Third Edition

Fluid Flow Measurement

A Practical Guide to Accurate Flow Measurement

Paul J. LaNasa
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PAUL J. LANASA AND E. LOY UPP†

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AMSTERDAM • BOSTON • HEIDELBERG • LONDON • NEW YORK • OXFORD
PARIS • SAN DIEGO • SAN FRANCISCO • SINGAPORE • SYDNEY • TOKYO
Butterworth-Heinemann is an imprint of Elsevier

Butterworth-Heinemann is an imprint of Elsevier
225 Wyman Street, Waltham, MA 02451, USA
The Boulevard, Langford Lane, Kidlington, Oxford, OX5 1GB, UK

First edition 2002
Second edition 2002
Third edition 2014

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Library of Congress Cataloging-in-Publication Data
A catalog record for this book is available from the Library of Congress.

ISBN: 978-0-12-409524-3

For information on all Butterworth-Heinemann publications visit our website at http://store.elsevier.com

Printed and bound in the United States of America

14 15 16 17 18 10 9 8 7 6 5 4 3 2 1

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DEDICATION

We dedicate this book to our families, particularly our wives, Carole LaNasa and Ann Upp, who assumed most of the responsibilities in raising our families while we worked and traveled in pursuit of our careers. And we express deepest appreciation to the companies—Tennessee Gas Pipeline, The Boeing Company, Daniel Industries (now the Daniel Division of Emerson Process Management), NuTech Industries, Ultra Field Measurement Company, The W.E.S.T. Corporation's CEESI Measurement Solutions, and CPL & Associates—whose assignments provided the opportunity for most of our flow measurement experience.

For over 48 years, we have helped solve flow measurement problems. During this time it has become apparent to us that good flow measurement is not a simple commodity to be selected solely by comparing product specifications. Rather, successful flow measurement results from application of good products with a full understanding of the equally important topics discussed in this book.

We subtitled the book "A practical guide to accurate flow measurement" and are quite confident that *practical* know-how comes only from a thorough understanding of fluid flow basics coupled with extensive experience. We have tried to share our experience and that of our peers through the examples and illustrations in the book. If our readers can make any contribution to reducing flow measurement uncertainties by application of the book's information, we will feel more than amply rewarded for the time and effort invested in writing it.

PREFACE

As noted in the preceding Dedication, the tendency to make flow measurement a highly theoretical and technical subject overlooks a basic tenet: *Practical application of meters, metering principles, and metering instrumentation and related equipment is the real key to quality measurement.* And that includes the regular maintenance by trained and experienced personnel with quality equipment required to keep flow measurement systems operating so as to achieve their full measurement potential.

We cannot begin to name the many friends who make up our background of experience. They include the pioneers in flow measurement, flow measurement design engineers, operating personnel—ranging from top management to the newest testers—academic and research based engineers and scientists, worldwide practitioners, theorists, and those just getting started in the business.

Our personal experience has been that understanding creates the most complete comprehension. Standing in front of a "class" as a "student" asks for an explanation of a point just covered, quickly and clearly separates what you have learned by rote from that which you truly understand. One finds out very rapidly what one really knows. Hopefully you will find that which you need to know and understand.

Why *another* book on flow measurement? Several factors motivated us. We have mentioned our emphasis on the *practical* side of the subject. Another reason is the large number of retirements and passings of experienced measurement personnel, including ourselves. And a third consideration is the tendency to make our various measurement standards "technically defensible"—but confusing.

We felt simply that a *practical guide* could be a useful project.

In the material covering standards, the brief overviews are coupled with our hope that interested readers will consult the documents and organizations listed for additional information. In the same vein, detailed theoretical discussions are left to such excellent sources as the latest edition of the *Flow Measurement Engineering Handbook* by R.W. Miller. Because of the extent of such detailed information, we present only outlines along with reference information for the reader's use.

We hope that enough practical information will be found in this book to help a reader analyze a flow problem to the extent that the other detailed references will become clear. We have tried to "demystify" flow measurement by breaking the subject into simple sections and discussing them in everyday terms. Each technology has its own terminology and jargon; that is why you will find many definitions and explanations of terms in the book.

In short, flow measurement is based in science, but successful application depends largely on the art of the practitioner. Too frequently we blindly follow the successful artist simply because "that is the way we've always done it." Industry experience the world over shows, however, that understanding *why* something is done can almost always generate better flow measurement.

Reference

Miller, R.W., Flow Measurement Engineering Handbook. 3rd Ed. McGraw-Hill, New York.

MEMORIAL

E. LOY UPP

Edmund Loy Upp, 79, of Sugar Land, TX, friend, colleague, and co-author passed away on June 24, 2007. E. Loy Upp was born September 10, 1927, in Stillwater, OK, to Faye and Dr. Charles Upp. He was the middle son of three sons raised in Baton Rouge, LA.

