

Guide to

Selection and application of flowmeters for the measurement of fluid flow in closed conduits

Committees responsible for this British Standard

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- Department of Energy (Gas and Oil Measurement Branch)
- Department of Trade and Industry (National Engineering Laboratory)
- Electricity Supply Industry in United Kingdom
- Energy Industries Council
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- Institution of Gas Engineers
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- Society of British Gas Industries
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Foreword

This British Standard has been prepared under the direction of the Industrial-process Measurement and Control Standards Policy Committee.

Grateful acknowledgement is made of the wide range of useful comments received on circulation of the Draft for Public Comment, many of which were taken into account in the further development of the draft.

A British Standard does not purport to include all the necessary provisions of a contract. Users of British Standards are responsible for their correct application.

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Summary of pages

This document comprises a front cover, an inside front cover, pages i to viii, pages 1 to 250, an inside back cover and a back cover.

This standard has been updated (see copyright date) and may have had amendments incorporated. This will be indicated in the amendment table on the inside front cover.

Section 1. General

1.0 Introduction

Flow measurement is one of the most important of all process measurements. Millions of pounds worth of fluids are bought and sold each day, with the value being determined by flow measurement. The control of chemical and other process plants also relies heavily on the performance of a wide range of different types of flowmeters. Every year new designs and advances in applications extend the duties where flowmeters can be used. Meters are now available to operate with good reliability at high pressures, at high and low temperatures and with aggressive fluids. There are also many publications on flowmeter applications that appear in numerous journals which show that no single flowmeter is suitable for every application.

1.1 Scope

This British Standard provides guidance on the selection and application of flowmeters. It classifies them into ten major groups and covers the basic operating principles and application of each group. Also included is information on secondary instrumentation and some aspects of flowmeter calibration. The scope is restricted to closed conduit measurements in circular or non-circular cross section and therefore open channel systems are not included in the guide.

A bibliography containing details of the references in the text, is given in Appendix A.

NOTE The titles of the publications referred to in this standard are listed on the inside back cover.

1.2 Definitions

For the purpose of this standard the definitions given in BS 5875 apply, together with the following.

1.2.1 Flowmeter related terms

1.2.1.1

flowmeter

a flow measuring device which indicates the measured flow rate

NOTE The English language also uses the term flowmeter for a device that indicates the total amount of fluid passed during a selected time interval.

1.2.1.2

primary device

a device which generates a signal enabling the flow rate to be determined. Depending on the principle used, the primary device can be internal or external to the conduit

1.2.1.3

secondary device

a device which receives from the primary device a signal and displays, records, converts and/or transmits it as a measure of the flow rate

1.2.1.4

auxiliary device

a device which enables the necessary ancillary measurements to be carried out in flow measurement systems to determine the value of such factors as pressure, pressure difference, temperature and humidity

1.2.2 Fluid related terms

1.2.2.1

flow rate

the quantity of fluid passing through the cross-section of a conduit in a short period of time, divided by that time

1.2.2.2

volume flow rate

flow rate in which the quantity of fluid is expressed as a volume

1.2.2.3

volume flow

the volume of fluid that has passed through a cross section of a conduit over a period of time

NOTE Some types of meter indicate this quantity directly and are therefore commonly called quantity meters or bulk meters. Volume flow can also be obtained by integrating the flow rate signal from other types of meter over a known period of time. Thus flow rate meters can be made to indicate total volume flow passed with the use of suitable secondary devices.

1.2.2.4

mass flow rate

flow rate in which the quantity of fluid is expressed as a mass

NOTE There are no flowmeters that indicate total mass flow in the same way that positive displacement meters indicate total volume flow. The total mass passed can only be obtained from integrating the mass flow rate over a period of time.

1.2.2.5

compressibility factor

correction factor expressing numerically the deviation from the ideal gas law of the behaviour of a real gas under given pressure and temperature conditions

NOTE The correction factor, Z , is given by the following formula:

$$Z = \frac{pM}{\rho RT}$$

1.2.2.6

mean axial fluid velocity

the volume flow rate divided by the area of the cross section

1.2.2.7

point or local velocity

the velocity measured at a discrete point in the cross section of the conduit

1.2.3 Performance related terms

1.2.3.1

accuracy

the qualitative expression for the closeness of a measured value to the true value

NOTE The quantitative expression of accuracy should be in terms of uncertainty. Good accuracy implies small random and systematic errors.

1.2.3.2

repeatability (of a measurement)

the quantitative expression of the closeness of agreement between successive measurements of the same value of the same quantity carried out by the same method with the same measuring instrument at the same location at appropriately short intervals of time

1.2.3.3

repeatability (of a measuring instrument)

the quantity which characterizes the ability of a measuring instrument to give identical indications or responses for repeated applications of the same value of the quantity measured under stated conditions of use

1.2.3.4

linearity of a meter

the deviation (within preset limits) of a flowmeter's performance from the ideal straight line relationship between meter output and flow rate

1.2.3.5

uncertainty

an estimate characterizing the range of values within which the true value of a measurand lies

1.2.3.6

rangeability (turndown)

the ratio of the specified maximum to minimum flow rates

1.2.3.7

meter factor

the number of pulses generated per unit volume of fluid metered

1.3 Symbols

For the purpose of this standard the symbols given in Table 1.1 apply.

Table 1.1 — Symbols

Symbol	Represented quantity	Dimensions M: Mass L: Length T: Time θ : Temperature I: Electric current	SI unit
A	Cross-sectional area of the conduit under operating conditions	L^2	m^2
B	Magnetic flux density	$MT^{-2} I^{-1}$	tesla (T)
c	Velocity of sound in a medium	LT^{-1}	m/s
C	Discharge coefficient	dimensionless	
d	Orifice diameter or throat of primary element at operating conditions; diameter of head of a Pitot tube	L	m
d_r	Orifice diameter or throat of primary element at reference conditions	L	m
D	Diameter of the circular cross section of the conduit at operating conditions	L	m
D_m	Nominal meter bore	L	m
f	Frequency output of turbine	T^{-1}	Hz
g	Acceleration of free fall due to gravity	LT^{-2}	m/s^2
K	Calibration factor	L	m
K_m	Meter factor	L^{-3}	pulses/ m^3
L_e	Distance between measuring electrodes	L	m
M	Molar mass of fluid	M	kg/mol
p	Absolute static pressure of the fluid	$ML^{-1} T^{-2}$	Pa
p_o	Stagnation or total pressure	$ML^{-1} T^{-2}$	Pa
Δp	Differential pressure	$ML^{-1} T^{-2}$	Pa
q_m	Mass flow rate	MT^{-1}	kg/s
q_v	Volume flow rate	$L^3 T^{-1}$	m^3/s
r	Radius of the conduit	L	m
R	Universal gas constant	$L^2 T^{-2} \theta^{-1}$	J/kg·K
Re	Reynolds number	dimensionless	
Re_D	Reynolds number based on conduit dimensions	dimensionless	
t	Temperature of primary device at flowing conditions	θ	K
t_r	Temperature of primary device at reference conditions	θ	K
T	Fluid absolute temperature	θ	K
u	Velocity of fluid	LT^{-1}	m/s
U	Mean axial fluid velocity	LT^{-1}	m/s
V	Flow signal (E.M.F.)	$L^2 MT^{-3} I^{-1}$	V
v	Local velocity of fluid	LT^{-1}	m/s
Z	Compressibility factor	dimensionless	
β	Diameter ratio, $\beta = \frac{d}{D}$	dimensionless	
ϵ	Expansibility (expansion) factor	dimensionless	
κ	Isentropic exponent	dimensionless	
λ	Linear expansion coefficient of primary device material	$L \theta^{-1}$	m/K
ν	Kinematic viscosity of the fluid	$L^2 T^{-1}$	m^2/s
ρ	Density of the fluid	ML^{-3}	kg/ m^3
τ	Period of vibration	T	s
ω	Angular velocity	T^{-1}	rad/s

Table 1.1 — Symbols

Symbol	Represented quantity	Dimensions M: Mass L: Length T: Time θ : Temperature I: Electric current	SI unit
Subscripts			
Symbol	Quantifying		
1	Upstream		
2	Downstream		
r	Reference conditions		
c	Centreline		
NOTE Other symbols used in this standard are defined at their place of use.			

1.4 Flowmeter classification

There are many different types of flowmeter available commercially. No one meter type is ideal for all applications and skill and knowledge is required to select the appropriate meter for a particular application. As there is a need to cover a wide range of industrial and research applications, several main operating principles have evolved. These operating principles conveniently form the basis for classifying flowmeters. Flowmeters considered in this standard are arranged in ten major closed conduit groups, as given in Table 1.2.

Table 1.2 — Flowmeter classification

Group	Description
1	Orifices, venturis and nozzles
2	Other differential pressure types
3	Positive displacement types
4	Rotary turbine types
5	Fluid oscillatory types
6	Electromagnetic types
7	Ultrasonic types
8	Direct and indirect mass types
9	Thermal types
10	Miscellaneous types

Table 1.3 gives a detailed listing of the metering technologies covered in this guide and the group into which they have been placed. The group number has also been used to designate clause numbers in sections 3 and 4, enabling the reader to locate information quickly.

Table 1.3 — Group designations of flowmeters

Group ^a	Metering technology
1	<i>Conventional differential pressure types</i> Sharp edged concentric orifice (corner tapping, D and $D/2$ pressure tapping and flange tapping designs) Venturi tubes (classical venturi tube and venturi-nozzle) Flow nozzles (ISA and long radius designs)
2	<i>Other differential pressure types</i> Annular orifice Eccentric or segmental orifice Integral orifice Gentile tube Spring loaded aperture meters Elbow meter Linear resistance meter Dall tube Proprietary flow nozzles Multi-port averaging pitots Wedge meter Pitot tube Variable area flowmeter Target meter Sonic nozzles Conical entrance and $\frac{1}{4}$ circle orifice plates
3	<i>Positive displacement types</i> Reciprocating piston Sliding vane Nutating disc Bi- and tri-rotor designs Roots type meters Diaphragm meters Rotary piston Oval gear Helical rotor meter Liquid metering pumps Wet gas meters Bellows meters
4	<i>Rotary turbine type meters</i> Axial turbine meter Mechanical helix meter Bearingless turbine Propeller meters Insertion turbine Twin rotor turbine meter Multi jet or vane type meter Pelton wheels Cup anemometers
5	<i>Fluid oscillatory types</i> Vortex shedding meter Swirlmeter Insertion vortex Fluidic oscillator Fluid deflection meter

Table 1.3 — Group designations of flowmeters

Group ^a	Metering technology
6	<i>Electromagnetic types</i> a.c. types d.c. types Velocity probe types
7	<i>Ultrasonic types</i> Time-of-flight meters Sing-around Reflex meters Doppler meters Long wave acoustic
8	<i>Direct and indirect mass types</i> Indirect methods Angular momentum turbine Parallel venturi Gyroscopic meter Driven angular momentum Coriolis type Wheatstone bridge
9	<i>Thermal types</i> Heat loss types Hot wire film anemometers Thermal profile meters Calorimetric heat grid
10	<i>Miscellaneous types</i> Cross correlation meters Nuclear magnetic resonance Gas ionization Laser anemometer Tracer injection meters Weighting methods Velocity area techniques

^a For group description see Table 1.2.

1.5 Proprietary names

Some types of flowmeters are known by their trade names, particularly where there is only one manufacturer of a particular design. Examples are Gilflo® (a linear differential pressure device) and Hoverflo® (a bearingless turbine type meter), etc. The inclusion of any trade name is not an endorsement of the meters by either this Guide or the British Standards Institution.

NOTE The following trade names are used within the standard.

“Dall tube” is the registered trade mark of ABB-Kent plc

“Rotary Shunt” is the registered trade mark of ABB-Kent plc

“Litre Meter” is the registered trade mark of Litre-meter Ltd

“Rotameter” is the registered trade mark of KDG Mobrey Ltd

“Gilflo” is the registered trade mark of Gervase Instruments Ltd

“Wedge meter” is the registered trade mark of ABB-Kent plc

“Roots meter” is the registered trade mark of Dresser Industries Inc

“Hoverflo” is the registered trade mark of B. Rhodes & Son Ltd

“Swirlmeter” is the registered trade mark of Fischer & Porter Co.

“Hastings” is the registered trade mark of Teledyne Hastings — Raydist Inc.

Section 2. General selection procedure

2.0 Introduction

The selection of a flowmeter for a required duty is complex and the consequences of an incorrect selection are loss of performance, time and money, with the possibility of damage to the equipment and installation. This section makes use of figures and tables to indicate (by a process of elimination) those metering techniques which do not match the user's application.

The aim is to restrict the choice of meter(s) to those that meet or nearly meet the requirements. If the latter point is reached then reference to the manufacturer may well provide a solution by the manufacture of a special version of the meter, which may be a simple modification.

The selection procedure can also act as a checklist to the experienced flowmeter user to ensure that all variables have been considered. In difficult cases it may be found necessary to consult with a flowmeter manufacturer or an independent evaluation authority.

The starting point of the selection is the consideration of the type of fluid to be metered, i.e. liquid, gas or miscellaneous fluid (see Table 2.1). The procedure is then to examine in more detail the five basic areas which define the application, as follows:

- a) performance considerations (see 2.0)
- b) fluid property considerations (see 2.3)
- c) installation and maintenance considerations (see 2.4)
- d) environmental considerations (see 2.5)
- e) economic considerations (see 2.6)

Within each basic area are a number of factors that have to be taken into account when considering a flowmeter specification (see Table 2.3 to Table 2.7 inclusive). It is recommended that the factors be reviewed together since the five areas are interactive. This is discussed further by Bailey (1980) and Spitzer (1984).

NOTE In basic meter selection not only should normal process conditions be considered but also extraordinary conditions should also be taken into account. These could include cleaning procedures, shut down, purging and other processes which occur on an occasional basis and which may have an adverse effect on the meter.

2.1 Basic meter selection

To select a flowmeter for a specific application, it is necessary to use a process of elimination, when the requirement of the application is compared with the published specification for all meters. When a meter specification does not meet the requirement of the application in one of the five listed areas, it is eliminated from the selection process.

NOTE It is important that the application is defined comprehensively, Table 2.2 should be used to ensure that all relevant factors are considered.

