PUMP HANDBOOK

EDITED BY

Igor J. Karassik
Joseph P. Messina
Paul Cooper
Charles C. Heald

THIRD EDITION

McGRAW-HILL

New York San Francisco Washington, D.C.
Auckland Bogotá Caracas Lisbon London
Madrid Mexico City Milan Montreal New Delhi
San Juan Singapore Sydney Tokyo Toronto

In memory of our good friends and colleagues
William C. Krutzsch
Warren H. Fraser
Igor J. Karassik

McGraw-Hill
A Division of The McGraw-Hill Companies

Copyright © 2001, 1986, 1976 by The McGraw-Hill Companies, Inc. All rights reserved. Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

1 2 3 4 5 6 7 8 9 0 DOC / DOC 0 6 5 4 3 2 1 0

ISBN 0-07-034032-3

The sponsoring editor for this book was Linda Ludewig, the editor supervisor was David Fogarty, and the production supervisor was Pamela A. Pelton. It was set in Century Schoolbook by D&G Limited, LLC.

Printed and bound by R. R. Donnelley & Sons Company.

McGraw-Hill books are available at special quantity discounts to use as premiums and sales promotions, or for use in corporate training programs. For more information, please write to the Director of Special Sales, Professional Publishing, McGraw-Hill, Two Penn Plaza, New York, NY 10121-2298. Or contact your local bookstore.

Information contained in this work has been obtained by The McGraw-Hill Companies, Inc. ("McGraw-Hill") from sources believed to be reliable. However, neither McGraw-Hill nor its authors guarantee the accuracy or completeness of any information published herein and neither McGraw-Hill nor its authors shall be responsible for any errors, omissions, or damages arising out of use of this information. This work is published with the understanding that McGraw-Hill and its authors are supplying information but are not attempting to render engineering or other professional services. If such services are required, the assistance of an appropriate professional should be sought.

This book is printed on recycled, acid-free paper containing a minimum of 50 percent recycled de-inked fiber.

OTHER MCGRAW-HILL REFERENCE BOOKS OF INTEREST

Handbooks

Baumeister • *Marks' Standard Handbook for Mechanical Engineers*
Bovay • *Handbook of Mechanical and Electrical Systems for Buildings*
Brady and Clauser • *Materials Handbook*
Brater and King • *Handbook of Hydraulics*
Chopey and Hicks • *Handbook of Chemical Engineering Calculations*
Croft, Carr, and Watt • *American Electricians' Handbook*
Dudley • *Gear Handbook*
Fink and Beaty • *Standard Handbook for Electrical Engineers*
Harris • *Shock and Vibration Handbook*
Hicks • *Standard Handbook of Engineering Calculations*
Hicks and Mueller • *Standard Handbook of Professional Consulting Engineering*
Juran • *Quality Control Handbook*
Kurtz • *Handbook of Engineering Economics*
Maynard • *Industrial Engineering Handbook*
Optical Society of America • *Handbook of Optics*
Pachner • *Handbook of Numerical Analysis Applications*
Parmley • *Mechanical Components Handbook*
Parmley • *Standard Handbook of Fastening and Joining*
Peckner and Bernstein • *Handbook of Stainless Steels*
Perry and Green • *Perry's Chemical Engineers' Handbook*
Raznjevic • *Handbook of Thermodynamic Tables and Charts*
Rohsenow, Hartnett, and Ganic • *Handbook of Heat Transfer Applications*
Rohsenow, Hartnett, and Ganic • *Handbook of Heat Transfer Fundamentals*
Rothbart • *Mechanical Design and Systems Handbook*
Schwartz • *Metals Joining Manual*
Seidman and Mahrous • *Handbook of Electric Power Calculations*
Shand and McLellan • *Glass Engineering Handbook*
Smeaton • *Motor Application and Control Handbook*
Smeaton • *Switchgear and Control Handbook*
Transamerica DeLaval, Inc. • *Transamerica DeLaval Engineering Handbook*
Tuma • *Engineering Mathematics Handbook*
Tuma • *Technology Mathematics Handbook*
Tuma • *Handbook of Physical Calculations*

Encyclopedias

Concise Encyclopedia of Science and Technology
Encyclopedia of Electronics and Computers
Encyclopedia of Engineering

Dictionaries

Dictionary of Mechanical and Design Engineering
Dictionary of Scientific and Technical Terms

LIST OF CONTRIBUTORS*

Able, Stephen D., B.S. (M.E.), MBA, M.S. (Eng) SECTION 3.6 DIAPHRAGM PUMPS
Senior Engineering Consultant, Ingersoll-Rand Fluid Products, Bryan, OH

Addie, Graeme, B.S. (M.E.) SUBSECTION 9.16.2 APPLICATION AND CONSTRUCTION OF CENTRIFUGAL SOLIDS HANDLING PUMPS
Vice President, Engineering and R&D, GIW Industries, Inc., Grovetown, GA