Mr. Upp graduated in 1944 from Louisiana State University with a Bachelor of Science Degree in Chemical Engineering. While in college, he was a member of the Sigma Chi Fraternity and served as Manager of Mike the Tiger. He was a lifetime LSU fan. After 50 years of dedication, he became a proud member and honoree of the LSU Gold Tiger Society.

Mr. Upp was well respected throughout his career in the oil and gas industry, and considered an expert in the field of flow measurement. He began his career at Tennessee Gas Pipeline Company, working as a measurement engineer. He traveled the world, offering his expertise in flow measurement to prominent universities and professional symposiums. Mr. Upp was the first President of the Gulf Coast Gas Measurement Society. In addition, he contributed articles/papers to the American Gas Association AGA-3, Gas Measurement Manual, ASME Fluid Meters, Sixth Edition, Gas Processors Association, Engineering Data Book and the American Petroleum Institute Petroleum Measurement Standards. He authored a prominent book on Fluid Flow Measurement.

Mr. Upp received many honors from the Petrochemical Industry, including: The Laurence Reid Award from the International School of Hydrocarbon Measurement, The AGA, The API Citation for Service, and the GPA recognition award. He

concluded his 48 year gas and liquid measurement career as Vice President of Operations, Ultra Field Measurement Company. Mr. Upp previously served over 20 years as Director of Technology, Daniel Industries.

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INTRODUCTION

Chapter Overview

The vast majority of this book relates to "conventional" flowmeters; for example, the admonition about single phase flow. Obviously, this comment does not apply to multiphase meters. Other exceptions are noted as they appear.

The book's general approach is to look first at basic principles, particularly with respect to differential and linear meters and the types used to measure fluid flow in the oil and gas industry. After a review of basic reference standards, "theory" is turned into "practice," followed by an overview of fluids and the fluid characteristics. "Flow" itself is examined next, followed by operating and maintenance concerns. Next, comments are offered on individual meters and associated equipment with a detailed review of the two classes of meters: differential and linear readout systems. Meter proving systems are covered in detail, followed by measurement data analysis and "lost and unaccounted for" procedures. The book concludes with a discussion of conversion to volumes, conversion of the volumes to billing numbers, and the audit procedures required to allow both parties to agree to the final measurement and money exchange.

Emphasis is not so much on individual meter details as on general measurement requirements and the types of meters available to solve particular problems.

Specifically, this first chapter presents some background information, overviews the requisites for "flow" and defines the major terms used throughout the book. Chapter 2 introduces various relevant subjects, starting with basic principles and fundamental equations. Chapter 3 details the types of fluid measurement: custody transfer and non-custody transfer. Chapter 4 is devoted entirely to listing the basic reference standards. Chapter 5 applies theory to the real world, and describes how various practical considerations make *effective* meter accuracy dependent on much more than simply the original manufacturer's specifications and meter calibration. Chapter 6 covers

Fluid Flow Measurement. ISBN: 978-0-12-409524-3

the limitations that fluid characteristics place on accurate flow measurements. Chapter 7 looks at flow in terms of the characteristics required, measurement units involved, and installation requirements for proper meter operation.

Chapter 8 reviews the necessary concerns in operating the meters properly, with examples of real problems found in the field. Chapter 9 covers the maintenance required for real metering systems to allow proper performance over time. Chapter 10 reviews meter characteristics, with comments on all the major meters used in the industry. Chapters 11 and 12 detail head and linear meters. Chapter 13 deals with related readout equipment. Chapter 14 discusses proving systems. Chapter 16 covers measurement data analysis and Chapter 15 covers material balance calculations and studies (i.e., lost and unaccounted for). Chapter 17 introduces the auditing required in oil and gas measurement.

Requisites of Flow Measurement

In this book, **fluids** are the common fluids (liquids, gases, steam, etc.) that are handled in the oil and gas industry, both in the pure state and in mixtures. However, each fluid of interest must be individually examined to determine whether it:

a. Is flashing or condensing;
b. Has well defined pressure, volume, temperature (PVT) relationships or density;
c. Has a predictable flow pattern based on Reynolds number;
d. Is Newtonian;
e. Contains any foreign material that will adversely affect the flow meter performance; (e.g., solids in liquids, liquids in gas);
f. Has a measurable analysis that changes slowly with time.

The flow should be examined to see if it:

a. Has a fairly constant rate or one that does not exceed the variation in flow allowed by the meter system response time;
b. Has a non-swirling pattern when entering the meter;
c. Is not two-phase or multiphase at the meter;
d. Is non-pulsating;
e. Is in a circular pipe running full;
f. Has provision for removing any trapped air (in liquid) or liquid (in gas) prior to entering the meter.

Certain meters may have special characteristics that can handle some of these problems, but they must be carefully evaluated to be sure of their usefulness for the fluid conditions actually encountered (Figure 1-1).