Table 2.1 — Broad areas of application

Group	Type	Application																	
		Liquids (see note 1)								Gases (see note 2)					Miscellaneous (see note 3)				
		A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q	R	S	T
1	Orifice	✓	?	✓	✓	✓	✓	✓		✓	?	✓	✓	✓	?	✓	?	?	?
	Venturi	✓		✓	✓	✓	✓			✓	?		?	?	?	✓	?	?	?
	Nozzle	✓		✓	✓	✓	✓			✓	✓	?	?	✓	?	✓	?	?	?
2	VA	✓	✓			#	?		✓	✓	✓							?	
	Target	✓				#				✓				✓	?	✓	?		
	Averaging pitot	✓		✓	✓	✓	?	✓		✓		✓	✓	✓		✓	?	?	?
	Sonic nozzle									✓	✓	?	?						
3	Sliding vane	✓		#			✓		✓							?			
	Oval gear	✓	✓	#		#	✓		✓							?		✓	
	Rotary piston	✓	?			#	✓		✓							?		#	
	Gas diaphragm									✓	✓								
	Rotary gas									✓	✓								
4	Turbine	✓		✓	#	✓	?	✓	✓	✓	?	✓				?	?	#	
	Pelton	✓	✓			✓		✓		?	?					?		?	
	Mechanical meter	✓													#	?			
	Insertion turbine	✓		✓	✓	✓		✓		✓		✓	✓	?		?	?		
5	Vortex	✓				✓		✓	✓	✓		?	✓	✓		?			
	Swirlmeter	✓								✓									
	Insertion vortex	✓		✓	✓	?		?	?	✓		✓	?	✓		✓		?	?
6	Electromagnetic	✓	✓	✓	✓	#	?		✓						✓	✓	?	✓	
	Insertion electromagnetic	✓		✓	✓	?			✓						?	✓	?	✓	
7	Doppler	✓		?	?	#			?						✓	✓	?	?	
	Transit time	✓	?	✓	✓	#	?	#	✓	#					?	?		#	#
8	Coriolis (direct)	✓				#	✓		✓	?					?	?		#	
	Twin rotor (indirect)	✓																	
9	Anemometer	✓		?	?	#				✓									
	Thermal mass		#							✓	✓								
10	Tracer	✓	#	✓	✓	✓	✓	✓		#		#	✓	✓		?	✓	#	#
	Laser	✓		?	?														

Key

✓ is suitable; generally applicable

? is worth considering; sometimes applicable

is worth considering, limited availability or tends to be expensive

A blank indicates unsuitable; not applicable

NOTE 1 Liquid applications are indicated by the following:

A General liquid application (< 50 cP) (< 0.05 Pa·s)

B Low liquid flows (< 0.12 m³/h) (< 2 L/min)C Large liquid flows (> 1 000 m³/h) (> 1.7 × 10⁴ L/min)

D Large water pipes (> 0.5 m bore)

E Hot liquids (temperatures > 200 °C)

F Viscous liquids (> 50 cP) (> 0.05 Pa·s)

G Cryogenic liquids

H Hygienic liquids

NOTE 2 Gas applications are indicated by the following:

J General gas applications

K Low gas flows (> 150 m³/h)L Large gas flows (> 5 000 m³/h)

M Hot gases (temperatures < 200 °C)

N Steam

NOTE 3 Miscellaneous applications are indicated by the following:

P Slurries and particle flows

Q Liquid/liquid mixtures

R Liquid gas mixtures

S Corrosive liquids

T Corrosive gases

Table 2.2 — Selection procedure variables

Performance considerations	Accuracy Repeatability Linearity Rangeability (turndown) Pressure drop Output signal characteristics Response time Uncertainty
Installation considerations	Orientation Flow direction Upstream and downstream pipework Line size Location for servicing Effects of local vibration Location of valves Electrical connections Provision of accessories (e.g. filters, straighteners, air eliminators, pressure and temperature transducers) Hazardous atmospheres Effect of pulsations/unsteady flow
Fluid property considerations	Liquid or gas Temperature Pressure Density Specific gravity Viscosity Lubricity Chemical properties Surface tension Compressibility Real gas effects Abrasive-ness Presence of other phases Presence of other components
Environmental considerations	Ambient temperature effects Humidity effects Safety factors Pressure effects Electrical interference
Economic considerations	Purchase price Installation costs Operation costs Maintenance costs Calibration costs Meter life Spares cost and availability Pumping power and headloss Technical optimization ^a
^a See (a) and (b) of Figure 2.5.	

The first consideration is the area of application. Table 2.1 lists 18 typical applications, broken down into the three major categories of liquid, gas and miscellaneous applications. This shows whether the more commonly available meters from each group are applicable. In the table, a ✓ indicates that a meter is generally suitable, a ? indicates three possible options:

- a) further thought should be given;
- b) checking is required as there is often doubt that the requirement can be met;
- c) other types in the group may be suitable.

A blank space in the table indicates that the type of meter considered is generally not suitable for the application. This table allows groups of meters that are clearly unsuitable to be eliminated, to give a short list of meter types to be considered further. An example of each would be that electromagnetic flowmeters (group 6) cannot be used on gases (applications J to N) because they need a conducting fluid and thermal mass meters (group 9) cannot be used on liquids (applications A to H) because they are available only for gas applications. Those meter types remaining in the short list can then be evaluated in detail in the five areas listed in 2.0.

Table 2.2 gives a detailed list of the factors that require consideration when evaluating those meters still present in the list of possibles. More detailed information on each of these factors can be found in 2.2 to 2.6. The tables and figures presented are for general guidance only and in some cases do not indicate the variations that occur between types of meter within a group or even variations between manufacturers for the same types of meter. Hayward (1979) also gives a comprehensive applications data table.

The initial requirements of the application may be so restrictive that the initial specification may need to be relaxed to enable suitable methods to be identified. It is important in specifying a flowmeter not to ask for a feature that is clearly difficult to achieve. For example, a flow range in excess of 100 : 1 is normally not required in an industrial application. If this is retained in the specification when clearly not needed, the meter chosen may not be ideal compared to one selected with a less stringent specification. Poor initial specification of the application could result in a meter being chosen which is far from ideal. Under-specifying could lead to a meter being chosen which is actually unsuitable and over-specifying could lead to an expensive meter being used where a cheaper alternative would have fulfilled the application.

Unfortunately we have yet to find the universal flowmeter and often the final choice is a compromise between several influencing factors [see for example Grebe (1984), Hayward (1975, 1982) or DeCarlo (1984)]. Flowmeter systems usually consist of primary and secondary devices and auxiliary instrumentation. The selection should therefore be made on a system basis and not merely limited to the characteristics of the primary device. One area not listed in Table 2.2 is personal preference. In some cases this may dominate the selection. Where quantities of one particular type of meter have been used in one application with generally good success, the selection of meters for another application may be influenced by this fact. This may or may not result in the optimum meter being chosen for the new application.

Table 2.3 — Performance factors in meter selection

Group	Type	Linearity (%)	Repeatability (%)	Rangeability	Pressure ^a drop at maximum flow	Flow parameter measured	Response time
1	Orifice Venturi Nozzle	#	#	3 or 4 : 1	3/4	<i>R</i>	#
		#	#	3 or 4 : 1	2	<i>R</i>	#
		#	#	3 or 4 : 1	2/3	<i>R</i>	#
2	Variable area Target Averaging pitot Sonic nozzle	$\pm 1 \% FS$ to $\pm 5 \% FS$	$\pm 0.5 \% FS$ to $\pm 1 \% FS$	10 : 1	3	<i>R</i>	No data
		NS	NS	3 : 1	3	<i>R</i>	NS
		# $\pm 0.25 \%$	$\pm 0.05 \% R$ to $\pm 0.2 \% R$ $\pm 0.1 \%$	# 100 : 1	1/2 3/4	<i>V_m</i> <i>R</i>	# NS
3	Sliding vane	$\pm 0.1 \% R$ to $\pm 0.3 \% R$	$\pm 0.01 \% R$ to $\pm 0.5 \% R$	10 to 20 : 1	4/5	<i>T</i>	> 0.5 s
	Oval gear	$\pm 0.25 \% R$	$\pm 0.05 R$ to $\pm 0.1 \% R$		4	<i>T</i>	< 0.5 s
	Rotary piston	$\pm 0.5 \% R$ to $\pm 1 \% R$	$\pm 0.2 \% R$	10 to 250 : 1	4/5	<i>T</i>	> 0.5 s
	Gas diaphragm	No data	No data	100 : 1	2	<i>T</i>	> 0.5 s
	Rotary gas	$\pm 1 \%$	$\pm 0.2 \%$	25 : 1	2	<i>T</i>	> 0.5 s
4	Turbine	$\pm 0.15 \% R$ to $\pm 1 \% R$	$\pm 0.02 \% R$ to $\pm 0.5 \% R$	5 to 10 : 1	3	<i>R</i>	5 ms to 25 ms
	Pelton	$\pm 0.25 \% R$ to $\pm 2 \% R$	$\pm 0.1 \% R$ to $\pm 0.25 \% R$	4 to 10 : 1	4	<i>R</i>	5 ms to 25 ms
	Mechanical meter	No data	$\pm 1 \% FS$	10 to 280 : 1	3	<i>R</i>	50 ms
	Insertion turbine	$\pm 0.25 \% R$ to $\pm 5 \% R$	$\pm 0.1 \% R$ to $\pm 2 \% R$	10 to 40 : 1	1/2	<i>V_p</i>	5 ms to 25 ms
5	Vortex	$\pm 1 \% R$	$\pm 0.1 \% R$ to $\pm 1 \% R$	4 to 40 : 1	3	<i>R</i>	0.5 s minimum
	Swirlmeter	$< \pm 2 \% R$	NS	10 to 30 : 1	3	<i>R</i>	NS
	Insertion vortex	$\pm 2 \%$	$\pm 0.1 \% R$	15 to 30 : 1	1	<i>V_p</i>	5 ms
6	Electromagnetic	$\pm 0.5 \% R$ to $\pm 1 \% R$	$\pm 0.1 \% R$ to $\pm 0.2 \% FS$	10 to 100 : 1	1	<i>R</i>	> 0.2 s
	Insertion electromagnetic	$\pm 2.5 \% R$ to $\pm 4 \% R$	$\pm 0.1 \% R$	10 : 1	1	<i>V_p</i>	NS
7	Doppler	No data	$\pm 0.2 \% FS$	5 to 25 : 1	1	<i>V_m, R</i>	
	Transit time	$\pm 0.1 \% R$ to $\pm 1 \% R$	$\pm 0.2 \% R$ to $\pm 1 \% FS$	10 to 300 : 1	1	<i>R</i>	0.02 s to 120 s
8	Coriolis	NS	$\pm 0.1 \% R$ to $\pm 0.25 \% R$	10 to 100 : 1	2/5	<i>R</i>	0.1 s to 3 600 s
	Twin rotor	No data	No data	10 to 20 : 1	3/4	<i>R</i>	50 ms
9	Anemometer	No data	$\pm 0.2 \% FS$	10 to 40 : 1	2	<i>V_p</i>	No data
	Thermal mass	$\pm 0.5 \% FS$ to $\pm 2 \% FS$	$\pm 0.2 \% FS$ to $\pm 1 \% R$	10 to 500 : 1	2	<i>R</i>	0.12 s to 7 s
10	Tracer	No data	No data	Up to 1 000 : 1	1	<i>V_m</i>	No data
	Laser	No data	$\pm 0.5 \% R$	Up to 2 500 : 1	1	<i>V_p</i>	No data

R is the flow rate
T is the volume flow
V_m is the mean velocity

V_p is the point velocity
% R is the percentage flow rate
% FS is the percentage full scale

NS indicates not specified
 # is dependent on differential pressure measurement

^a 1 is low; 5 is high



Documents

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Obtaining precise process data to select a meter is difficult but essential. In many applications the fluid composition, pressure and temperature variations and other variables may not be known and often only a best estimate of conditions can be made. Familiarity with the process is valuable, since the process operator has data and experience which often aids the instrumentation engineer in compiling the outline specification. Flowmeter selection should wherever possible involve two or more engineers to ensure that the correct specification is drawn up.

When the selection procedure is complete, it is advisable to reappraise the specification, modify it as necessary and go through the selection process again.

2.2 Performance considerations

2.2.1 General

The performance of flowmeters can vary significantly depending on both the design and type of meter. Table 2.3 indicates typical data for the more common meters listed in Table 2.1. These are ranges of figures for each of the meter types and it is possible to find suppliers with products that are better or worse than those given. New products are continually appearing on the market and improvements in performance are being made all the time.

Flowmeter performance is often judged from accuracy and repeatability figures. They are very frequently, though incorrectly, used synonymously. Accuracy is required for custody transfer and material balance applications. If a meter is consistently accurate then it is also repeatable. However, repeatability by itself does not guarantee accuracy.

2.2.2 Meter accuracy

Accuracy is defined in **1.2.3.1**. It is an indication of performance but no real numbers can be associated with it since the standards against which meters are assessed have errors themselves. It is not possible to measure flow absolutely. (See also **2.2.6**).

Confusion surrounds the specification of flowmeters as some are quoted in terms of percentage of reading and others in terms of a percentage of full scale or of span. Figure 2.1 gives an example of how the actual error in flow measurement differs at various flow rates depending on which of the two methods is being used. It is important to note from this figure that percentage of reading is the error that applies over the stated flowrange of the meter. If the intention is to use a meter at the bottom end of the quoted range, it is prudent to calculate the actual errors over the range required.

2.2.3 Repeatability

Repeatability is defined in **1.2.3.2** and **1.2.3.3**. It can be affected by variations in temperature, pressure, viscosity and other fluid properties as well as external environmental influences. The variations in output deviate from a mean value in accordance with established statistical laws. These aspects are discussed in more detail in Appendix B.

2.2.4 Linearity

Linearity is often an important parameter in determining the selection of a flowmeter but it should not be confused with uncertainty. Two ways of showing linearity bands are given in (a) and (b) of Figure 2.2 where limits are drawn at $\pm A$ % apart. The linearity of the meter can then be quoted as $\pm A$ % of full scale for (a) and $\pm A$ % of reading for (b) of Figure 2.2.