Arnold, Conrad L., B.S., (E.E.) SUBSECTION 6.2.3 FLUID COUPLINGS
Director of Engineering, American Standard Industrial Division, Detroit, MI

Ashton, Robert D., B.S. (E.T.M.E.) SUBSECTION 2.2.4 CENTRIFUGAL PUMP INJECTION-TYPE SHAFT SEALS
Manager, Proposal Applications, Byron Jackson Pump Division, Borg-Warner Industrial Products, Inc., Long Beach, CA

Bean, Robert, B.A.(Physics), M.S. (M.E.) SECTION 3.6 DIAPHRAGM PUMPS
Engineering Manager, Milton Roy Company, Flow Control Division, Ivyland, PA

Beck, Wesley W., B.S. (C.E.), P.E. CHAPTER 13 PUMP TESTING
Hydraulic Consulting Engineer, Denver, CO. Formerly with the Chief Engineers Office of the U.S. Bureau of Reclamation

Benjes, H. H., Sr., B.S. (C.E.), P.E. SECTION 9.2 SEWAGE TREATMENT
Retired Partner, Black & Veatch, Engineers-Architects, Kansas City, MO

*Note: Positions and affiliations of the contributors generally are those held at the time the respective contributions were made.

Bergeron, Wallace L., B.S. (E.E.) Subsection 6.1.2 Steam Turbines
Senior Market Engineer, Elliott Company, Jeannette, PA

Birgel, W. J., B.S. (E.E.) Subsection 6.2.1 Eddy-Current Coupling
President, VS Systems, Inc., St. Paul, MN

Birk, John R., B.S. (M.E.), P.E. Section 9.6 Chemical Industry
Consultant, Senior Vice President (retired), The Duriron Company, Inc., Dayton, OH

Brennan, James R., B.S. (M.I.E.) Section 3.7 Screw Pumps; Section 9.17 Oil Wells
Manager of Engineering, Imo Pump, a member of the Colfax Pump Group, Monroe, NC

Buse, Frederic W., B.S. (Marine Engrg.) Section 2.2.7.1 Sealless Pumps: Magnetic Drive Pumps; Section 3.1 Power Pump Theory; Section 3.2 Power Pump Design and Construction; Section 5.2 Materials of Construction for Nonmetallic (Composite) Pumps; Section 9.6 Chemical Industry
Retired Senior Engineering Consultant, Flowserve Corporation, Phillipsburg, NJ

Cappellino, C. A., B.S. (M.E./I.E.), M.S. (Product Dev't.), P.E. Section 9.8 Pulp and Paper Mills
Engineering Project Manager, ITT Fluid Technology Corp., Industrial Pump Group

Chaplis, William K., B.S. (M.E.), MBA Section 3.1 Power Pump Theory; Section 3.2 Power Pump Design and Construction
Product Engineering Manager, Flowserve Corporation, Phillipsburg, NJ

Clopton, D. E., B.S. (C.E.), P.E. Section 9.1 Water Supply
Assistant Project Manager, Water Quality Division, URS/Forrest and Cotton, Inc., Consulting Engineers, Dallas, TX

Cooper, Paul, B.S. (M.E.). M.S. (M.E.), Ph.D. (Engrg.), P.E. Chapter 1 Introduction: Classification and Selection of Pumps; Section 2.1 Centrifugal Pump Theory; Section 2.2.6 Centrifugal Pump Magnetic Bearings; Section 2.3.1 Centrifugal Pumps: General Performance Characteristics; Section 9.19.2 Liquid Rocket Propellant Pumps
Retired Director, Advanced Technology, Ingersoll-Dresser Pumps, now Flowserve Corporation, Phillipsburg, NJ

Costigan, James L., B.S. (Chem.) Section 9.9 Food and Beverage Pumping
Sales Manager, Tri-Clover Division, Ladish Company, Kenosha, WI

Cunningham, Richard G., B.S. (M.E.), M.S. (M.E.), Ph.D. (M.E.) Section 4.1 Jet Pump Theory
Vice President Emeritus for Research and Graduate Studies and Professor Emertitus of Mechanical Engineering, Pennsylvania State University, University Park, PA

Cutler, Donald B., B.S. (M.E.) Subsection 6.3.1 Pump Couplings and Intermediate Shafting
Techncial Services Manager, Rexnord Corporation, Warren, PA

Cygnor, John E., B.S. (M.E.) Subsection 9.19.1 Aircraft Fuel Pumps
Retired Manager, Advanced Fluid Systems, Hamilton Sundstrand, Rockford, IL

Czarnecki, G. J., B.Sc., M.Sc. (Tech.) Section 3.7 Screw Pumps
Chief Engineer (Retired), Imo Pump, a member of the Colfax Pump Group, Monroe, NC

Dahl, Trygve, B.S. (M.E.), M.S. (M.E. Systems), Ph.D. (M.E.), P.E. Chapter 11 Selecting and Purchasing Pumps
Chief Technology Officer, IntellEquip, Inc., Bethlehem, PA. Formerly with Ingersoll-Dresser Pump Co., now part of Flowserve Corporation.

