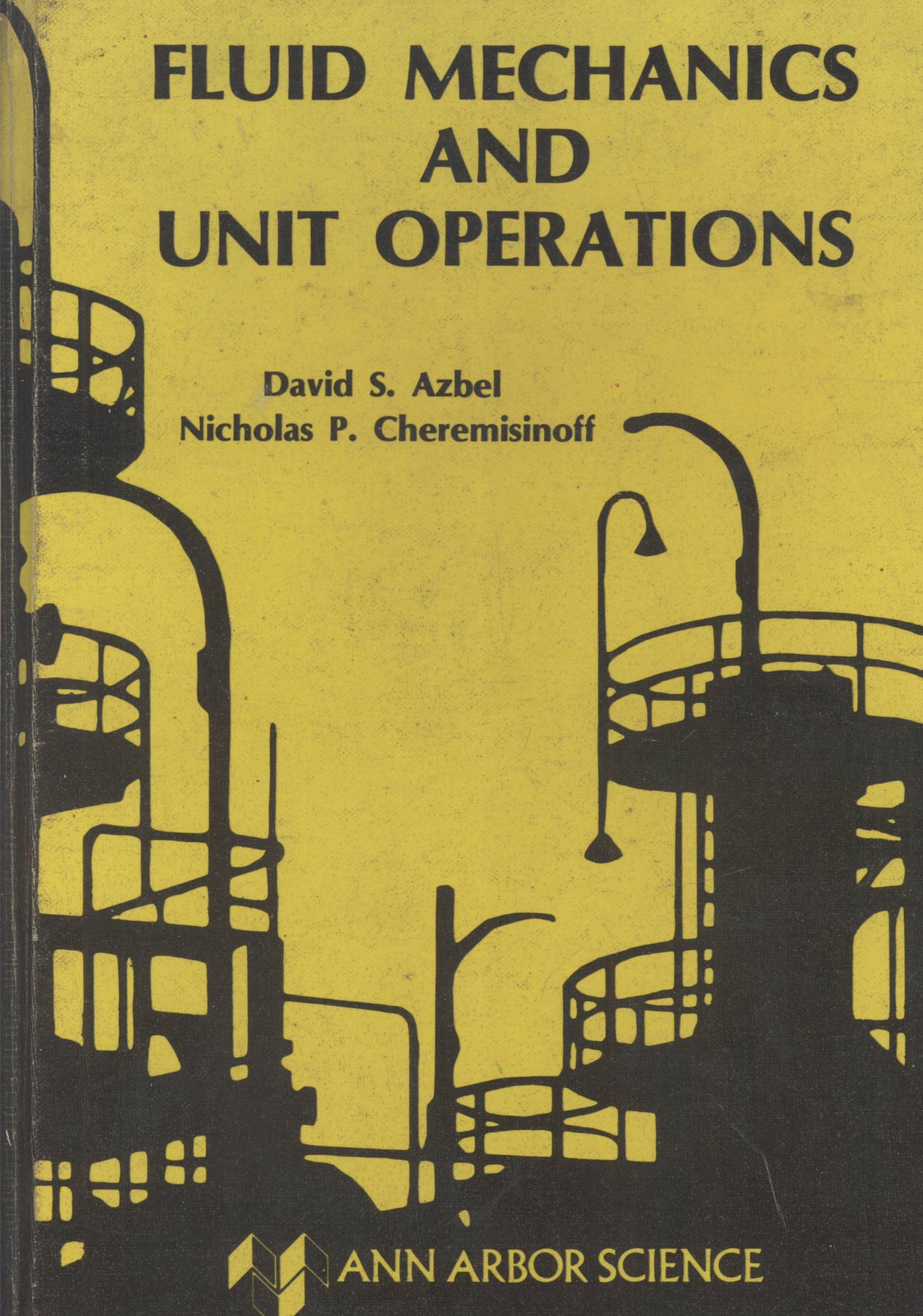

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PREFACE

It is the intent of this book to provide fundamental instruction in the subject of applied fluid mechanics, relying heavily on the methodology and language of industry. The concept has evolved from the authors' teaching experiences and from consultations with academic and industrial colleagues who have concluded that the majority of chemical engineering curricula leave a void between theory and industrial practice. Often, the steps needed to relate the principles of fluid mechanics to the detailed design of a particular unit operation are only superficially examined in course work.

The term "unit operation" refers to industrial practices whose scientific principles of operation are the same, regardless of the specific industry to which they are applied. For example, the unit operation of extraction is employed in the paper, petroleum, pharmaceutical and chemical industries. Although the specific processes, materials and conditions may vary, the design principles for an extraction tower are identical. In the broadest sense, the design of unit operations draws on knowledge from three principal subjects: fluid mechanics, heat transfer and mass transfer. All three comprise the general subject of transport phenomena. Because it is not our intent to present an overview, but rather detailed instruction, we have elected to cover only those operations that demand a thorough understanding of fluid dynamics. Those operations requiring knowledge of heat and mass exchange principles are best covered in separate volumes.

The book is divided into four sections. The first, Chapters 1 through 4, reviews approaches to problem analysis, modeling and fluid transport properties. The material presented is applied throughout the balance of the book.

The second section covers the design of related practices, referred to as the *internal problems of hydrodynamics*. Extensive discussions are devoted to the dynamics of single-phase flows in Chapter 5, with emphasis on problem analysis. These principles and methodologies are applied to the operation of fluid transportation for both incompressible and compressible mediums in Chapters 6 and 7, respectively.