NOTE An alternative indication of linearity, applicable to a turbine meter, is shown in Figure 3.4.2.

The value of good meter linearity is particularly important for pulse output meters, where a single value of meter factor can be used to indicate rate over the specified operating range. One fact commonly overlooked is the addition of ancillary instrumentation which frequently alters the linearity of the system.

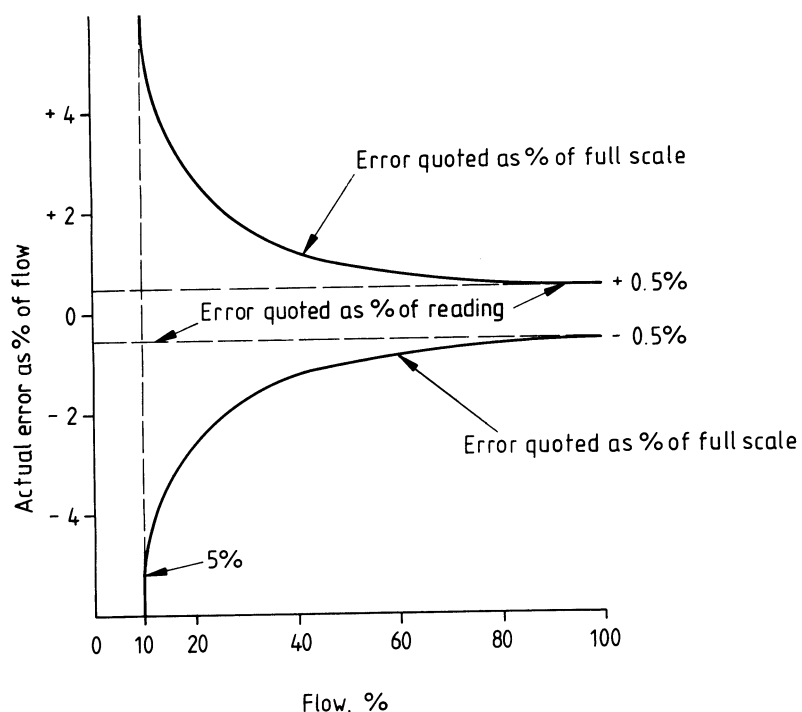
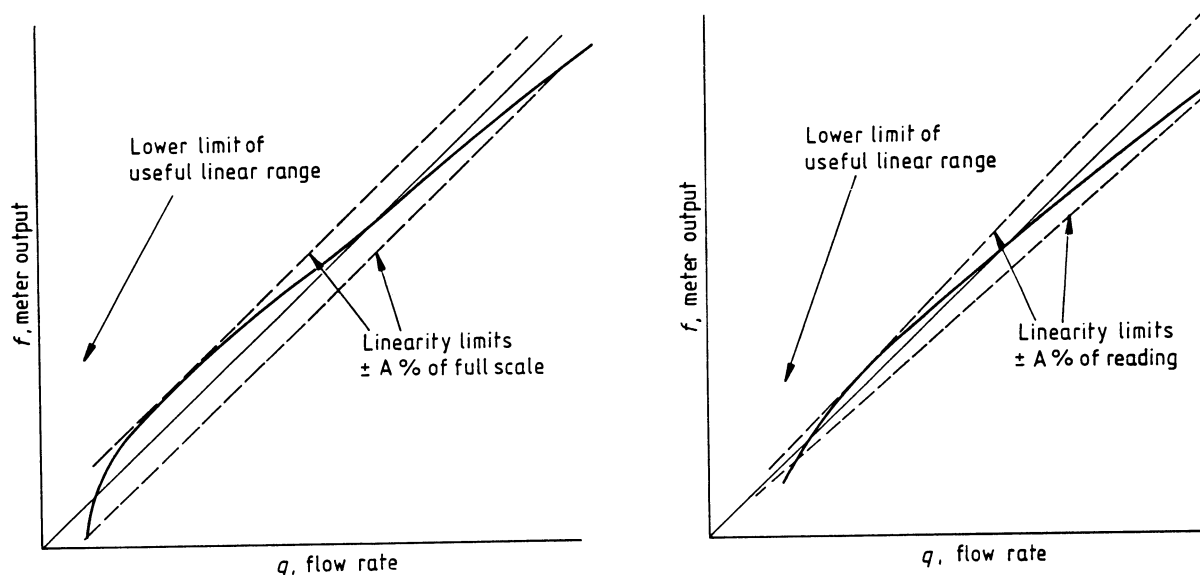


Figure 2.1 — Example of the effect of metering error on two methods of specifying flowmeter uncertainty



(a) Flowmeter linearity as percentage of full scale

(b) Flowmeter linearity as percentage of reading

Figure 2.2 — Flowmeter linearity

2.2.5 Flow rangeability (turndown)

Flow rangeability is defined in 1.2.3.6. The ability of a particular meter to operate over a wide flow range is sometimes the major requirement. Modern meters such as turbine, mass and oscillatory meters can have a wide turndown. If a meter is highly repeatable but not necessarily linear, the output can be conditioned to increase the useful flow range. The manufacturer will often advise on the various ways to increase turndown for his product. Fluid property effects, particularly density and viscosity are also important since these may alter the linear operating range of the meter significantly.

The flow rate corresponding to the full scale output can be altered on many modern flowmeters. An example is the electromagnetic flowmeter where velocity ranges from 0 m/s to 1 m/s up to 0 m/s to 10 m/s are commonly available. It is not always clear if the quoted rangeability of 10 : 1 still applies when the meter output is changed to operate over the lowest range of flows.

2.2.6 Uncertainty

Meter performance is increasingly being expressed in terms of uncertainty and a confidence level.

Uncertainty is defined in 1.2.3.5 and it gives the user a much better indication of the performance of the meter. It arises from both random and systematic errors as discussed in Appendix B. They are not normally separated by the flowmeter manufacturer when he specifies the performance of the instrument.

It is important to distinguish between error and uncertainty. Uncertainty can be calculated as detailed in Appendix B whereas error is the difference between true and indicated values. As the true value is not precisely known, then the measurement error is also unknown.

2.2.7 Output signal characteristics

Often the output signal dictates the choice of meter. Depending on design and type this could be a function of:

- a) volume flow rate;
- b) mass flow rate;
- c) total volume throughput;
- d) mean flow velocity;
- e) point velocity.

Some meters generate voltage or current outputs while others give pulse outputs, each pulse corresponding to a discrete volume of fluid. Outputs from volume flowmeters are sometimes scaled in mass units and vice-versa. Pulse output meters are generally better suited to rate indication or flow totalization applications while analogue signals interface with control loop elements such as valves more easily. Output levels from analogue meters may vary considerably (for example from a few millivolts to several volts) while pulse outputs range from almost a direct current up to 10 kHz. The magnitude and type of output signal should also be examined for compatibility with flow computers, data loggers, alarm instruments and data transmissions systems. The complete system should be kept as simple as possible to minimize the number of sources of error. As discussed in section 6, this will reduce the total uncertainty of measurement from the complete system.

2.2.8 Pressure drop at maximum flow

Constraints on the maximum allowable pressure drop should be defined before meter selection. The application may have limited inlet pressure or pumping capacity and a high loss generated by selecting the wrong meter may affect process efficiency. Most flowmeters have a non-recoverable headloss which varies with flow rate. This can vary from close to zero to as high as several bar¹⁾. In some liquid applications, notably high vapour pressure hydrocarbon liquids, excessive pressure drop may result in cavitation or vaporization of the liquid with the consequent loss of metering accuracy and possible damage to the meter.

¹⁾ 1 bar = 1×10^5 N/m² = 1×10^5 Pa.

2.2.9 Response time

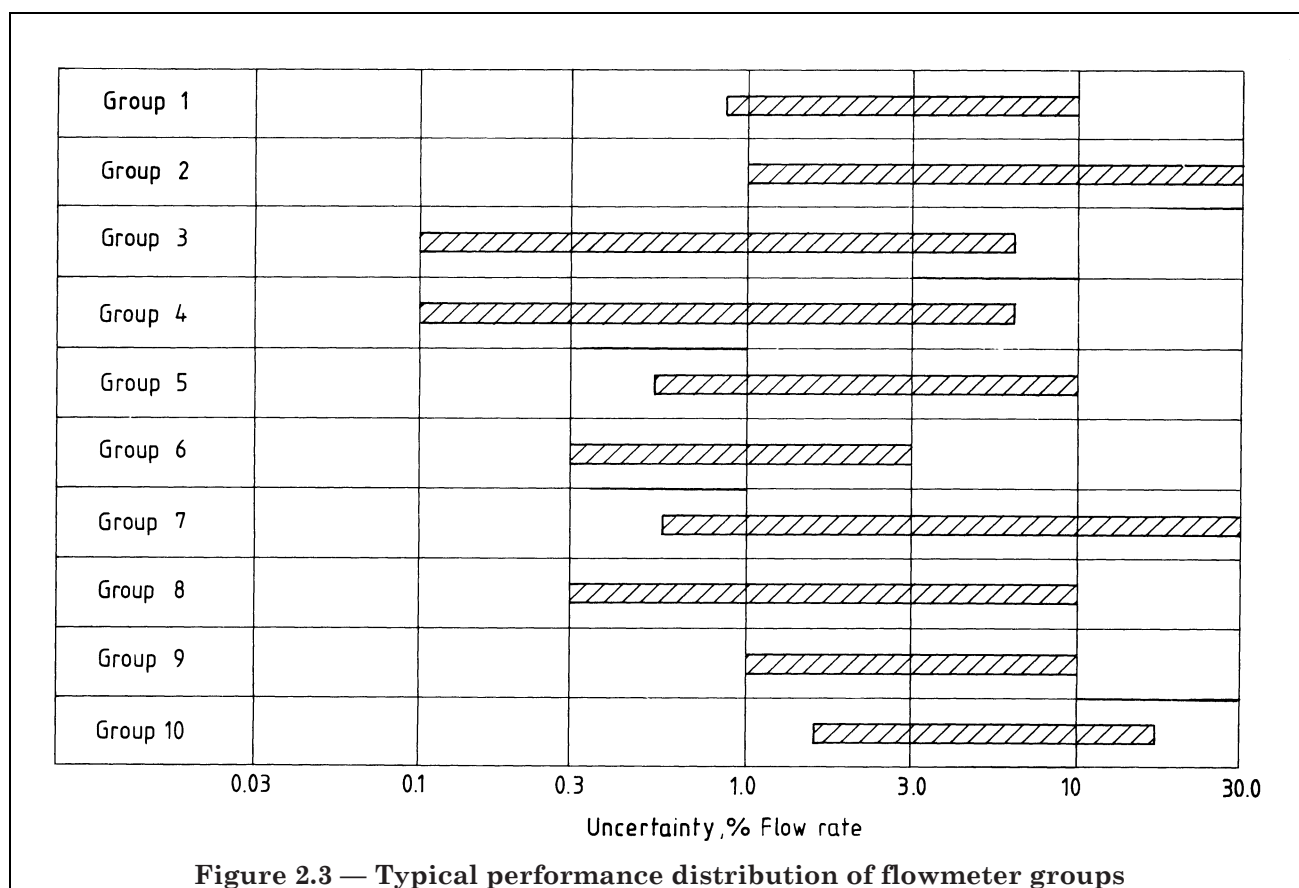
The meter's response to step changes in flow could be important in those applications where flow fluctuations are present. In some cases it may be necessary for the output of the meter to follow the variations, in others a slower response output may be designed to provide an integrated average. Transient response is normally stated in the form of a time constant or simply a response time. Where the exact meaning of the figures is unclear clarification should be sought from the manufacturer. Published values for response time vary from a few milliseconds to several seconds. The addition of secondary instrumentation may lengthen this time considerably.

2.2.10 Performance selection data

Figure 2.3 gives an indication of typical performance data for each group of flowmeters. It has been compiled from a survey of a large amount of published literature and may be used to eliminate those types which cannot meet the required level of performance. For example, Doppler ultrasonic meters cannot be considered if an uncertainty of the order of 0.2 % of rate is required.

NOTE Not all meters in a group will meet the uncertainties quoted over the full range.

Table 2.3 gives more detailed information on the performance of the more common meters in each of the 10 groups. This indicates typical ranges of repeatabilities, linearities, turndowns and other factors. This table is for general guidance only and does not indicate the variations that occur between manufacturers. Reference to specific manufacturers' data sheets will give details of the performance of the meter(s) of interest.



2.3 Fluid property considerations

2.3.1 General

All flowmeters are affected to some degree by one or more fluid properties. Therefore the nature of the fluid being measured has a large influence on the type of meter that can be chosen. For well known pure fluids, there are many reference texts and physical property data handbooks which list viscosity, specific gravity, vapour pressure and other parameters. This data can be compared against the meter specification to estimate the suitability of that particular flowmeter. Often the exact composition of the fluid stream, the temperature and pressure variations, and the nature of the stream are not known. This places a great burden on the user to quantify the fluid properties so that the manufacturer can assess whether his products are applicable or not. Table 2.4 gives pressure and temperature ranges, recommended minimum Reynolds numbers and the applicability of meters to liquids, gases and multi-phase flows.

2.3.2 Fluid temperature and pressure

The operating pressure and temperature at the flowmeter has to be carefully defined, especially in gas applications where large density variations may alter the selection of the measurement technology. Temperature and/or pressure compensation may be required if the variations in physical properties of the flow are large. Flowmeter body design is also influenced by the fluid pressure and temperature. Both the maximum and minimum pressure and temperature should be known, as the choice of materials of construction may also be affected. Where the application has large variations in fluid pressure or temperature, extra care in selection should be exercised.

Where applications involve meters being subjected to vacuum conditions, choice of both design and materials of construction are important. For example, some tube liners of magnetic flowmeters can collapse under vacuum.

2.3.3 Fluid density and specific gravity

For most liquid applications, the density or specific gravity is relatively constant but in instances where temperature variations are large, some form of compensation may be needed. This can be easily accomplished but the need should be identified as the metering technique may be influenced.