DiMasi, Mario, B.S. (M.E.), M.B.A. SECTION 9.4 FIRE PUMPS
District Manager, Peerless Pump, Union, NJ

Divona, A. A., B.S. (M.E.) SUBSECTION 6.1.1 ELECTRIC MOTORS AND MOTOR CONTROLS
Account Executive, Industrial Sales, Westinghouse Electric Corporation, Hillside, NJ

Dolan, A. J., B.S. (E.E.), M.S. (E.E.), P.E. SECTION 6.1.1 ELECTRIC MOTORS AND MOTOR CONTROLS
Fellow District Engineer, Westinghouse Electric Corporation, Hillside, NJ

Dornaus, Wilson L., B.S. (C.E.), P.E. SECTION 10.1 INTAKES, SUCTION PIPING, AND STRAINERS
Pump Consultant, Lafayette, CA

Drane, John, C.Eng., M.I. Chem.E. SECTION 9.9 FOOD AND BEVERAGE PUMPING
Technical Support Engineer, Mono Pumps Limited, Manchester, England, UK

Eller, David, B.S. (A.E.), P.E. SUBSECTION 6.3.2 HYDRAULIC PUMP AND MOTOR POWER-TRANSMISSION SYSTEMS
President and Chief Engineer, M&W, Pump Corporation, Deerfield Beach, FL

°Elvitsky, A. W., B.S. (M.E.), M.S. (M.E.), P.E. SECTION 9.7 PETROLEUM INDUSTRY
Vice-President and Chief Engineer, United Centrifugal Pumps, San Jose, CA

***Foster, W. E.,** B.S. (C.E.), P.E. SECTION 9.2 SEWAGE TREATMENT
Partner, Black & Veatch, Engineers-Architects, Kansas City, MO

°Fraser, Warren H., B.M.E. SECTION 2.3.2 CENTRIFUGAL PUMP HYDRAULIC PERFORMANCE AND DIAGNOSTICS
Chief Design Engineer, Worthington Pump Group, McGraw-Edison Company, Harrison, NJ

Freeborough, Robert M., B.S. (Min. E.) SECTION 3.3 STEAM PUMPS
Manager, Parts Marketing, Worthington Corporation, Timonium, MD

Furst, Raymond B. SUBSECTION 9.19.2 LIQUID ROCKET PROPELLANT PUMPS
Retired Manager of Hydrodynamics, Rocketdyne, now The Boeing Company, Canoga Park, CA

Giddings, J. F., Diploma, Mechanical, Electrical, and Civil Engineering SECTION 9.8 PULP AND PAPER MILLS
Development Manager, Parsons & Whittemore, Lyddon, Ltd., Croydon, England

Glanville, Robert H., M.E. SECTION 9.15 METERING
Vice President Engineering, BIF, A Unit of General Signal, Providence, RI

Guinzburg, Adiel, B.Sc. (Aero. E.), M.S. (Aero.), Ph.D. (M.E.) SUBSECTION 9.19.2 LIQUID ROCKET PROPELLANT PUMPS
Engineering Specialist, Rocketdyne Propulsion & Power, The Boeing Company, Canoga Park, CA

°Gunther, F. J., B.S. (M.E.), M.S. (M.E.) Subsection 6.1.3 ENGINES
Late Sales Engineer, Waukesha Motor Company, Waukesha, WI

Haentjens, W. D., B.M.E., M.S. (M.E.), P.E. SECTION 9.10 MINING
Manager, Special Pumps and Engineering Services, Hazleton Pumps, Inc., Hazleton, PA

°Deceased.

Hawkins, Larry, B.S. (M.E.), M.S. (M.E.) Subsection 2.2.6 Centrifugal Pump Magnetic Bearings
Principal, Calnetix, Torrance, CA

Heald, Charles C., B.S. (M.E.) Subsection 2.2.1 Centrifugal Pumps: Major Components; Subsection 9.7 Petroleum Industry; Section 10.1 Intakes, Suction Piping, and Strainers; Chapter 12 Installation, Operation, and Maintenance
Retired Manager of Engineering, Ingersoll-Dresser Pumps, now Flowserve Corporation, Phillipsburg, NJ

Hendershot, J. R., B.S. (Physics) Subsection 6.1.1 Electric Motors and Motor Controls; Subsection 6.2.2 Single-Unit Adjustable-Speed Electric Drives
President, Motorsoft, Inc., Lebanon, OH

Honeycutt, F. G, Jr., B.S. (C.E.) P.E. Section 9.1 Water Supply
Assistant Vice President and Head Water Quality Division, URS/Forrest and Cotton, Inc., Consulting Engineers, Dallas, TX

