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# UNIT OPERATIONS OF CHEMICAL ENGINEERING

Sixth Edition

## 化学工程单元操作

第六版 (英文影印版)

Warren L.McCabe Julian C.Smith Peter Harriott



化学工业出版社

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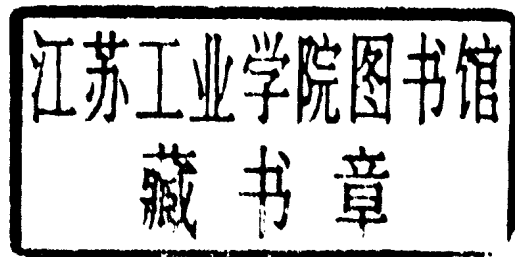
# Unit Operations of Chemical Engineering

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## 前 言

随着中国社会主义现代化建设进入新的阶段，以高质量的高等教育培养千百万专门人才，迎接新世纪的挑战，是实现“科教兴国”战略的基础工程，也是完成“十五”计划各项奋斗目标的重要保证。为切实加强高等学校本科教学并提高教学质量，教育部于2001年专门下发文件提出12条意见，对高等学校教学工作从认识、管理、教师队伍到教学方法和教学手段等给予指导。文件强调，按照“教育要面向现代化、面向世界、面向未来”的要求，为适应经济全球化和科技国际化的挑战，本科教育要创造条件使用英语等外语进行公共课和专业课教学。

在文件精神指导下，全国普通高等学校尤其是重点高校中兴起了使用国外教材开展教学活动的潮流。如生物技术与工程、环境科学与工程、材料科学与工程及作为其学科基础理论重要组成部分的化学技术和化学工程技术又是这股潮流中最为活跃的领域之一。在教育部“化工类专业人才培养方案及教学内容体系改革的研究与实践”项目组及“化工类专业创新人才培养模式、教学内容、教学方法和教学改革的研究与实践”项目组和“全国本科化学工程与工艺专业教学指导委员会”的指导和帮助下，化学工业出版社及时启动了引进国外名校名著的教材工程。

出版社组织编辑人员多次赴国外学习考察，通过国外出版研究机构对国外著名的高等学校进行调查研究，搜集了一大批国际知名院校的现用教材选题。他们还联络国内重点高校的专家学者组建了“国外名校名著评价委员会”，对国外和国内高等本科教学进行比较研究，对教材内容质量进行审查评议，然后决定是否引进。他们与国外许多著名的出版机构建立了联系，有的还建立了长期合作关系，以掌握世界范围内优秀教材的出版动态。

以其化学化工专业领域的优势资源为基础，化学工业出版社的教材引进主要涉及化学、化学工程与工艺、环境科学与工程、生物技术与工程、材料科学与工程、制药工程等专业，对过程装备与控制工程、自动化等传统专业教材的引进也在规划之中。

他们在影印、翻译出版国外教材的过程中，注意学习国外教材出版的经验，提高编辑素质，密切编读联系，整合课程体系，更新教材内容，科学设计版面，提高印装质量，更好地为教育服务。

在化工版“国外名校名著”系列教材即将问世之际，我们不仅感谢化学工业出版社为高等教育所做的努力，更应赞赏他们严谨认真的工作作风。

中国科学院院士，天津大学教授

余国琮

2002年4月

## PREFACE

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This sixth edition of the text on the unit operations of chemical engineering has been extensively revised and updated, with much new material and considerable condensation of some sections. Its basic structure and general level of treatment, however, remain unchanged. It is an introductory text, written for undergraduate students in their junior or senior years who have completed the usual courses in mathematics, physics, chemistry, and an introduction to chemical engineering. An elementary knowledge of material and energy balances and of thermodynamic principles is assumed.

Separate chapters are devoted to each of the principal unit operations, grouped into four sections: fluid mechanics, heat transfer, mass transfer and equilibrium stages, and operations involving particulate solids. One-semester or one-quarter courses may be based on any of these sections or combinations of them. The order of the first 16 chapters has not been changed; later ones, dealing with mass transfer and operations involving solids, have been rearranged in a more logical order.

Nearly all equations have been written for SI units, and the Newton's law conversion factor  $g_c$  has been eliminated except in the few instances where it must be included. Symbols for dimensionless groups have been changed to  $Re$  for  $N_{Re}$ , for example,  $Pr$  for  $N_{Pr}$ , and so forth. Many new examples and problems have been added, some reflecting the importance of biochemical engineering processes. Material on handling, mixing, and grinding particulate solids has been greatly condensed and dealt with in a single chapter. The number of appendixes is reduced from 22 to 19.

Derivations of the differential equations for continuity and momentum balances, leading to the Navier-Stokes equation, have been added, as well as the differential forms of Fourier's law and Fick's law, emphasizing the analogies among momentum, heat, and mass transfer. The chapter on adsorption has been expanded to include new material on chromatography and ion exchange, and renamed "Fixed-bed Separations." Other new material has been added on viscoelastic fluids, laminar flow in annuli, drag coefficients, affinity laws for pumps, high-efficiency agitators and motionless mixers, plate-type heat exchangers, boiling by submerged tube bundles, cooling towers, aqueous phase extraction, cross-flow filtration, and many other topics.

Many of the problems at the ends of the chapters are new or revised. Most are expressed in SI units. Nearly all the problems can be solved with the aid of a pocket calculator; for a few, a computer solution is preferable.

McGraw-Hill and the authors thank Dr. N. T. Obot for his many suggestions regarding fluid mechanics and heat transfer, and Professor Charles H. Gooding of Clemson University for his detailed and helpful review of the manuscript.

Julian C. Smith  
Peter Harriott

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## SECTION I

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# Introduction