In gas applications the rangeability and linearity of some meters depend on the gas density, the value of which, at standard and flowing conditions, is generally required to be known in order to select the appropriate meter. Pressure and temperature transducers located close to the flowmeter enable on-line compensation of the gas density to be performed, or the density can be measured directly. They also permit conversion of the flowing conditions to some agreed reference. This is common in the case of custody transfer of hydrocarbon vapours. Low density applications can present difficulties to some methods, particularly those which use the momentum of the gas to operate the meter (group 4). Care is needed in sizing the meter correctly to ensure good performance.

2.3.4 Viscosity and lubricity

Meter performance is often a function of Reynolds numbers, which, in part, is established by the viscosity of the liquid.

Precise knowledge of gas viscosity is not as critical as for liquids. Gas viscosities, unlike those of liquids, do not change significantly with temperature and pressure. Gas viscosities are generally low, and the variation between different gases is also relatively small.

Viscosity can affect the rangeability of flowmeters in different ways. Most types of group 3 meters (displacement types) can increase in flow range as viscosity increases whereas some group 4 meters (inferential types) suffer from reduced rangeability as viscosity increases.

NOTE Inferential is the term given to group 4 meters (turbine type) where the flow rate is inferred from the speed of the rotor. Knowledge of the temperature/viscosity characteristics is often required to assess meter applicability.

Some liquids are non-Newtonian in nature and their flow behaviour is very complex and not easily predictable. In these applications the selection of meters should be made with extreme caution and always in full consultation with the supplier.

Lubricity is a more difficult quantity to evaluate. Frequently, though sometimes incorrectly, a fluid with high viscosity is also assumed to have good lubricity. This parameter is important in meters with moving parts, for example groups 3 and 4. Some liquids, notably solvents, have poor lubricity and bearing life may be reduced which will affect both meter performance and rangeability.

Table 2.4 — Selection by fluid property constraints

Group	Type	Maximum pressure (bar)	Temperature range (°C)	Minimum Rep	Gas (G) or Liquid (L)	Two or more phases
1	Orifice	400	< + 650	3×10^4	L, G	P
	Venturi	400	< + 650	10^5	L, G	P
	Nozzle	400	< + 650	2×10^4	L, G	N
2	Variable area	700	– 80 to + 400	No data	L, G	N
	Target	100	– 40 to + 120	3×10^4	L, G	S
	Averaging pitot	400	< + 540	10^4	L, G	N
	Sonic nozzle	400	< + 650	2.5×10^4	G	N
3	Sliding vane	100	– 30 to + 200	10^3	L	N
	Oval gear	100	– 15 to + 290	10^2	L	N
	Rotary piston	170	– 40 to + 170	10^2	L	N
	Gas diaphragm	200	– 30 to + 200	2.5×10^2	G	N
	Rotary gas	100	– 40 to + 150	10^3	G	N
4	Turbine	3 500	– 268 to + 530	} 10^4	L, G	N
	Pelton	600	– 225 to + 530		L, G	N
	Mechanical meter	70	– 25 to + 200		L, G	N
	Insertion turbine	250	– 50 to + 430		L, G	N
5	Vortex	260	– 260 to + 430	2×10^4	L, G	P
	Swirlmeter	100	– 40 to + 110	No data	L, G	N
	Insertion vortex	70	– 30 to + 150	5×10^3	L, G	N
6	Electromagnetic	300	– 60 to + 220	No limit	L	S/P
	Insertion electromagnetic	20	+ 5 to + 25	No data	L	N
7	Doppler	*	– 20 to + 80	5×10^3	L	S
	Transit time	200	– 200 to + 250	5×10^3	L, G	N/P
8	Coriolis	390	– 240 to + 400	10^2	L	P
	Twin rotor	400	– 240 to + 350	10^4	L	N
9	Anemometer	20	– 200 to + 400	No data	L, G	N
	Thermal mass	300	0 to + 100	No data	L, G	N
10	Tracer	No data	No data	No limit	L, G	P
	Laser	*	No data	No limit	L, G	N
Key S is suitable P is possible N is not suitable * is dependent on the rating of the pipe wall						

2.3.5 Chemical properties

The chemical nature of the flowing stream can sometimes be critical. Certain fluids can promote corrosion, scaling of surfaces or electrolytic action on metal surfaces. All of these can affect the life of the meter and many manufacturers offer a choice of materials to withstand most fluids. Where chemical attack is expected, thicker body walls and strengthened components may be needed to ensure safe operation.

Certain chemicals can cause coating or crystallization on surfaces. This could affect clearances on moving parts, efficiency of sensing and transmission of ultrasound. Degradation of performance must be accepted where this cannot be avoided.

Radioactivity presents special problems. Here meters offering high reliability are required since it is often not possible to perform regular maintenance. This generally necessitates the use of meters with no moving parts and remote electronic secondary instrumentation. Special materials of construction may also be required.

2.3.6 Compressibility and other variables

For gas and vapour applications, compressibility data may be needed to determine the operating density of the fluid. This information is available for many fluids of constant composition allowing density calculation to be made using pressure, temperature, compressibility and composition data. For fluids of variable composition and for operation close to or in the supercritical region on-line measurement of density should be considered.

Certain metering techniques require consideration of specific fluid properties. For example group 6 meters (electromagnetic types) depend on sufficient electrical conductivity to function, and some group 9 meters require adequate thermal capacity and conductivity.

Fluids which are inflammable or react violently with other materials need flowmeters that are manufactured to a certified design. Acetylene gas for example has been known to ignite spontaneously where steep pressure and velocity gradients exist inside flowmeters.

2.3.7 Multi-phase and multi-component flows

The metering of multi-phase and multi-component flows should be approached with extreme caution. Experience has shown that performance can be very variable and in some cases is unknown. Usually the performance of the meter is assessed on single phase flows and there are no two phase standards to assess any systematic variations from the single fluid calibration. Meter life can also vary widely from that expected. Wherever possible phases should be separated to ensure lowest uncertainty of measurement, but there are applications where this is not practical, possible or desirable.

Sometimes the fluid itself is present in two phases, the most common example of which is wet steam. Here water droplets are carried along in a vapour medium. Ambient or process variations in temperature and pressure may alter the flowing state from that expected and the meter might not be able to cope with the fluid property variations. Meters are available for these applications but the specification requires greater care than for single phase applications.

Slurries can be handled by electromagnetic and special designs of mass, ultrasonic and differential pressure meters. It is important where possible to define the fluid conditions fully. This means defining particle size and concentration and the nature of solid phase. The solids may be abrasive, fibrous or non-uniform in size. Abrasive mixtures will cause steady erosion which can cause a steady increase in meter error and can ultimately result in meter failure.

When mixtures of liquids and gases are flowing the characteristics of the phases plus possible inter-phase phenomena affect the nature of the flow. The flow regime is dependent on the relative proportions of liquid and gas and the orientation of the pipe. The meter may be required to cope with many different flow patterns and often the exact distribution of the phases is unknown. The performance obtained in these cases is difficult to estimate but is usually many times worse than for single phase operation.

Often two or more liquids flow together and metering of the mixture is required. Where the liquids are miscible this does not present major problems. Where the liquids are immiscible, there is often a problem of homogeneity of the stream. The flow may exist as stratified or slug flow, with the actual flow pattern being dependent on the relative concentrations and the difference in density. As with gas/liquid flows the meter may be subjected to widely varying flow characteristics which are also dependent on the design of the installation.

2.4 Installation considerations

2.4.1 General

Installation requirements vary for the differing metering techniques. Some designs need long upstream straight lengths of pipe to ensure fully developed flow at the inlet to the meter (some group 1 and 4 meters for example) whereas others, notably group 3 meters are not influenced by the inlet pipework to the same extent. However some meters are specified without due consideration of the location of the meter in relation to flow direction, orientation, servicing and maintenance aspects or other parameters. Published data on flowmeter performance shows the strong influence of installation effects. Table 2.2 lists the various factors that need consideration under installation constraints. Table 2.5 gives data on installation requirements and indicates whether components such as filters or flow straighteners should be installed.

2.4.2 Pipework orientation

The orientation of the pipework can in some instances affect the choice of flowmeter. The performance of some meters may vary between horizontal and vertical installations. For example, severe effects may be noted in some downward vertical flows where loading on rotary components could lead to loss of linearity or poor repeatability. The orientation of most meters is specified by the manufacturer and these recommendations should be followed. Where the need to install the meter in other orientations is required further clarification should be sought from the supplier. The orientation may also be dependent on the nature of the flow. For example, settling of solid particles may occur in horizontal pipes, and therefore slurry metering is best performed in vertical lines.

Single phase flowmeters should be installed in horizontal lines wherever possible unless otherwise stated. This more closely approximates the installation in which the meter was probably calibrated. Some meters however are not affected significantly by orientation and Table 2.5 gives broad guidelines.

2.4.3 Flow direction

It is very important to note that some flowmeters operate in one direction only and incorrect installation could result in permanent damage. It is also important to identify the possibility of reverse flow existing in fault conditions. If so the installation may require non-return or check valves to safeguard the meter. The performance of those capable of bi-directional operation may vary between forward and reverse directions. Most flowmeters have the direction of flow clearly marked on the meter body. The manufacturers' calibration will apply only for use in this direction. Bi-directional meters should be calibrated in both directions.

2.4.4 Upstream and downstream pipework

Most flowmeters are affected to some degree by the inlet flow conditions and care should be taken to ensure good flow profiles. The design of pipework can introduce various types of flow disturbance, the most common being velocity profile distortion and swirl. Velocity profile distortion can be caused by an obstruction partially blocking the pipe, for example a valve, or by the influence of a bend. Swirl is commonly caused by two or more bends in different planes. These effects can be controlled either by ensuring an adequate straight length of pipe upstream of the meter or by installing a flow straightening device.

In badly designed installations, both effects will probably occur together and special flow conditioners will be required. It is not just the fitting immediately upstream of the meter that needs to be considered because combinations of fittings further up the line may in fact be the source of disturbances different to that produced by the nearest fitting. These effects can be reduced by introducing as long a distance as possible between the disturbance-producing components, rather than grouping them closely together, as often occurs. A very common example is a single bend downstream of a partly opened valve. It is also important to ensure that short unobstructed downstream straight lengths are also included to minimize flow effects at the outlet of the meter.

Cavitation and condensation are two more effects which can be caused by bad pipework. Such problems can be avoided by ensuring that no sudden large changes in pipework diameter or direction occur. Pipework configurations can also generate pulsations (see 2.4.12).

Table 2.5 — Selection by installation constraints

Group	Type	Orientation	Direction	Quoted range of upstream lengths	Quoted range of minimum downstream lengths	Filter	Pipe bore range
1	Orifice Venturi Nozzle	H, VU, VD, I H, VU, VD, I H, VU, VD, I	U, B U U	$5D/80D$ $0.5D/29.5D$ $5D/80D$	$2D/8D$ $4D$ $2D/8D$	N N	mm 6 to 2 600 > 6
2	Variable area Target Averaging pitot Sonic nozzle	VU H, VU, VD, I H, VU, VD, I H, VU, VD, I	U U U, B U	$0D$ $6D/20D$ $2D/25D$ > $5D$	$0D$ $3.5D/4.5D$ $2D/4D$ > $0D$	P N P N	2 to 600 12 to 100 > 25 ≥ 5
3	Sliding vane Oval gear Rotary piston Gas diaphragm Rotary gas	H, VU, VD, I H H, VU, VD, I H H, VU, VD, I	U U U U U, B	$0D$ $0D$ $0D$ $0D$ $0D/10D$	$0D$ $0D$ $0D$ $0D$ $0D/5D$	R R R N R	25 to 250 4 to 400 6 to 1 000 20 to 100 50 to 400
4	Turbine Pelton Mechanical meter Insertion turbine	H, VU, VD, I H, VU, VD, I H, VU, VD, I H, VU, VD, I	U, B U U U, B	$5D/20D$ $5D$ $3D/10D$ $10D/80D$	$3D/10D$ $5D$ $1D/5D$ $5D/10D$	P R R P	5 to 600 4 to 20 12 to 1 800 > 75
5	Vortex Swirlmeter Insertion vortex	H, VU, VD, I H, VU, VD, I H, VU, VD, I	U U U	$1D/40D$ $3D$ $20D$	$5D$ $1D$ $5D$	N N N	12 to 200 12 to 400 > 200
6	Electromagnetic Insertion electromagnetic	H, VU, VD, I H, VU, VD, I	U, B U, B	$0D/10D$ $25D$	$0D/5D$ $5D$	N N	2 to 3 000 > 100
7	Doppler Transit time	H, VU, VD, I H, VU, VD, I	U, B U, B	$10D$ $0D/50D$	$5D$ $2D/5D$	N N	> 25 > 4
8	Coriolis Twin rotor	H, VU, VD, I H, VU, VD, I	U U	$0D$ $20D$	$0D$ $5D$	N N	6 to 150 6 to 150
9	Anemometer Thermal mass	H, VU, VD, I H, VU, VD, I	U, B U	$10D/40D$ No data	No data No data	R R	> 25 2 to 300
10	Tracer Laser	H, VU, VD, I H, VU, VD, I	U, B U, B	# $0D$	# $0D$	N P	Unlimited
Key H is horizontal flow VU is upward vertical flow VD is downward vertical flow I is inclined flow # is mixing length U is uni-directional flow B is bi-directional flow R is recommended N is not necessary P is possible							

2.4.5 Line sizes

Very small or very large pipes often restrict the choice of flowmeter. Some flowmeters are not manufactured in a wide range of sizes and although one particular meter may match the users requirements, it may not be commercially available. Figure 2.4 gives the size ranges that are available for the 10 groups discussed and examples of the more common meter sizes within these groups is shown in Table 2.5.

Low velocities in large pipes or high velocities in small pipes can require a change of pipe diameter to produce a velocity which falls within the range of commercial flowmeters. Too low a velocity restricts the choice of meter and too high a velocity may cause damage through overspeeding or excess pressure drop.

2.4.6 Location for servicing

The importance of location for servicing is not always recognized. As a general rule all-round accessibility should be provided and the meter should be located to enable full replacement and servicing with the minimum of effort.

Some meters may be installed in environments which restrict servicing. These are usually hazardous areas, for example areas of high radiation. In these cases the choice of meter is influenced by the requirement for no servicing.