House, D. A., B.S. (M.E.) Section 9.2 Sewage Treatment
Product Engineering Manager, Flowserve Corporation, Taneytown, MD

Ingram, James H., B.S. (M.E.), M.S. (M.E.) Subsection 2.3.3 Centrifugal Pump Mechanical Performance, Instrumentation, and Diagnostics
Senior Engineering Specialist, Monsanto Fibers and Intermediates Company, Texas City, TX

Jackson, Charles, B.S. (M.E.), A.A.S. (Electronics), P.E. Subsection 2.3.3 Centrifugal Pump Mechanical Performance, Instrumentation, and Diagnostics
Distinguished Fellow, Monsanto Corporate Engineering, Texas City, TX

Jaskiewicz, Stephen A., B.A. (Chemistry) Subsection 2.2.7.2 Sealless Pumps: Canned Motor Pumps
Product Manager, Chempump (Division of Crane Pumps & Systems, Inc.), Warrington, PA

Jones, Graham, B.S. (M.E.), M.B.A. Subsection 2.2.6 Centrifugal Pump Magnetic Bearings
Former Project Manager for Magnetic Bearings, Technology Insights, San Diego, CA

Jones, R. L., B.S. (M.E.), M.S. (M.E.), P.E. Subsection 9.7 Petroleum Industry
Senior Staff Engineer, Shell Chemical Company, Shell Oil Products Company, Houston, TX

Jumpeter, Alex M., B.S. (Ch.E.) Subsection 4.2 Jet Pump Applications
Engineering Manager, Process Equipment, Schutte and Koerting Company, Cornwells Heights, PA

Kalix, David A., B.S. (C.E.), P.E. (M.E.) Subsection 2.3.4 Centrifugal Pump Minimum Flow Control Systems
Senior Product Development Engineer, Yarway Corporation, Blue Bell, PA

°Karassik, Igor J., B.S. (M.E.), M.S. (M.E.), P.E. Subsection 2.2.1 Centrifugal Pumps: Major Components; Section 2.4 Centrifugal Pump Priming; Section 9.5 Steam Power Plants; Chapter 12 Installation, Operation, and Maintenance
Chief Consulting Engineer, Worthington Group, McGraw-Edison Company, Basking Ridge, NJ

°Deceased.

Kawohl, Rudolph, Dipl. Ing. SECTION 9.4 FIRE PUMPS
Retired Engineering Manager, Ingersoll-Dresser Pumps, now Flowserve Corporation, Arnage, France

Kittredge, C. P., B.S. (C.E.), Doctor of Technical Science (M.E.) SUBSECTION 2.3.1 CENTRIFUGAL PUMPS: GENERAL PERFORMANCE CHARACTERISTICS
Consulting Engineer, Princeton, NJ

Koch, Richard P., B.S. (M.E.) SECTION 9.5 STEAM POWER PLANTS
Manager of Engineering, Pump Services Group, Flowserve Corporation, Phillipsburg, NJ

Kron, H. O., B.S. (M.E.), P.E. SUBSECTION 6.2.4 GEARS
Executive Vice President, Philadelphia Gear Corporation, King of Prussia, PA

°**Krutzsch, W. C.,** B.S. (M.E.), P.E. SI UNITS—A COMMENTARY; CHAPTER 1 INTRODUCTION: CLASSIFICATION AND SELECTION OF PUMPS
Late Director, Research and Development, Engineered Products, Worthington Pump Group, McGraw-Edison Company, Harrison, NJ

Landon, Fred K., B.S. (Aero. E.), P.E. SUBSECTION 6.3.1 PUMP COUPLINGS AND INTERMEDIATE SHAFTING
Manager, Engineering, Rexnord, Inc., Houston, TX

Larsen, Johannes, B.S. (C.E.), M.S. (M.E.) SECTION 10.2 INTAKE MODELING
Retired Vice President, Alden Research Laboratory, Inc., Holden, MA

Lippincott, J. K., B.S. (M.E.) SECTION 3.7 SCREW PUMPS
Vice President, General Manager (Retired), Imo Pump, a member of the Colfax Pump Group, Monroe, NC

Little, C. W., Jr., B.E. (E.E.), D. Eng. SECTION 3.8 VANE, GEAR, AND LOBE PUMPS
Former Vice President, General Manager, Manufactured Products Division, Waukesha Foundry Company, Waukesha, WI

Maxwell, Horace J., B.S. (M.E.) SUBSECTION 2.3.4 CENTRIFUGAL PUMP MINIMUM FLOW CONTROL SYSTEMS
Director of Engineering, Yarway Corporation, Blue Bell, PA

Mayo, Howard A., Jr., B.S. (M.E.), P.E. SUBSECTION 6.1.4 HYDRAULIC TURBINES; SECTION 9.13 PUMPED STORAGE
Consulting Engineer, Hydrodynamics Ltd., York, PA

