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PUMP HANDBOOK

THIRD EDITION



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PUMP HANDBOOK

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In memory of our good friends and colleagues
William C. Krutzsch
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SI UNITS— A COMMENTARY

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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 1a and 1b 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 ($1 \text{ lb/in}^2 = 6,894.757 \text{ Pa}$) or to the old, established metric unit of pressure the kilogram per square centimeter ($1 \text{ kgf/cm}^2 =$

[†]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 ($1 \text{ lb/in}^2 = 6.894757 \text{ kPa}$) and is a rational multiple of a true SI unit. The other group, equally vocal, supports the bar ($1 \text{ bar} = 10^5 \text{ Pa}$). 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 ($101,325.0 \text{ Pa}$) or to the so-called metric atmosphere ($1 \text{ kgf/cm}^2 = 98,066.50 \text{ Pa}$), 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 ($1 \text{ m}^3/\text{s} = 15,850.32 \text{ U.S. gal/min}$) 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 ($1 \text{ l/s} = 10^{-3} \text{ m}^3/\text{s} = 15.85032 \text{ U.S. gal/min}$), while others have maintained strong support for the traditional metric unit of flow rate, the cubic meter per hour ($1 \text{ m}^3/\text{h} = 4.402867 \text{ U.S. gal/min}$). 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.

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