2.4.7 Local vibration

Some meters are susceptible to vibration and the design of proper pipework supports should be considered in all metering runs. Pulsation dampers may remove the effects of pumps and compressors but all instruments should be located well away from sources of vibration or pulsation. It is good practice to allow meter manufacturers to review the piping layout to advise on any modifications that may be required to minimize these effects.

2.4.8 Location of valves

Flowmeter lines generally have flow control valves and line isolation valves. The flow control valves should be located downstream of the meter to avoid any disturbance in flow profile or cavitation associated with the valves, affecting the meter. The valves, apart from controlling flow can also increase the back pressure on the meter. It is essential that the pressure in the meter is maintained significantly higher than the vapour pressure to avoid cavitation for certain types of meters, e.g. liquid turbines.

Upstream and downstream valves are frequently provided to isolate the meter for maintenance. The upstream valves should be full bore but even then should be located far enough upstream to avoid disturbance of the flow profile at the meter inlet. For custody transfer using multiple lines the downstream valves should be high integrity double block and bleed. A spare or by-pass line is often provided to permit flow when a meter is being maintained or calibrated.

2.4.9 Electrical connections

Most modern meter systems incorporate electronic equipment at or near the meter. It is important that the power source available is sufficient for the meter selected. When the level of the output signal generated by the meter is inadequate, preamplifiers, compatible with the application environment, should be used. All electrical connections should be protected against stray electrical interference (see 2.4.10). Manufacturers can advise on electrical connections and types of cabling required.

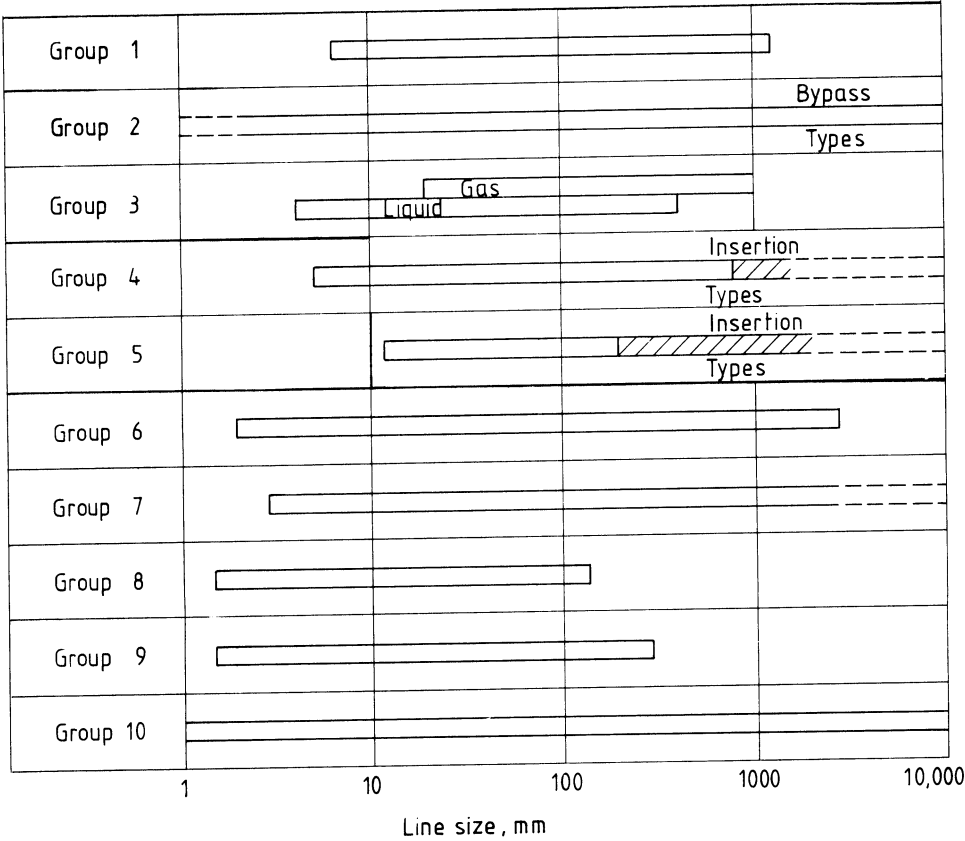
2.4.10 Electromagnetic interference

Output signals from some types of flowmeters are susceptible to the presence of large power sources. These power sources may produce surges in signal cables which are detected on the output pulses from the meter. They may also affect the electrical working of the meter, e.g. electromagnetic flowmeter field distortion. Signal cables should be routed well away from power cables and power sources to minimize the effects of electromagnetic interference (EMI) and radio frequency interference (RFI) effects.

2.4.11 Provision of accessories

Some metering installations may require additional equipment to guarantee satisfactory operation of the meter. For example, positive displacement (group 3) and turbine meters (group 4) generally require some form of filtration upstream of the meter.

Some applications may also require additional instrumentation to complete the measurement required. For example mass flow applications may use conventional volume flowmeters with temperature and pressure instrumentation. Alternatively pressure and temperature measurements may be required for compensation purposes, (see section 5).



NOTE The shaded areas represent the overlapping range of insertion and full bore meters.

Figure 2.4 — Size distribution of flowmeter groups

Other equipment could include gas detectors to provide a warning if the meter is not running full of liquid or trace heating to prevent freezing of the line fluid or to control condensation. More exotic pieces of equipment could include lightning arrestors or battery back-up systems.

2.4.12 Pulsations and unsteady flow

Pulsating flows should be avoided wherever possible since the majority of flowmeters over register in these applications. Common causes are the presence of displacement pumps, reciprocating compressors, oscillating valves or regulators, or hydraulic oscillations such as vortex shedding. If the presence of pulsations is suspected, the amplitude and frequency should be measured by a fast response device such as a hot-wire anemometer probe. This will determine whether the need for high response should be listed along with the other performance parameters before the start of the selection procedure. It is well known that differential pressure meters of all types are subject to pulsation errors as discussed in 4.1.5.4, but it is less well known that turbine and vortex meters, for example, may give rise to over-registration errors just as serious as those incurred by orifice meters. It is also necessary to appreciate that there may be separate pulsation effects on the primary and secondary devices. Pulsation effects can be minimized by the installation of dampers as indicated in 4.1.5.4. Unsteady flow is a less serious form of pulsation which may arise from, for example, the operation of oversized control valves. High frequency response flowmeters can usually tolerate low levels of flow unsteadiness.

2.5 Environmental considerations

2.5.1 General

The ambient conditions and possible variations in these conditions expected around the flowmeter should be considered in the selection procedure. Table 2.2 and Table 2.6 list the relevant factors.

2.5.2 Ambient temperature

The electronics and in some cases the meters can be affected by temperature change. The flowmeter may experience dimensional changes whilst affected components in the secondary electronics may lower its performance. Density or viscosity changes of the fluid may also occur due to heat transfer through the meter body. It is sometimes possible to locate the meter and readout devices in different places to protect the electronics from the effects of temperature. The use of environmentally controlled housings may be necessary in certain instances.

Thermal insulation of the pipework is required where ambient temperature changes affect the properties of the flow. When total uncertainty of flow measurement is being calculated, ambient effects can be one significant source of uncertainty. In addition, materials of construction of the meter and associated pipework need careful assessment when large variations of ambient and process temperatures occur.

2.5.3 Humidity

High humidity can accelerate atmospheric and electrolytic corrosion and can lower electrical insulation. Low humidity can induce static electricity. Problems arising from humidity can be caused by rapid ambient or process temperature changes. The user should know the range of expected variations and check that this does not lead to problems in operation, taking into account the meter being used.

2.5.4 Safety

In applications with hazardous environments, flowmeters should be selected with regard to atmospheric compatibility, electrical area classification and other safety regulations or standards that may apply. Details of the zone classifications and of equipment necessary to ensure safe operation of systems in hazardous areas are given in 5.5.7 (see BS 5501).

Chemically aggressive atmospheres can result in external corrosion of the meter or can affect the electronic readouts if not mounted remotely. Special enclosures should be considered in these cases and where flammable vapours or flammable dust particles are present. Large electrical energy sources should not be used in these environments. Waterproof enclosures for the meter and electronics may be required in many process applications. Often complete installations are hosed down during routine cleaning and the instrumentation has to be protected to ensure safe operation.

2.5.5 Electrical interference

Power cables, electric motors and process switchgear all produce EMI which may cause sources of error (see 2.4.10).

2.6 Economic considerations

2.6.1 General

When looking at the full cost of metering several factors should be examined and not simply the purchase price. Table 2.2 includes a list of the economic variables to be considered, and Table 2.7 indicates the relative costs of the more important of these. These should be used with caution since the various designs within each group vary considerably in all the aspects listed. Discussions on specific economic considerations can be found in Baker (1986).

2.6.2 Purchase price

The purchase price for various liquid flowmeters, flowrates and pipe sizes is shown in a) and b) of Figure 2.5. These plot price against throughput, but with meter bore as an additional variable. At 250 m³/h for example, these figures show that a 200 mm orifice run, a 150 mm vortex meter or a 100 mm electromagnetic meter could be used. Thus the full costs of the complete installation can be more directly compared. Each data point is an average of prices from different suppliers. Figure 2.5 should be used for a relative indication only. The actual purchase price will depend on many variables such as pressure ratings, materials of construction, etc. Therefore a wide variation can be placed on each data point shown.

Table 2.6 — Selection by environmental constraints

Group	Type	Temperature effect ^a	Intrinsically safe version	Water and explosion proof version	EMI or RFI effect ^a
1	Orifice	4	#	#	1/2
	Venturi	3	#	#	1/2
	Nozzle	3	#	#	1/2
2	Variable area	3	A	A	1
	Target	3	NA	A	3
	Averaging pitot	3	#	#	2
	Sonic nozzle	3	A	NA	1/2
3	Sliding vane	4	A	A	1/3
	Oval gear	4	A	A	1/3
	Rotary piston	4	A	A	1/3
	Gas diaphragm	4	A	NA	1/3
	Rotary gas	4	A	NA	1/3
4	Turbine	3	A	A	4
	Pelton	3	A	A	4
	Mechanical meter	3	A	A	1
	Insertion turbine	3	A	A	4
5	Vortex	2	A	A	4
	Swirlmeter	2	A	A	3
	Insertion vortex	1	A	N	3
6	Electromagnetic	1	A	A	3
	Insertion electromagnetic	1	A	N	3
7	Doppler	3/4	A	A	4
	Transit time	3/4	NA	A	4
8	Coriolis	1	A	A/NA	4
	Twin rotor	2	No data	No data	4
9	Anemometer	3	NA	NA	2
	Thermal mass	4	A	A	2
10	Tracer	1	N	N	1
	Laser	1	NA	NA	4
Key N is not necessary A is available NA is not available # is dependent on differential pressure measurement ^a 1 is low 5 is high					

2.6.3 Installation costs

Some metering methods require attention to flow conditioning and the provision of long inlet lengths to ensure good performance. Correct installation could require extra pipework or the provision of by-pass lines for routine maintenance and checking. An orifice plate plus differential pressure (DP) cell is relatively inexpensive but when correctly installed in a full metering run with the appropriate plate fittings, the full cost is many times the cost of the basic element. Other cost factors could include the need to purchase shut-off valves, filters or other ancillary equipment to complete the run. These all contribute to the complete installation costs, but are seldom considered in economic aspects of selection.

2.6.4 Calibration costs

Calibration costs generally increase in proportion to the level of performance required. For low uncertainty calibrations, certified test facilities are needed, and these may be expensive to build or hire. Calibration costs listed in Table 2.7 indicate this fact. The frequency of calibration affects the overall costs. Some meters require periodic recalibration while others need to be checked infrequently. Other types of meters require only visual inspection and dimensional checking (group 1 for example), and flow testing may not be required, provided the meters are designed and used in accordance with the appropriate standards. Again the required level of performance is important when examining calibration costs. The supplier can advise on the required frequency of calibration and the cost for specific applications.

2.6.5 Operation costs

Operation costs are mainly associated with the energy required to operate the meter system chosen. They may include the costs of power to drive the electronics within the system, (which is very low in most modern meters), as well as the pumping costs of actually driving the fluid through the meter. This means that meter headloss is important since in most cases this is not recoverable. Insertion meters, for example, offer considerable savings in costs over full bore meters in large pipes, because they offer much lower blockage ratios. Their performance however is not as good as that of the full bore meter and the selection may become a trade-off between these factors. Each application should be examined to determine whether savings can be made if different metering techniques meet all other criteria.

2.6.6 Maintenance costs

Maintenance costs are the expenses of keeping a flowmetering system functioning, once it has been installed and commissioned and has two major components, parts and labour. Meters with moving parts generally require more maintenance. Examples may be the periodic replacement of bearings, rotors, shafts or transmission gears that experience wear with time. However, meters with no moving parts may also require frequent attention, a common example being the checking of orifice plate edges.

2.6.7 Spares cost and availability

The cost of spares generally increases with the complexity of the meter and with those meters capable of good performance. Spare parts for meters manufactured abroad may cost more than locally produced instruments, and spares availability may also be more of a problem. The figures given in the last column of Table 2.7 can vary significantly depending on the source and design of the meter. Advice from several suppliers of the same type should be sought if spares cost and availability is important.