McCaul, Colon O., B.S., M.S. (Metallurgical Engrg.), P.E. SECTION 5.1 METALLIC MATERIALS OF PUMP CONSTRUCTION
Senior Engineering Consultant, Flowserve Corporation, Phillipsburg, NJ

Messina, Joseph P., B.S. (M.E.), M.S. (C.E.), P.E. SECTION 8.1 GENERAL CHARACTERISTICS OF PUMPING SYSTEMS AND SYSTEM-HEAD CURVES; SECTION 8.2 BRANCH-LINE PUMPING SYSTEMS
Consultant

Miller, Ronald S., B.Sc. (M.E.), B.Sc (Metallurgical Engrg.) SECTION 5.1 METALLIC MATERIALS OF PUMP CONSTRUCTION
Manager, Advanced Materials Engineering, Ingersoll-Rand Company

Moll, Steven A., B.S. (E.E.) SECTION 6.2.1 EDDY-CURRENT COUPLINGS
Senior Marketing Representative, Electric Machinery, Minneapolis, MN

°Deceased.

Moyes, Thomas L., B.S. (M.E.) SUBSECTION 9.18 CRYOGENIC LIQUEFIED GAS SERVICE
Chief Engineer - R&D, Flowserve Corporation, Tulsa, OK

Netzel, James P., B.S. (M.E.) SUBSECTION 2.2.2 CENTRIFUGAL PUMP PACKING; SUBSECTION 2.2.3 CENTRIFUGAL PUMPS: MECHANICAL SEALS
Chief Engineer, John Crane, Inc., Morton Grove, IL

Nolte, P. A., B.S. (M.E.) SECTION 9.20 PORTABLE TRANSFER OF HAZARDOUS LIQUIDS
Director of Agricultural Business, Flowserve Corporation, Memphis, TN

Nuta, D., B.S. (C.E.), M.S. (Applied Mathematics and Computer Science), P.E. SUBSECTION 9.14.2 NUCLEAR PUMP SEISMIC QUALIFICATIONS
Associate Consulting Engineer, Ebasco Services, Inc., New York, NY

O'Keefe, W., A.B., P.E. SUBSECTION 2.3.4 CENTRIFUGAL PUMP MINIMUM FLOW CONTROL SYSTEMS; CHAPTER 7 PUMP CONTROLS AND VALVES
Editor, Power Magazine, *McGraw-Hill Publications Company, New York, NY*

°Olson, Richard G., M.E. M.S., P.E. SECTION 6.1.5 GAS TURBINES
Late Marketing Supervisor, International Turbine Systems, Turbodyne Corporation, Minneapolis, MN

Padmanabhan, Mahadevan, B.S. (C.E.), M.S. (C.E.), Ph.D., P.E. SECTION 10.2 INTAKE MODELING
Vice President, Alden Research Laboratory, Inc. Holden, MA

Parmakian, John, B.S. (M.E.), M.S. (C.E.), P.E. SECTION 8.3 WATERHAMMER
Consulting Engineer, Boulder, CO

Parry, W. E., Jr., B.S. (M.E.), P.E. SUBSECTION 9.14.1 NUCLEAR ELECTRICAL GENERATION; SUBSECTION 9.14.2 NUCLEAR PUMP SEISMIC QUALIFICATIONS
Project Engineering Manager, Nuclear Equipment/Vertical Pumps, Flowserve Corporation, Phillipsburg, NJ

Patel, Vinod P., B.S. (M.E.), M.S. (Metallurgical Engrg.), P.E. CHAPTER 11 SELECTING AND PURCHASING PUMPS
Senior Principal Engineer, Machinery Technology, Kellogg Brown & Root, Inc., Houston, TX

Peacock, James H., B.S. (Met.E.) SECTION 9.6 CHEMICAL INDUSTRY
Manager, Materials Division, The Duriron Company, Inc., Dayton, OH

Platt, Robert A., B.E., M.E., P.E. SECTION 3.8 VANE, GEAR AND LOBE PUMPS
General Manager, Sales and Marketing, Carver Pump Company, Muscatine, IA

Potthoff, E. O., B.S. (E.E.), P.E. SUBSECTION 6.2.2 SINGLE-UNIT ADJUSTABLE-SPEED ELECTRIC DRIVES
Industrial Engineer (retired), Industrial Sales Division, General Electric Company, Schenectady, NY

Prang, A. J. SECTION 3.7 SCREW PUMPS
Manager, Engineering and Quality Assurance, Flowserve Corporation, Brantford, Ontario, Canada

Ramsey, Melvin A., M.E., P.E. SECTION 9.12 REFRIGERATION, HEATING, AND AIR CONDITIONING
Consulting Engineer, Schenectady, NY

°Deceased.

