# FLOWMETERS

## A BASIC GUIDE AND SOURCE-BOOK FOR USERS

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# To Peggy

Who has given me –

– thirty years of happy married life

– two fine children

– and her loyal support while I have struggled through the production of half a dozen books (although only another author's wife will be able to appreciate what that means!)

# Preface

My main aim in this book has been to tell the man in the works office, who probably has an overflowing in-tray and a harassed look on his face, almost everything he really needs to know about fluid flowmeters. What I have tried to do is to state in simple language:

(1) just enough about every important kind of flowmeter to help him decide which is—and, perhaps more significantly, which is not—suitable for use in any combination of circumstances he is likely to come across;
(2) how to use flowmeters to their best advantage, thus saving both time and money, and what to do when their performance falls off;
(3) the best places to obtain further information on any particular aspect of flow metering.

With any luck this means that the book will tell him the answer to 90 per cent of his questions, and will advise him where to find an answer to nine out of the remaining ten. That leaves one question in a hundred which, in all probability, simply cannot be answered by anyone at present—otherwise there would be no justification for all those fellows beavering away in research laboratories.

The plan of the book is quite simple and can be seen at a glance from the detailed table of contents. This should enable the reader to find his way about in it easily. Although the book is intended for straightforward reading there is a detailed index at the end and a flowmeter selection table in Chapter 9, which should make things easy for the enquirer with no time to spare who wants to use the book as a work of reference.

To keep the book small it has been necessary to cut out nearly all the frills. Above all else a user wants to know exactly what a flowmeter will do, and to a limited extent he is interested to see how it does it. However, he is unlikely to enthuse about the finer points of theory and the long, contorted trail of engineering evolution which lies behind today's model.

So I have taken all the mathematical proofs for granted and resolutely refused to explore any fascinating but profitless blind-alleys. Likewise, the bibliography at the end of the book is not designed to show how much (or how little!) the author has read: it is there to point the way to the relatively few books, standard specifications and original papers of first-rate importance.

There has been no attempt to mention every individual flowmeter on the market, of which there are certainly hundreds and possibly thousands; that would have been rather pointless, and quite impossible in a short book. Instead, I have tried to describe every class of flowmeter which, in my opinion, it is well worth a mechanical or chemical engineer's while to know about—and that has still necessitated describing several dozen basic types. (Civil engineers may feel disappointed that there is no mention of weirs and flumes and other structures used to measure the flow of rivers and open channels. I am sorry about this omission, but there are two good reasons for it: opinions differ on whether these can properly be classed as flowmeters and I have used up my whole ration of space, anyway.)

However, I may well have failed to meet even this limited objective. New flowmeters are coming on the market almost every year and one or two valuable devices could easily have been overlooked. If so, it may be possible to rectify the omissions in a future edition or reprint. Should you have a pet flowmeter which to your great disappointment has not been mentioned, do please send me some information about it. Obviously I cannot promise to adopt every suggestion sent to me, but they will all be considered carefully.

*Leamington Spa, 1979* *A.T.J.H*

# Acknowledgements

When I began writing this book I had the good fortune to be working in the Flow Measurement Division of Britain's National Engineering Laboratory—an organisation which is justly proud of its reputation as the 'flow measurement centre for Europe'. I am grateful to the Director of NEL for allowing me to publish the book, and for permission to reproduce a number of illustrations from NEL publications.

On a more personal level, I am deeply indebted to a number of friends who read the first draft of those chapters where they felt most at home and suggested a great many improvements. In particular, I am grateful to Dr E A Spencer, the Head of Flow Measurement Division, NEL, who gave me much useful information as well as commenting upon the full text of the first draft. Mr R S Medlock, the former Technical Director of the George Kent Group, also gave most generously of his time to work through the complete text. Helpful comments were made on portions of the first draft by Professor R C Baker, Dr T J S Brain, Mr B C Ferguson, Mr R W F Gould, Mr P Harrison, Dr J J Hunter, Mr K I Jespersen, Dr F C Kinghorn, Mr L M Macdonald, Dr W C Pursley and Mr R W W Scott.

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# Notation

| | |
|---|---|
| $A$ | Cross-sectional area of pipe |
| $B$ | Magnetic flux density |
| $C$ | Coefficient of discharge of a flowmeter, $(=Q_T/Q_I)$ or other dimensionless calibration coefficient |
| $c$ | Concentration of one substance in another |
| $c_p$ | Specific heat capacity at constant pressure |
| $D$ | Diameter of pipe |
| $d$ | Diameter of a constriction—for example, the throat of a venturi tube |
| $F$ | Meter factor $(= V_T/V_I)$ |
| $f$ | Frequency |
| $g$ | Acceleration of gravity |
| $H$ | Power supplied in the form of heat; or, height |
| $H_n$ | Hodgson number |
| $K$ | '$K$-factor' $(=n/V_T)$ |
| $K_n$ | Nominal $K$-factor |
| $L$ | Length |
| $M$ | Mass |
| $m$ | Area ratio $(= A_2/A_1$ where $A_2$ and $A_1$ are throat and upstream cross-sections, respectively) |
| $n$ | Meter pulse count |
| $P$ | Pressure |
| $\delta P$ | Pressure difference |
| $Q$ | Flowrate |
| $Q_I$ | Indicated flowrate |
| $Q_M$ | Mass flowrate $(= \mathrm{d}M/\mathrm{d}t)$ |
| $Q_T$ | 'True' flowrate (as measured by a calibration standard) |
| $Q_V$ | Volumetric flowrate $(= \mathrm{d}V/\mathrm{d}t)$ |
| $q$ | One-pulse volume $(= 1/K)$ |
| $R$ | Radius |
| $Re_D$ | Reynolds number (based on pipe diameter) $(= \rho\bar{v}D/\eta)$ |
| $Re_d$ | Reynolds number (based on meter throat diameter) |

| | |
|---|---|
| $T$ | Temperature |
| $t$ | Time |
| $U$ | Voltage |
| $V$ | Volume |
| $V_I$ | Indicated volume |
| $V_s$ | Specific volume (= $V/M$) |
| $V_T$ | 'True' volume (as measured by a calibration standard) |
| $v$ | Velocity at a point |
| $v_I$ | Indicated velocity |
| $v_T$ | 'True' velocity (as measured by a calibration standard) |
| $\bar{v}$ | Mean velocity over a cross-section |
| $Y$ | Flowmeter readout |
| $\beta$ | Thermal expansion coefficient ($=\{1/V_s\}\{dV_s/dT\}$); or, diameter ratio (= $d/D$) |
| $\gamma$ | Shear strain |
| $\dot{\gamma}$ | Rate of shear strain |
| $\Delta$ | Meter correction ($=\{V_T - V_I\}/V_I$) |
| $\epsilon$ | Expansibility factor |
| $\eta$ | Viscosity (= $\tau/\dot{\gamma}$) |
| $\kappa$ | Compressibility ($= -\{1/V_s\}\{dV_s/dP\}$) |
| $\nu$ | Kinematic viscosity (= $\eta/\rho$) |
| $\rho$ | Density |
| $\tau$ | Shear stress |

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