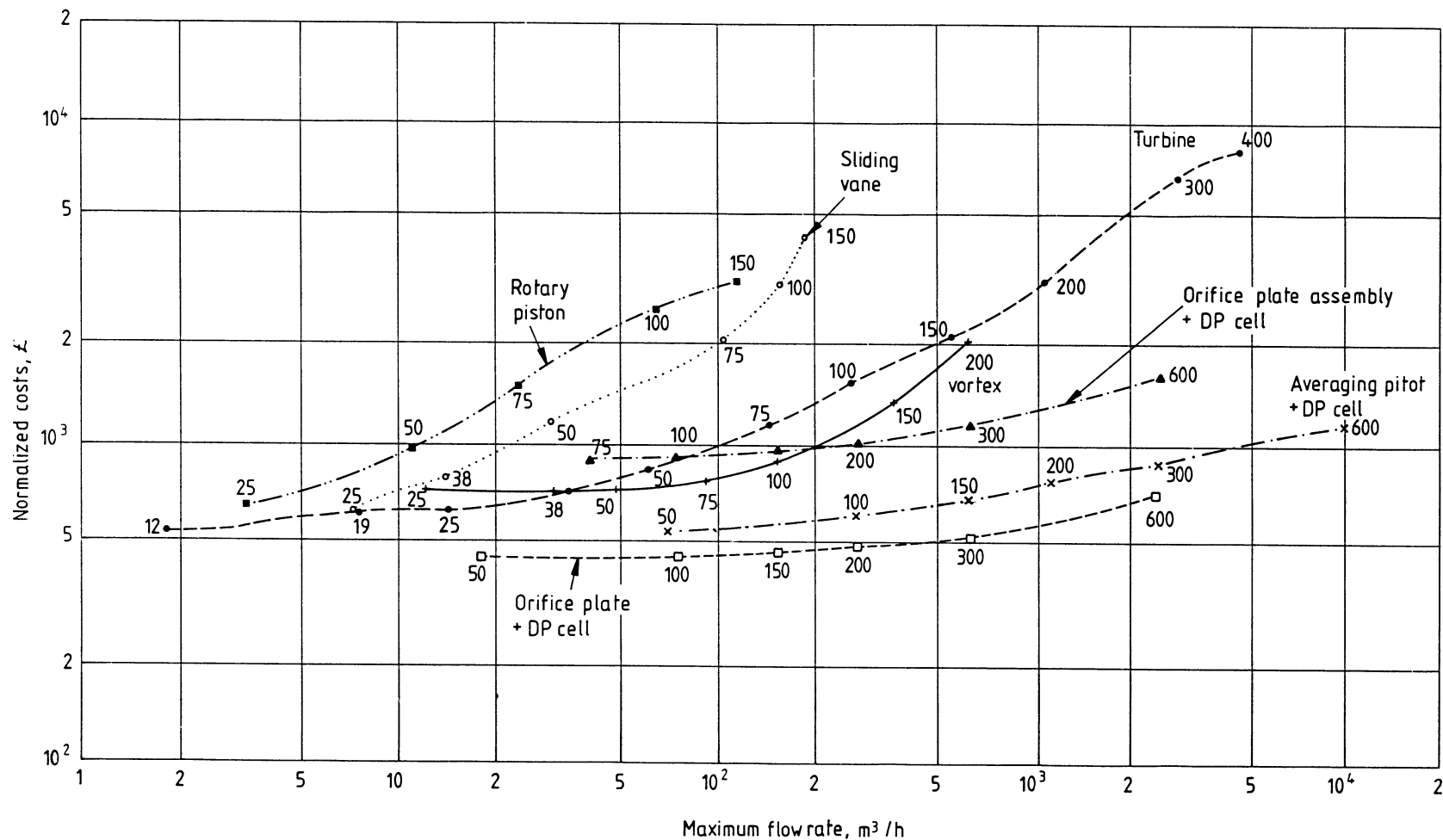
2.7 Examples of flowmeter selection

2.7.1 General

This section of the guide illustrates the use of the various data tables and figures. The examples will illustrate the important considerations and judgements to be made in selecting applicable techniques.

Table 2.7 — Selection by economic factors

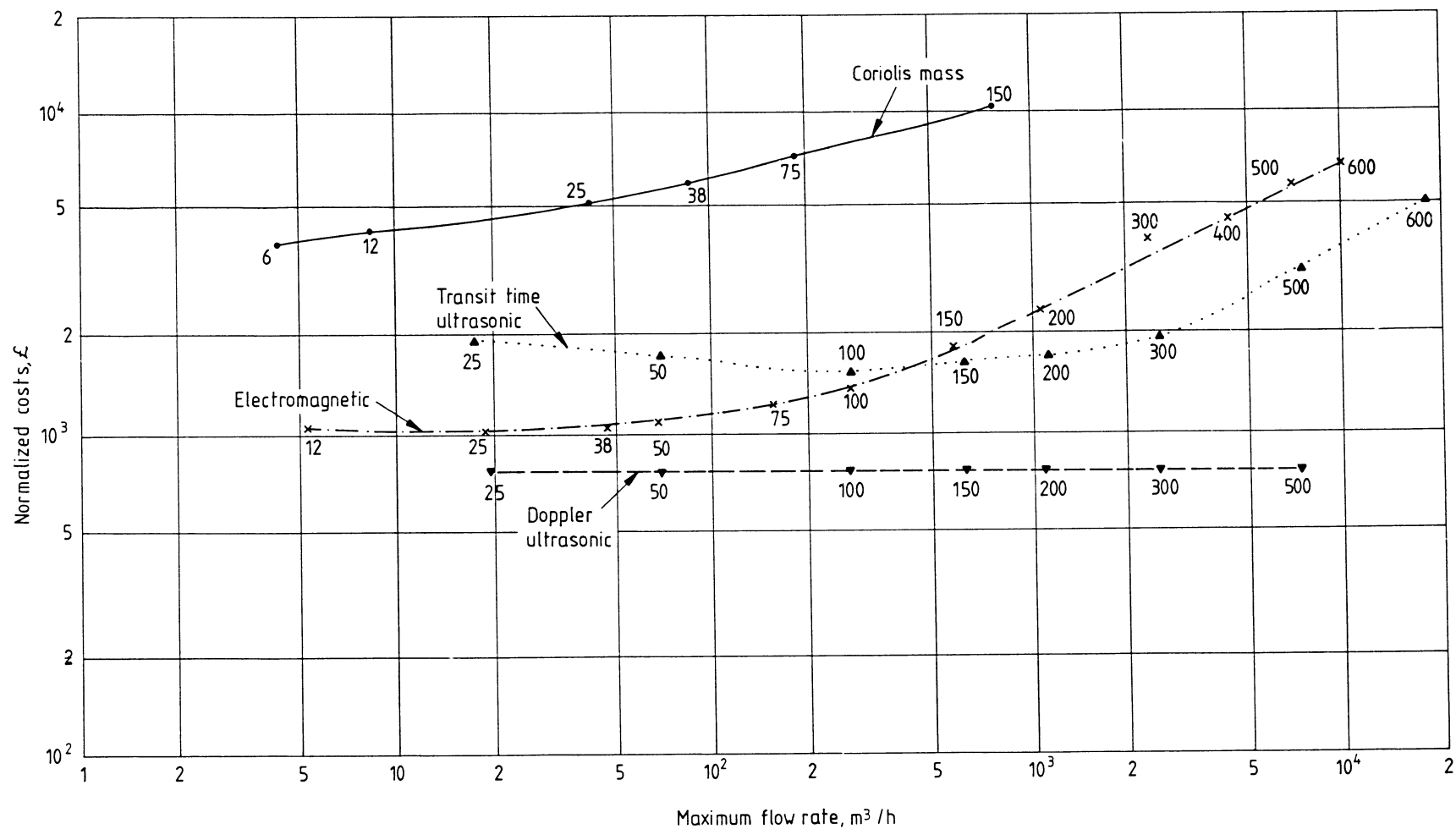
Group	Type	Installation costs	Calibration costs	Operation costs	Maintenance costs	Spares costs
1	Orifice	2/4	1	3	2	1
	Venturi	4	1/4	2	3	3
	Nozzle	3	3	2	3	2
2	VA	1/3	2	2	1	1
	Target	3	3	2	3	3
	Averaging pitot	2	3	2	2	2
	Sonic nozzle	2	1	3/4	2	1
3	Sliding vane	3	5	4	4	5
	Oval gear	3	4	4	4	5
	Rotary piston	3	3	3	3	4
	Gas diaphragm	3	3	1	2	2
	Rotary gas	3	4	3	3	3
4	Turbine	3	4	3	4	4
	Pelton	4	3	3	4	3
	Mechanical meter	3	2	2	3	3
	Insertion turbine	2	3	2	2	3
5	Vortex	3	3	3	3	3
	Swirlmeter	3	4	3	3	3
	Insertion vortex	2	3	2	3	3
6	Electromagnetic	3	3	1	3	3
	Insertion electromagnetic	2	3	2	3	2
7	Doppler	1/3	1	1	3	2
	Transit time	1/3	3	1	3	2
8	Coriolis	3	4	4	3	3
	Twin rotor	3	3	3	3	3
9	Anemometer	3	2	1	3	3
	Thermal mass	3	4	2	4	3
10	Tracer	2	—	4	2	4
	Laser	5	—	4	5	5
Key 1 is low 5 is high NOTE For purchase price see (a) and (b) of Figure 2.6.						



NOTE Numbers on data points indicate pipe size in millimetres.

(a)

Figure 2.5 — Flowmeter purchase price comparison (liquids)



NOTE Numbers on data points indicate pipe size in millimetres.

(b)

Figure 2.5 — Flowmeter purchase price comparison (liquids) (concluded)

2.7.2 Example 1

The following outline specification of requirements was supplied by the process engineer of a chemical plant:

Application:	batch acid production
Line size:	25 mm
Fluid:	hydrochloric acid
Operating pressure:	3 bar
Operating temperature:	25 °C to 35 °C
Uncertainty required:	1 % actual flow rate
Flow rate:	3.5 m ³ /h
Output signal:	to interface with process computer
Pipework constraints:	3D upstream, 3D downstream, pipe horizontal
Capital spend:	not critical

First step. Examine Table 2.1 to determine applicable groups of meters and Table 2.1 to confirm that all the applicable parameters are considered in the specification. Application S in Table 2.1 is the required duty.

Applicable groups: groups 1, 2, 3, 4, 6, 7, 8 and 10.

Second step. Examine Table 2.3 and Figure 2.3 to determine groups meeting the performance specification.

Applicable remaining groups: groups 1, 3, 4, 6, 7 and 8.

Third step. Examine Table 2.4 to investigate possible limitations of fluid properties, particularly Reynolds number, (calculating it if not already known), on remaining groups.

Temperature variation is small, pressure is low, all remaining groups from step two are still applicable.

Applicable remaining groups: groups 1, 3, 4, 6, 7 and 8.

Fourth step. Examine Table 2.5 to determine which types of flowmeter within the applicable remaining groups are suitable for the pipework constraints applying to this application.

Examination of Table 2.5 shows that only a limited selection of types of flowmeter are suitable from within the applicable groups. Thus, in group 1, only a Venturi meter is possible; in group 3, all except the gas meters are possible; in group 4, only a mechanical meter might be possible; in group 6, only an electromagnetic meter might be possible; in group 7, only a transit time meter might be possible, and in group 8, only a coriolis meter is possible.

Fifth step. Examine Table 2.6 for environmental constraints; this does not eliminate further groups, but indicates that groups 6 and 8 are less sensitive to temperature and all have similar response to EMI and RFI. The possible ranking is then:

1st choices groups 6 and 8, 2nd choice group 3.

Sixth step. Examine (a) and (b) of Figure 2.5 for indication of purchase price and Table 2.7 for economic factors to be considered.

Purchase costs indicate the following ranking:

1st: group 6; 2nd, group 3 and 3rd group 8.

Table 2.7 indicates installation and calibration costs are all comparable, group 6 has the lowest maintenance and spares costs.

Conclusion. Steps four, five and six indicate that group 6 (electromagnetic) is the first choice, with group 3 (positive displacement) second on economic factors, group 8 (coriolis meter) as a third option.

If research covering that particular installation has not been done or it suggests that the electromagnetic meter should not be located at 3D from the installation, a positive displacement meter would be suitable, with a coriolis meter as a possible option.

The final choice will be made after reading the relevant text in **3.3**, **3.6**, and **3.8** for technology limitations and **4.3**, **4.6** and **4.8** for application constraints.

Once the meter has been selected, any limitations of the chosen meter should be compared in detail with the requirements of the original specification. If the differences are significant, the selection procedure should be repeated after reviewing the original specification.

This application was relatively well defined and shows the importance of collecting as much process data as possible. The ranking of possible meters has been eased by the process engineer looking at the location of the required meter and the performance needed to meet production criteria.

2.7.3 Example 2

The discharge of steam from a plant boiler requires monitoring for billing purposes. Because this involves financial aspects, the Company accountant has decreed that metering to $\pm 0.5\%$ of reading is required. The plant engineer drew up the process specification as follows:

Application:	plant steam billing
Line size:	0.3 m
Fluid:	superheated steam
Operating pressure:	40 bar approx. (600 psi)
Operating temperature:	300 °C
Uncertainty required:	0.5 % actual flow rate
Flowrate:	4 kg/s to 45 kg/s
Output signal:	pulse preferred for totalization
Pipework constraints:	not specified
Capital budget:	very limited

First step. Examine Table 2.1 to determine applicable groups. Application N in this table is the required duty.

Applicable groups. Groups 1, 4(?), 5 and 10.

Second step. Examine Figure 2.3 to determine groups meeting the performance specification.

Applicable remaining groups: groups 4(?) and 5.

Third step. Examine Table 2.4 to investigate possible limitations of fluid properties on remaining groups.

Temperature and pressure variations are not specified, but both line pressure and temperature are high.

Applicable remaining groups: groups 4(?) and 5.

Fourth step. As pipework installation constraints are not specified no further elimination is made.

However, examination of Figure 2.4 shows that group 5 meters (fluid oscillatory) are not available in the required line size unless an insertion type is used.

Fifth step. The choice of meters is now limited to two groups; reference to **3.4**, **3.5**, **4.4** and **4.5** shows that only insertion types are available. These sections also indicate that other factors such as installation, headloss, reduced rangeability need further consideration. Furthermore, insertion meters have a performance outside the required specification. This means that the required performance specification has to be relaxed.

Conclusion. No meter is applicable to meet the requirements of the specification. Re-evaluation of actual needs plus complete re-specification is required before selection can be made. All the factors given in Table 2.2 now become an essential check list before selection can be undertaken properly.

Section 3. Flow measurement techniques

3.0 Introduction

3.0.1 General

This section of the guide looks at the basic principles of operation of the flowmeters covered. The aim is to emphasize the essential features of the design and construction of the more common types of meter within the 10 groups discussed. Theory has been kept to a minimum so that the limited space available can be used to summarize the essential features of the various flowmeters. Not all the commercially available flowmeters are described, because there are many adaptations and variations available.

Some indication of typical performance for each meter is given, but this should not be taken as an indication of installed performance. The limitations on application and the possible resulting change in behaviour can be found in section 4 of the guide and the reader is encouraged to study both section 3 and 4 for full details of the flowmeter of interest.