°**Rich, George R.,** B.S. (C.E.), C.E., D.Eng., P.E. SECTION 9.13 PUMPED STORAGE
Late Director, Senior Vice President, Chief Engineer, Chas. T. Main, Inc., Boston, MA

Robertson, John S., B.S. (C.E.), P.E. SECTION 9.3 DRAINAGE AND IRRIGATION
Chief, Electrical and Mechanical Branch, Engineering and Construction, Headquarters, U.S. Army Corps of Engineers

Roll, Daniel R., B.S. (M.E.), P.E. SECTION 9.8 PUMP AND PAPER MILLS
Vice President, Engineering & Development, Finish Thompson Inc, Erie, PA

Rupp, Warren E. SECTION 3.6 DIAPHRAGM PUMPS
President, The Warren Rupp Company, Mansfield, OH

Sellgren, Anders, M.S. (C.E.), Ph.D. (Hydraulics) SUBSECTION 9.16.1 HYDRAULIC TRANSPORT OF SOLIDS; SUBSECTION 9.16.2 APPLICATION AND CONSTRUCTION OF CENTRIFUGAL SOLIDS HANDLING PUMPS
Professor, Division of Water Resources Engineering, Lulea University of Technology, Lulea, Sweden

Sembler, William J., B.S. (Marine Eng.), M.S. (M.E.) SECTION 9.11 MARINE PUMPS
Tenured Associate Professor, United States Merchant Marine Academy, Kings Point, NY

Shapiro, Wilbur, B.S., M.S. SUBSECTION 2.2.5 CENTRIFUGAL PUMP OIL FILM JOURNAL BEARINGS
Consultant, Machinery Components, Niskayuna, NY

Shikasho, Satoru, B.S. (M.E.), P.E. SECTION 9.21 WATER PRESSURE BOOSTER SYSTEMS
Chief Product Engineer, Packaged Products, ITT Bell & Gossett, Morton Grove, IL

Smith, L. R. SECTION 9.18 CRYOGENIC LIQUIFIED GAS SERVICE
Retired, formerly of J. C. Carter Company, Costa Mesa, CA

Smith, Will, B.S. (M.E.), M.S. (M.E.), P.E. SECTION 3.5 DISPLACEMENT PUMP FLOW CONTROL; SUBSECTION 9.16.3 CONSTRUCTION OF SOLIDS-HANDLING DISPLACEMENT PUMPS
Engineering Product Manager, Custom Pump Operations, Worthington Division, McGraw-Edison Company, Harrison, NJ

Snyder, Milton B., B.S. (B.A.) SUBSECTION 6.2.5 ADJUSTABLE-SPEED BELT DRIVES
Sales Engineer, Master-Reeves Division, Reliance Eectric Company, Columbus, IN

Sparks, Cecil R., B.S. (M.E.), M.S. (M.E.), P.E. SECTION 8.4 PUMP NOISE
Director of Engineering Physics, Southwest Research Institute, San Antonio, TX

Szenasi, Fred R., B.S. (M.E.), M.S. (M.E.), P.E. SECTION 3.4 DISPLACEMENT PUMP PERFORMANCE, INSTRUMENTATION, AND DIAGNOSTICS; SECTION 8.4 PUMP NOISE
Senior Project Engineer, Engineering Dynamics Inc., San Antonio, TX

Taylor, Ken W., MIProdE. CEng. SECTION 9.15 METERING
Vice President, Global Business Development, Wayne Division, Dresser Equipment Group, a Halliburton Company

Tullo, C. J., P.E. SECTION 2.4 CENTRIFUGAL PUMP PRIMING
Chief Engineer (retired), Centrifugal Pump Engineering, Worthington Pump, Inc., Harrison, NJ

Vance, William M., M.B.A. SECTION 9.17 OIL WELLS
Senior Project Sales Engineer, Weir Pumps Limited, Glasgow, Scotland, UK

°Deceased.

VanLanningham, F. L., SECTION 6.2.4 GEARS
Consultant, Rotating and Turbomachinery Consultants

Wachel, J. C., B.S. (M.E.), M.S. (M.E.) SECTION 3.4 DISPLACEMENT PUMP PERFORMANCE, INSTRUMENTATION, AND DIAGNOSTICS; SECTION 8.4 PUMP NOISE
Manager of Engineering, Engineering Dynamics, Inc., San Antonio, TX

Webb, Donald R., B.S. (M.E.), M.S. (Engrg Administration) SUBSECTION 6.1.4 HYDRAULIC TURBINES
Plant Assessment Manager, Voith Siemens Hydro, York, PA

Wepfer, W. M., B.S. (M.E.), P.E. SUBSECTION 9.14.1 NUCLEAR ELECTRICAL GENERATION
Consulting Engineer, formerly Manager, Pump Design, Westinghouse Electric Corporation, Pittsburgh, PA