The third section, Chapters 8 through 11, is devoted to operations comprising the class of problems of *external hydrodynamics*. Chapter 8 provides background on heterogeneous systems (solid-liquid) and categorizes the specific unit operations of handling and separation. The operations covered are gravity sedimentation (Chapter 9), centrifugal separation techniques (Chapter 10) and mixing practices (Chapter 11).

The last section, Chapters 12 through 14, concerns the mixed problems of hydrodynamics. The practices of filtration are presented in Chapter 12. The final two chapters cover two-phase operations: gas-solid (Chapter 13) and gas-liquid relations (Chapter 14). Some of the methods outlined in the last section have not appeared in the engineering literature and are presented to stress new concepts and better understanding of multiphase operations.

Considerable thought has been given to the calculations and procedures presented. Each problem posed, along with selected solutions, is based on actual industrial encounters. Consequently, the book will be useful to the practicing engineer, as well as to the student.

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Nicholas P. Cheremisinoff

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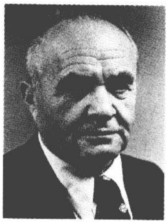

Azbel **Cheremisinoff**

David S. Azbel is Professor of Chemical Engineering at the University of Missouri–Rolla. He was previously Research Professor at the State University of New York at Stony Brook and Visiting Professor, University of Minnesota. From 1966 to 1972 he was Professor of Chemical Engineering at the All-Union Polytechnical Institute (Moscow, USSR); from 1961 to 1965 he was Chief of the Technology Department of the Organic and Synthetic Products Research Institute (Moscow, USSR). Previously he was project chief at the Chemical Engineering Research Institute and Petrochemical Research Institute (Irkutsk, Siberia, USSR). Dr. Azbel graduated from Moscow Institute of Chemical Engineering in 1939 and received his Doctor of Science degree from the Mendeleev Institute of Chemical Technology, Moscow, USSR. His engineering, design, research and teaching span the broadest range of chemical, petroleum and nuclear experience. Dr. Azbel is co-author of *Chemical and Process Equipment Design–Vessel Design and Selection*, published by Ann Arbor Science.

Nicholas P. Cheremisinoff heads the Reactor and Fluid Dynamics Modelling Group in the Chemical Engineering Technology Division of Exxon Research and Engineering Company, Florham Park, New Jersey, and was previously a research scientist for a paper company. He is involved in research and engineering on atomization, fluidized-bed reactor design, shale oil development, coal gasification, instrumentation, and equipment design and development. Dr. Cheremisinoff received his BS, MS and PhD degrees in Chemical Engineering from Clarkson College of Technology. He is author of numerous papers and books, including *Fluid Flow: Pumps, Pipes and Channels; Handbook of Fluids In Motion; Cooling Towers: Selection, Design and Practice; Chemical and Nonchemical Disinfection;* and *Gasohol for Energy Production*, published by Ann Arbor Science. He is a member of a number of professional and honor societies, including the American Institute of Chemical Engineers, Tau Beta Pi and Sigma Xi.

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CHAPTER 1

ELEMENTS OF FLUID MECHANICS AND UNIT OPERATIONS

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INTRODUCTION AND SCOPE

Chemical engineering involves the application of the fundamental branches of science to the conception, design, implementation and operation of industrial processes for the manufacture of the products needed by civilization. It is, by nature, a profession based on practicality of solutions rather than on the platonic search for academic truth. The types of processes and industries that require the skills of chemical engineers are so diversified that engineering curricula rarely specialize, except at advanced levels. Despite the diversification of industry, broad generalities enable engineering to proceed on the basis of fundamental principles. Furthermore, although the number of individual processes is significant, they may be categorized by a series of steps referred to as operations. These individual operations are based, in turn, on the same scientific principles. Regardless of the specific industry, operations overlap; for example, fluids are transported, feedstocks are combined or mixed, fluid-solid systems are separated, materials are dried. Hence, the concept of the unit operation is to approach all process steps with a unified and systematic approach.

Unit operations are applicable to both physical and chemical processes. Most often the physical processes are entangled in chemical synthesis. It is not the intention of this book to cover all unit operations. Instead, its scope is directed toward the hydrodynamics of unit operations. Unit operations aimed at the transfer of mass and heat between process constituents, as well as the thermokinetics in chemical synthesis, all depend on the governing principles of fluid mechanics. Without a thorough understanding of process hydrodynamics, the design of any unit operation becomes an art, specific to the particular process. It is this aspect that is largely responsible for our ability to treat unit operations as a unified subject.

On this premise, we divide unit operations into three broad categories based on the nature of the hydromechanics. Each category refers to a class of problems frequently encountered in industrial fluid mechanics.

1. those that constitute the *internal problems of hydrodynamics*, which include the unit operations of liquid pumping, as well as gas compression and transportation;
2. those that constitute the *external problems of hydrodynamics*, which include the unit operations of sedimentation, centrifugal separation and mixing; and
3. those problems that constitute the *mixed problems of hydrodynamics*, which include filtration, fluidized bed operations and two-phase gas-liquid operations.

UNITS OF MEASURE

First, we will define an engineering system of units that provides a standard format for measuring, interpreting and reporting phenomenological evidence, as well as a vehicle by which such information may be applied to benefit mankind. Historically, units of measure have been arbitrary; investigators working in a particular field would elect to devise convenient definitions. To standardize definitions of measure, the scientific and engineering communities have formulated a policy of an International System of Units (SI) through the International Organization of Standardization (ISO).