As no flowmeter can satisfy all flowmeter requirements, advantages and disadvantages of each type are given. These should be used along with the comprehensive list of factors given in section 2 to decide if the meter offers the characteristics to meet the application. Some indication of materials of construction are given as some types of flowmeter can be made from a wide range of materials. In some instances this can affect both the performance (in terms of possible flow range and/or pressure drop) and the application.

3.0.2 Layout

The section looks in turn at each of the eleven major types of flowmeter. Wherever possible illustrations have been used to support the text and to enable the reader to appreciate the design and construction of flowmeters. The clause numbers have been designated to match the group number, so for instance **3.6** indicates that group 6 meters (electromagnetic) are being discussed.

3.1 Group 1 meters: orifices, venturis and nozzles

3.1.1 General

Orifice, venturi and nozzle meters are some of the most common flowmeters currently in use. The vast majority of these are square edged orifice plates but the basic theory applies to all types in this group. For many years these meters were the only way of measuring flow with reasonable performance, good reliability and at a moderate cost. The principle of operation is based on the use of a restriction in the flow. The resulting pressure drop across the restriction is used as a measure of flow rate.

3.1.2 Differential pressure meter theory

The complex flow distribution through an orifice plate is shown in (a) of Figure 3.1.1 and will be used to discuss the general performance of this class of meter. The diameter of the restriction is $d = \beta D$. The fluid continues to converge downstream of the restriction to a minimum flow area of $c \frac{\pi}{4} d^2$.

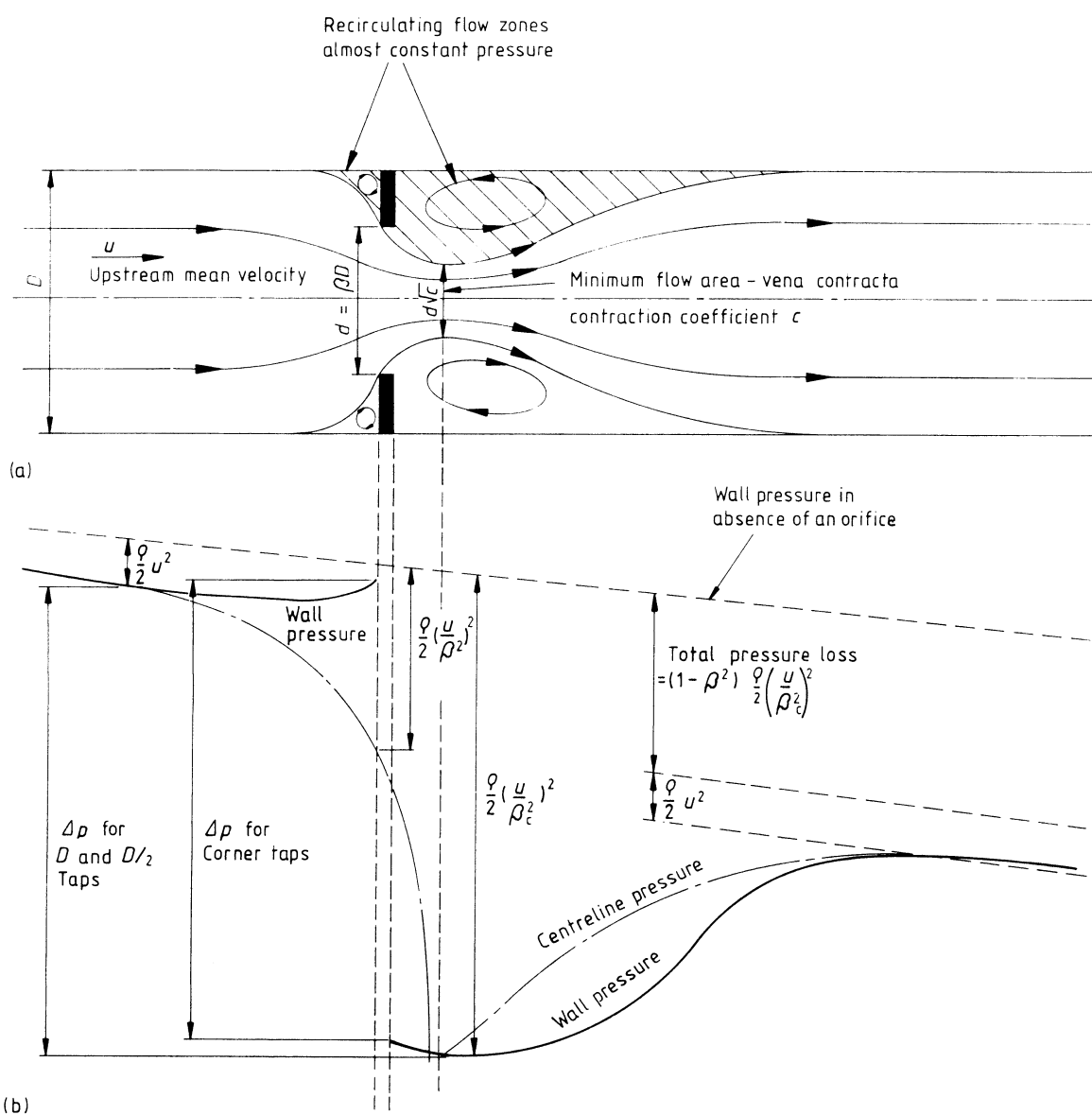


Figure 3.1.1 — Pressure profile and flow pattern through an orifice meter

The acceleration of the fluid up to the maximum velocity gives a reduction in pressure according to Bernoulli's energy equation. As the fluid diverges further downstream, losses become significant and Bernoulli's equation no longer applies. Immediately upstream and downstream of the plate, there are zones of slowly recirculating fluid. Within these the pressure variations are relatively very small. The pressure variation along the centre line of the flow and along the pipe wall are shown in (b) of Figure 3.1.1. If Δp is the pressure drop measured at the wall on either side of the plate,

$$\Delta p \approx \frac{\rho}{2} \left(\frac{u}{\beta^2 c} \right)^2$$

or

$$q_m = \frac{\pi}{4} D^2 \rho u \approx c \frac{\pi}{4} d^2 (2\rho \Delta p)^{1/2} \quad (3.1.1)$$

where

c is the contraction coefficient

The discharge coefficient, C , is defined by the following:

$$q_m = C \frac{\pi}{4} d^2 \left(\frac{2\rho \Delta p}{1 - \beta^4} \right)^{1/2} \quad (3.1.2)$$

Comparing these equations shows that, if $\beta < 1$, $C \approx c$. The actual value of C will depend on the type of meter, the precise location of the pressure tapings, the value of β , the Reynolds number, and the detailed flow distribution in the upstream section of the pipe. C has been obtained empirically and is found to be about 0.6 for orifice plates and slightly less than 1 for venturis and nozzles. Values of C for orifice plates, nozzles and venturi tubes are given in BS 1042-1.1.

It should be noted that the measured Δp is proportional to the square of the flow rate. If, for instance, a flow rate of 1/10 of maximum is to be measured, the pressure drop will only be 1/100 of maximum. To maintain accuracy at low flow rates, the instrument used to measure differential pressure has to retain a sufficiently high accuracy at the bottom of the required range. Alternatively, the meter range should be divided and separate measuring instruments used for each subdivision. This is fundamental to all differential pressure meters.

The theory outlined so far has been for an incompressible fluid. When a gas or vapour is being metered, an adjustment is necessary to allow for a change in density through the contraction. The fluid density changes as a result of both velocity and pressure changes, and compressibility effects are therefore extremely important. Deriving the basic equation from first principles results in the following expression:

$$q_m = C \frac{\pi}{4} d^2 \epsilon \left[\frac{2\rho_1 \Delta p}{(1 - \beta^4)} \right]^{1/2} \quad (3.1.3)$$

The interesting feature of this expression is the similarity with equation 3.1.2. The only difference between liquids and gases is the inclusion of an expansion factor ϵ . The density used in this equation is the upstream value ρ_1 . For nozzles and venturis the assumption of an isentropic expansion is reasonable and the value of ϵ can be calculated in accordance with 9.1.6.3 of BS 1042-1.1:1992.

There are restrictions given in BS 1042 for the applicability of the equation used for such a calculation. Test data exists for air, steam and natural gas only. In the case of orifice plates, the expansion involves turbulent shear flow and does not conform to the isentropic assumption, particularly for small β ratios or large pressure differentials. Instead an empirical relationship for ϵ is used:

$$\epsilon = 1 - (0.41 + 0.35 \beta^4) \frac{\Delta p}{K p_1} \quad (3.1.4)$$

Some values of ϵ have been tabulated in BS 1042-1.1 and Miller (1982). Provided the ratio of the plate and the actual operating pressure differential are known, the value of ϵ can be used directly from the tables. The expansion factor calculation can also be based on the downstream pressure and temperature conditions. Tables exist for ϵ_2 (downstream) values as well as ϵ_1 (upstream) in the references cited. For mixtures of gases it is usual to use upstream conditions.

3.1.3 Orifice plates

3.1.3.1 Basic design and construction

The flowmeter in most common use throughout the world is the square-edged concentric orifice. Its design specifications have been standardized and are fully described in such documents as BS 1042-1.1 and BS 1042-1.2. Figure 3.1.2 shows a common type of industrial installation, where the orifice plate is clamped between pipe flanges. The most important features of the design are as follows.

- The sharp, square upstream edge. The discharge coefficient is highly dependent on the edge profile. The edge radius should not be greater than $0.0004 d$ and should be inspected regularly to check that it has not become eroded, corroded or otherwise damaged during use.
- A cylindrical throat concentric with the pipe bore. The axial length of the throat is specified in the standards and must be sufficiently short for re-attachment of the fluid jet formed at the throat inlet edge to be impossible. Eccentricity of the orifice can result in significant changes in discharge coefficient especially if single tapings are used.
- A flat upstream face and plate thickness sufficient to withstand buckling.

d) When bevelled plates are used the tabulated coefficients are for flow with the sharp edge facing upstream. If reverse flow should occur or the plate is installed the wrong way round, the indicated flow will be about 20 % below the true flow.

Other possible sources of error are buckling, edge effects and flow profile effects.

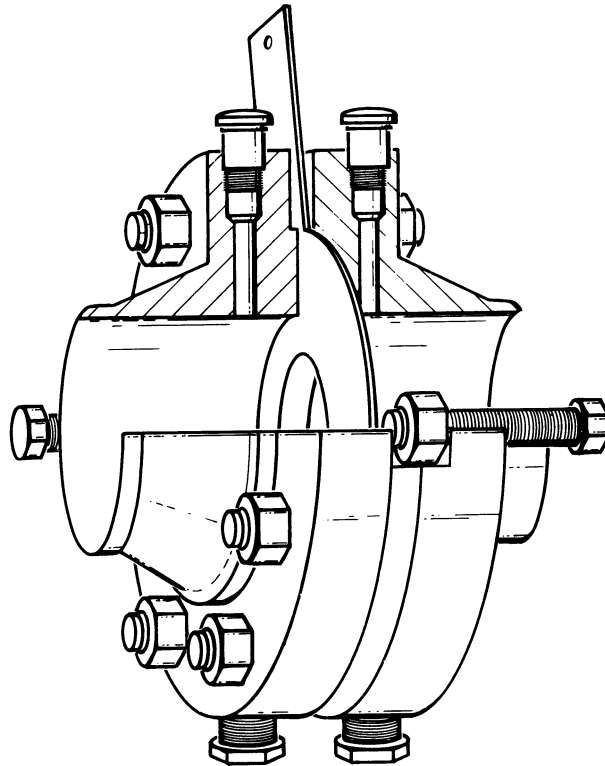


Figure 3.1.2 — Typical orifice plate installation

3.1.3.2 Pressure tapings

The three types of pressure tapings covered by BS 1042 are the corner, flange and D and $D/2$ types shown in Figure 3.1.3. Some are welded to the pipe and then drilled while others are prefabricated during construction. Any can be used provided the relevant standards are followed. There are no general universally accepted rules for selecting one type of tapping in preference to another but current practice tends to suggest that flange tapings are the most popular.

3.1.3.3 Vent holes

Some orifice plates may be specified with vent or drain holes for various applications. The vent hole permits any gas present in a liquid at the top of the pipe to pass through the plate. Similarly, drain holes permit any condensate present to pass through the plate. The diameter of the vent/drain hole and its discharge coefficient may be used to correct the orifice bore, see BS 1042-1.2. Where these holes are specified it is important to remember that they are liable to blocking which can affect performance. This is particularly common in gas lines with condensate present. The plate will act as a dam and uncertainty of measurement will increase significantly.

3.1.3.4 Performance

The coefficient data for square-edged orifices is expressed in BS 1042-1.1 and BS 1042-1.2 in terms of a complicated empirical expression known as the Stoltz equation. The equation contains terms to allow for the dependence of the discharge coefficient on diameter ratio, Reynolds number and tapping position. The obvious advantage of an equation compared with tabulated coefficient data, is that it facilitates the use of a computer for flow rate and orifice design calculations.

The uncertainty in the basic data used to derive the Stoltz equation is around 0.6 %. When uncertainties in the expansibility factor, the measurement of orifice and pipe diameters and the measurement of differential pressure and density are taken into account together with variations in ambient and process conditions, it is unlikely that overall uncertainties much better than about 1 % full scale deflection will be achieved. A figure of about 2 % full scale deflection would be typical even when the installation complies with the requirements of the appropriate standard. This typical level of metering uncertainty is not generally appreciated. The uncertainty in the discharge coefficient may be reduced by calibration especially if the complete meter run (the meter plus the immediate up and downstream pipe work) can be tested in the calibration flow rig.

When the secondary instrumentation includes a flow computer the inherent non-linearity of the orifice tends to restrict the range but it is not a major problem. If the accurate range of a differential pressure cell is 10 then the meter range will be $\sqrt{10}$. The range can be extended by using two or more DP cells in parallel, or by the use of the new smart DP transmitter (see 5.1.6).