Whippen, Warren G., B.S. (M.E.), P.E. SUBSECTION 6.1.4 HYDRAULIC TURBINES
Retired Manager of Hydraulic Engineering, Voith Siemens Hydro, York, PA

Wilson, Kenneth C., B.A.Sc. (C.E.), M.Sc.(Hydraulics), Ph.D. SUBSECTION 9.16.1 HYDRAULIC TRANSPORT OF SOLIDS
Professor Emeritus, Dept. of Civil Engineering, Queen's University, Kingston, Ontario, Canada

Wotring, Timothy L., B.S. (M.E.), P.E. SUBSECTION 2.2.4 CENTRIFUGAL PUMP INJECTION-TYPE SHAFT SEALS
Engineering Manager, Flowserve Corporation, Phillipsburg, NJ

Zeitlin, A. B., M.S. (M.E.), Dr.-Eng. (E.E.), P.E. SECTION 9.22 HYDRAULIC PRESSES
President, Press Technology Corporation, Mamaroneck, NY

SI UNITS—A COMMENTARY

W.C. KRUTZSCH
P. COOPER

Since the publication of the first edition of this handbook in 1976, the involvement of the world in general, and of the United States in particular, with the SI system of units has become quite common. Accordingly, throughout this book, SI units have been provided as a supplement to the United States customary system of units (USCS). This should make it easier, particularly for readers in metric countries, who will no longer find it necessary to make either approximate mental transpositions or exact mathematical conversions.

The designation SI is the official abbreviation, in any language, of the French title "Le Système International d'Unités," given by the 11th General Conference on Weights and Measures (sponsored by the International Bureau of Weights and Measures) in 1960 to a coherent system of units selected from metric systems. This system of units has since been adopted by the International Organization for Standardization (ISO) as an international standard.

The SI system consists of seven basic units, two supplementary units, a series of derived units, and a series of approved prefixes for multiples and submultiples of the foregoing. The names and definitions of the basic and supplementary units are contained in Tables la and lb of the Appendix. Table 2 lists the units and Table 3 the prefixes. Table 10 provides conversions of USCS to SI units.

As with the second edition, the decision has been made to accept variations in the expression of SI units that are widely encountered in practice. The quantities mainly affected are pressure and flow rate, the situation with each being explained as follows.

The standard SI unit of pressure, the pascal, equal to one newton[*] per square meter[†], is a minuscule value relative to the pound per square inch (1 lb/in^2 = 6,894.757 Pa) or to the old, established metric unit of pressure the kilogram per square centimeter (1 kgf/cm^2 =

[*]The newton (symbol N) is the SI unit of force, equal to that which, when applied to a body having a mass of 1 kg, gives it an acceleration of 1 m/s^2.

[†]In countries using the SI system exclusively, the correct spelling is *metre.* This book uses the spelling *meter* in deference to prevailing U.S. practice.

98,066.50 Pa). In order to eliminate the necessity for dealing with significant multiples of these already large numbers when describing the pressure ratings of modern pumps, different sponsoring groups have settled on two competing proposals. One group supports selection of the kilopascal, a unit which does provide a numerically reasonable value (1 lb/in^2 = 6.894757 kPa) and is a rational multiple of a true SI unit. The other group, equally vocal, supports the bar (1 bar = 10^5 Pa). This support is based heavily on the fact that the value of this special derived unit is close to one atmosphere. It is important, however, to be aware that it is not exactly equal to a standard atmosphere (101, 325.0 Pa) or to the so-called metric atmosphere (1 kgf/cm^2 = 98,066.50 Pa), but is close enough to be confused with both.

As yet, there is no consensus about which of these units should be used as the standard. Accordingly, both are used, often in the same metric country. Because the world cannot agree and because we must all live with the world as it is, the editors concluded that restricting usage to one or the other would be arbitrary, grossly artificial, and not in the best interests of the reader. We therefore have permitted individual authors to use what they are most accustomed to, and both units will be encountered in the text.

Units of pressure are utilized to define both the performance and the mechanical integrity of displacement pumps. For kinetic pumps, however, which are by far the most significant industrial pumps, pressure is used only to describe rated and hydrostatic values, or mechanical integrity. Performance is generally measured in terms of total head, expressed as feet in USCS units and as meters in SI units. This sounds straightforward enough until a definition of head, including consistent units, is attempted. Then we encounter the dilemma of mass versus force, or weight.

The total head developed by a kinetic pump, or the head contained in a vertical column of liquid, is actually a measure of the internal energy added to or contained in the liquid. The units used to define it could be energy per unit volume, or energy per unit mass, or energy per unit weight. If we select the last, we arrive conveniently, in USCS units, as foot-pounds per pound, or simply feet. In SI units, the terms would be newton-meters per newton, or simply meters. In fact, however, metric countries weigh objects in kilograms, not newtons, and so the SI term for head may be defined at places in this volume in terms of kilogram-meters per kilogram, even though this does not conform strictly to SI rules.

Similar ambiguity is observed with the units of flow rate, except here there may be even more variations. The standard SI unit of flow rate is the cubic meter per second, which is indeed a very large value (1 m^3/s = 15,850.32 U.S. gal/min) and is therefore really only suitable for very large pumps. Recently, some industry groups have suggested that a suitable alternative might be the liter per second (1l/s = 10^{-3} m^3/s = 15.85032 U.S. gal/min), while others have maintained strong support for the traditional metric unit of flow rate, the cubic meter per hour (1 m^3/h = 4.402867 U.S. gal/mm). All of these units will be encountered in the text.

These variations have led to several forms of the specific speed, which is the fundamentally dimensionless combination of head, flow rate, and rotative speed that characterizes the geometry of kinetic pumps. These forms are all related to a truly unitless formulation called "universal specific speed," which gives the same numerical value for any consistent system of units. Although not yet widely used, this concept has been appearing in basic texts and other literature, because it applies consistently to all forms of turbomachinery. Equivalencies of the universal specific speed to the common forms of specific speed in use worldwide are therefore provided in this book. This is done with a view to eventual standardization of the currently disparate usage in a world that is experiencing globalization of pump activity.

The value for the unit of horsepower (hp) used throughout this book and in the United States is the equivalent of 550 foot pounds (force) per second, or 0.74569987 kilowatts (kW). The horsepower used herein is approximately 1.014 times greater than the metric horsepower, which is equivalent to 0.735499 kilowatts. Whenever the rating of an electric motor is given in this book in horsepower, it is the output rating. The equivalent output power in kilowatts is shown in parentheses.

Variations in SI units have arisen because of differing requirements in various user industry groups. Practices in the usage of units will continue to change, and the reader will have to remain alert to further variations of national and international practices in this area.

ABOUT THE EDITORS

Igor Karassik, now deceased, was an original editor of this book. His extensive contributions to the earlier editions remain a signal feature of this edition. A major figure in the pump industry for the greater part of the past century, he also authored or co-authored six books in this field. Beginning in 1936, he wrote more than 600 articles on centrifugal pumps and related subjects, which appeared in over 1500 publications worldwide. For the greater part of his career, he held senior engineering and marketing positions within the Worthington Pump & Machinery Company, which after a number of permutations became part of the Flowserve Corporation. Igor Karassik received his B.S. and M.S. degrees in Mechanical Engineering from Carnegie Mellon University. He was a Life Fellow of the American Society of Mechanical Engineers and recipient of the first ASME Henry R. Worthington Medal (1980).

Joseph P. Messina, also one of the original editors, has spent his entire career in the pump industry; and his past contributions on pump and systems engineering continue to be presented in their entirety in this edition. He served as Manager of Applications Engineering at the Worthington Pump Company. He became a Pump Specialist at the Public Service Electric and Gas Company in New Jersey, serving as a committee member of the Electric Power Research Institute to improve the performance of boiler feed pumps. He assisted in updating the Hydraulic Institute Standards and taught centrifugal pump courses. He also taught Fluid and Solid Mechanics at the New Jersey Institute of Technology and holds a B.S. in Mechanical Engineering and an M.S. in Civil Engineering from the same institution. Now a pump technology consultant, he has been a contributor to the technical journals and holds pump-related patents.

Paul Cooper has been involved in the pump industry for over forty years. He began by specializing in the hydraulic design of centrifugal pumps and inducers for aerospace applications at TRW Inc. This was followed by a career in research and development on pump hydraulics and cavitation at the Ingersoll-Dresser Pump Company, now part of the Flowserve Corporation, where he conducted investigations at the Ingersoll-Rand Research Center and later served as the director of R&D for the company. A Life Fellow of the ASME, he received that society's Fluid Machinery Design Award (1991) and the Henry R. Worthington Medal (1993). He received his B.S. (Drexel University) and M.S. (Massachusetts Institute of Technology) degrees in Mechanical Engineering and a Ph.D. in Engineering from Case Western Reserve University. Now a consultant, he is the author of many technical papers and holds several patents on pumps.

Charles C. Heald has spent his entire career in the pump industry. He conducted the hydraulic and mechanical design of several complete lines of single and multistage pumps for the Cameron Pump Division of Ingersoll-Rand, which became part of the Ingersoll-Dresser Pump Company. He served as Chief Engineer and Manager of Engineering. Currently a consultant, he continues to function as the editor of the company's *Cameron Hydraulic Data Book*. The petroleum industry has always been the focus of his efforts, and he has served for over 35 years as a member of the API 610 specification task force, receiving a resolution of appreciation from API in 1995. A Life Member of the ASME, he obtained the B.S. degree in Mechanical Engineering from the University of Maine, and he is the author of several technical articles and the holder of patents pertaining to pumps.