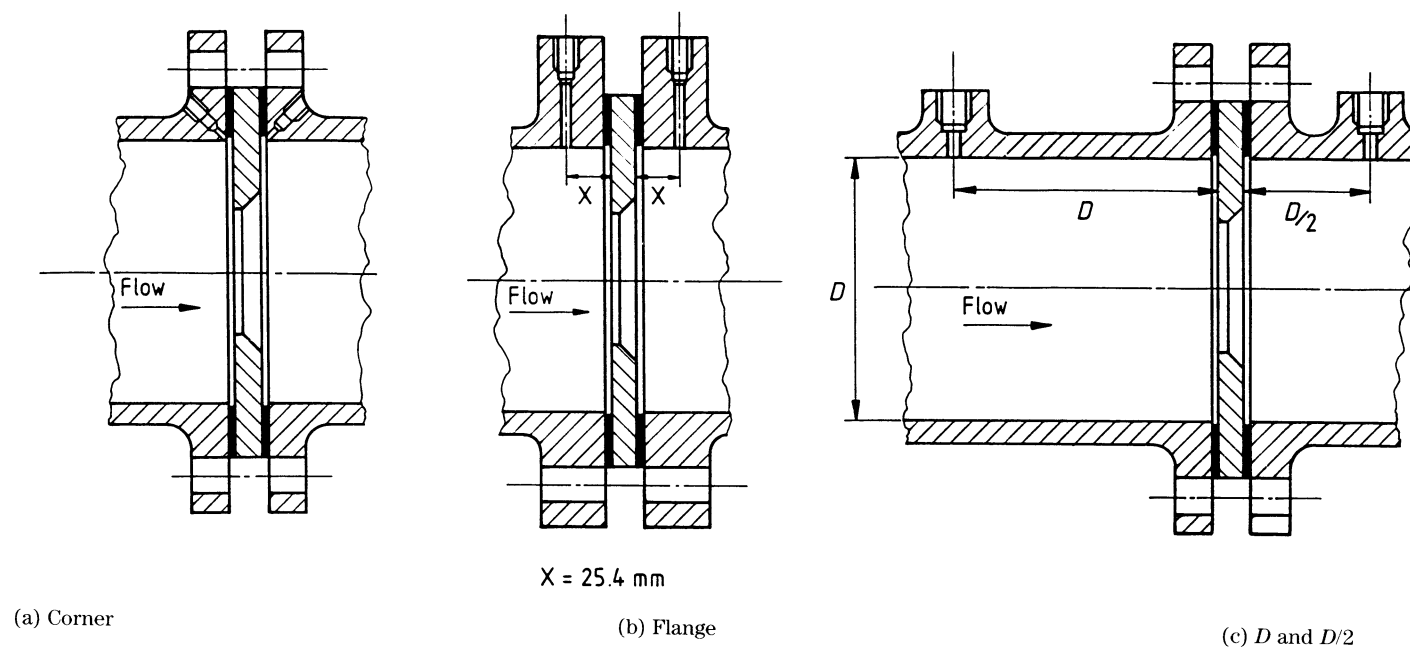


Figure 3.1.3 — Corner, flange and D and $\frac{D}{2}$ tap orifice designs

3.1.3.5 Advantages and disadvantages

The advantages of the orifice meter are as follows.

- a) a robust and simple primary device;
- b) low manufacturing cost;
- c) easy to install;
- d) well established type of meter and enjoys universal confidence;
- e) no need for calibration for standard installations;
- f) can be used on liquids and gases, including steam.

The disadvantages of the orifice meter are as follows:

- 1) only 3 : 1 typical flow range;
- 2) erosion and damage to the upstream face or edge change calibration;
- 3) affected by upstream disturbances particularly for a large β ratio;
- 4) significant pressure loss increasing as area ratio decreases.

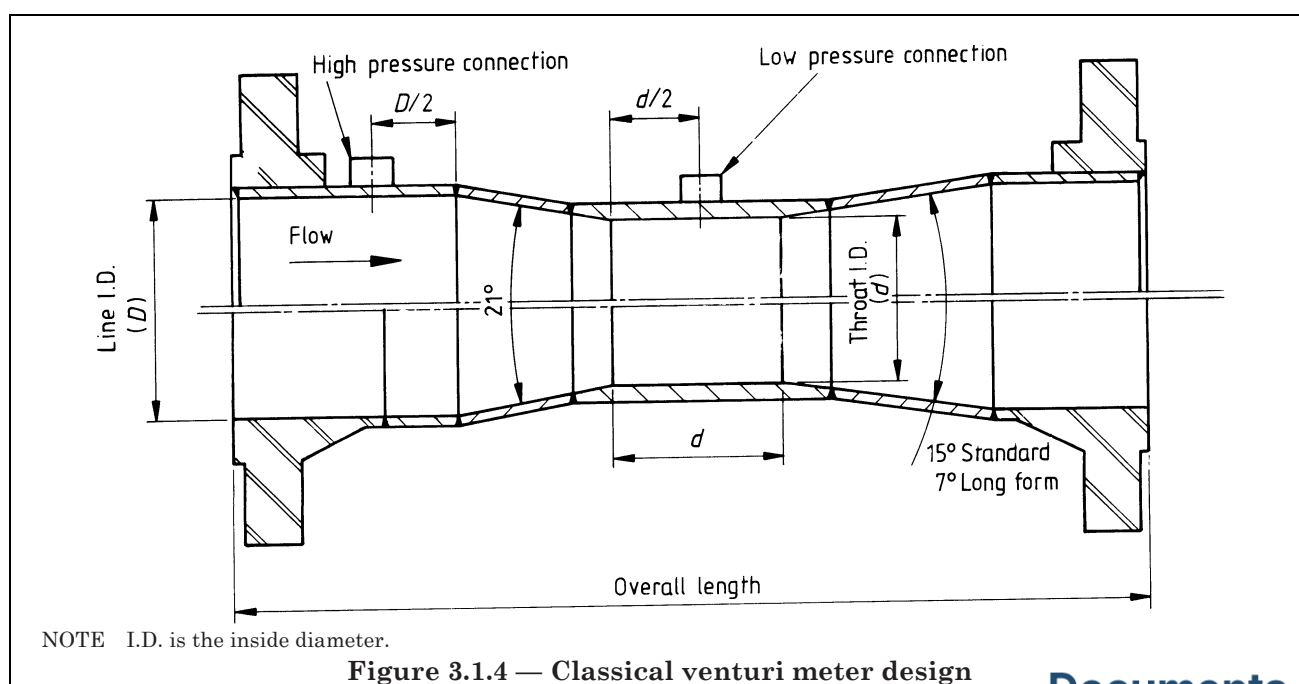
3.1.4 Venturi tubes

3.1.4.1 Basic design and construction

The classical venturi tube, shown in Figure 3.1.4, is a design standardized in BS 1042-1.1. There is a gradual change in section between the pipe diameter and the cylindrical throat. The differential pressure is measured between tapings in the entrance and the throat. The tolerance on the upstream tapping location, together with the blending radii between the conical and cylindrical sections, are specified in the standards for three different types of venturi, depending on the method of manufacture. These types are as follows:

- a) classical venturi tube with a rough cast convergent section;
- b) classical venturi tube with a machined convergent section;
- c) classical venturi tube with a rough welded sheet-iron convergent section.

At both upstream and downstream locations there should be at least four equi-spaced tappings linked together. The main function of the divergent section is to decelerate the flow with maximum pressure recovery. However, it is possible to truncate the length of this section by up to 35 % without affecting the pressure recovery significantly. The overall pressure loss of the venturi tube depends on such factors as the throat/inlet diameter ratio, Reynolds number, divergent angle, surface finish, installation alignment, etc., and is generally between 5 % and 20 % of the measured differential pressure.



3.1.4.2 Performance

The discharge coefficients of venturi tubes are independent of diameter ratio and Reynolds number for the Reynolds number range 2×10^5 to 2×10^6 . When manufactured and installed in accordance with the appropriate standards, the coefficient data for uncalibrated venturi tubes have uncertainties of:

- 0.7 % for tubes with rough case convergent sections
- 1.0 % for tubes with machined convergent sections
- 1.5 % for tubes with rough welded sheet-iron convergent sections

As with the orifice meter, these uncertainties can be reduced by flow calibration. The overall uncertainty in the flow measurement must allow for uncertainties in the expansibility, the throat and pipe diameters, the differential pressure and density measurements. Compared with the orifice the slightly greater uncertainty in the venturi discharge coefficient can be set against a smaller uncertainty in the venturi expansibility factor. The total measurement uncertainty achievable in liquid applications is around 2 % full scale and, in the comparatively rare applications in gases, around 3 % full scale.

3.1.4.3 Advantages and disadvantages

The advantages of the venturi tube compared with an orifice plate are as follows:

- a) more robust than the orifice plate and less susceptible to particulate flows;
- b) lower overall pressure loss than an orifice plate for the same differential pressure;
- c) less sensitive to distorted velocity profiles and swirling flow, requiring shorter upstream straight lengths of pipe.

The disadvantages of the venturi tube compared with the orifice plate are as follows:

- 1) more expensive to manufacture;
- 2) occupies more space in the line, perhaps eight pipe diameters in length;
- 3) the larger sizes are more difficult to handle;
- 4) more susceptible to errors due to burrs or deposits round the throat tapping.

3.1.5 Nozzles

3.1.5.1 Basic designs and construction

There are two designs of nozzles in general use and both are standardized and described in BS 1042-1.1. These are the ISA 1932 nozzle and the long radius or ASME nozzle and are shown in Figure 3.1.5 and Figure 3.1.6 respectively. The ISA 1932 design is most commonly used in Europe whereas the ASME design is favoured in the USA. Both designs are intended for mounting between pipe flanges with the pressure tapings located in the pipe wall. Corner tapings are used for the ISA 1932 nozzle and D and $D/2$ tapings are specified for the long radius nozzle. The ISA 1932 nozzle profile is part of an ellipse.

The advantage in using a nozzle with throat taps is that a diffuser cone can be fitted to the downstream end to reduce pressure losses. This is done on a design known as a venturi nozzle standardized in BS 1042 and illustrated in Figure 3.1.7. The profile of the contraction in this device is that of the ISA 1932 nozzle.

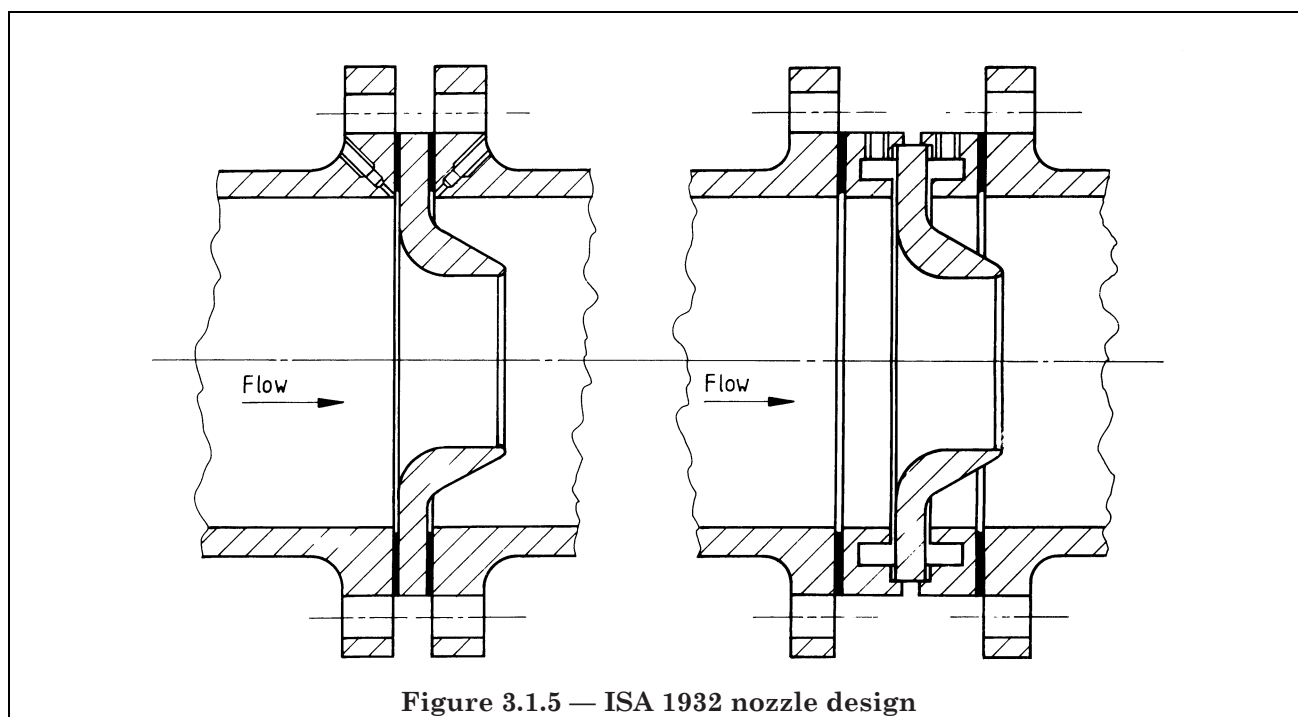


Figure 3.1.5 — ISA 1932 nozzle design

3.1.5.2 Performance

The discharge coefficients of all the standard nozzles and venturi nozzles range between about 0.9 and 0.99 and depend on β ratio and Reynolds number. The uncertainty in the coefficient data varies both with the nozzle design and β ratio. BS 1042-1.1 gives the following typical values:

0.8 % for ISA 1932 nozzles ($\beta \approx 0.6$)

2 % for long radius nozzles ($0.2 \approx \beta \approx 0.6$)

Further data can be found in the relevant clauses of BS 1042-1.1. When combined with the other factors which contribute to total uncertainty an overall performance figure of around 3 % full scale at best is realized. This can be reduced significantly by flow calibration at operating conditions.

3.1.5.3 Advantages and disadvantages

The advantages of nozzles compared with orifice plates are as follows:

- a) no sharp edge to erode;
- b) better retention of calibration for long periods.

The disadvantage of flow nozzles compared with orifice plates are as follows:

- 1) they are more expensive to manufacture;
- 2) they are more difficult to install and remove from the pipe;
- 3) throat tap type nozzles are more susceptible to errors due to burrs or deposits round the throat tapping.

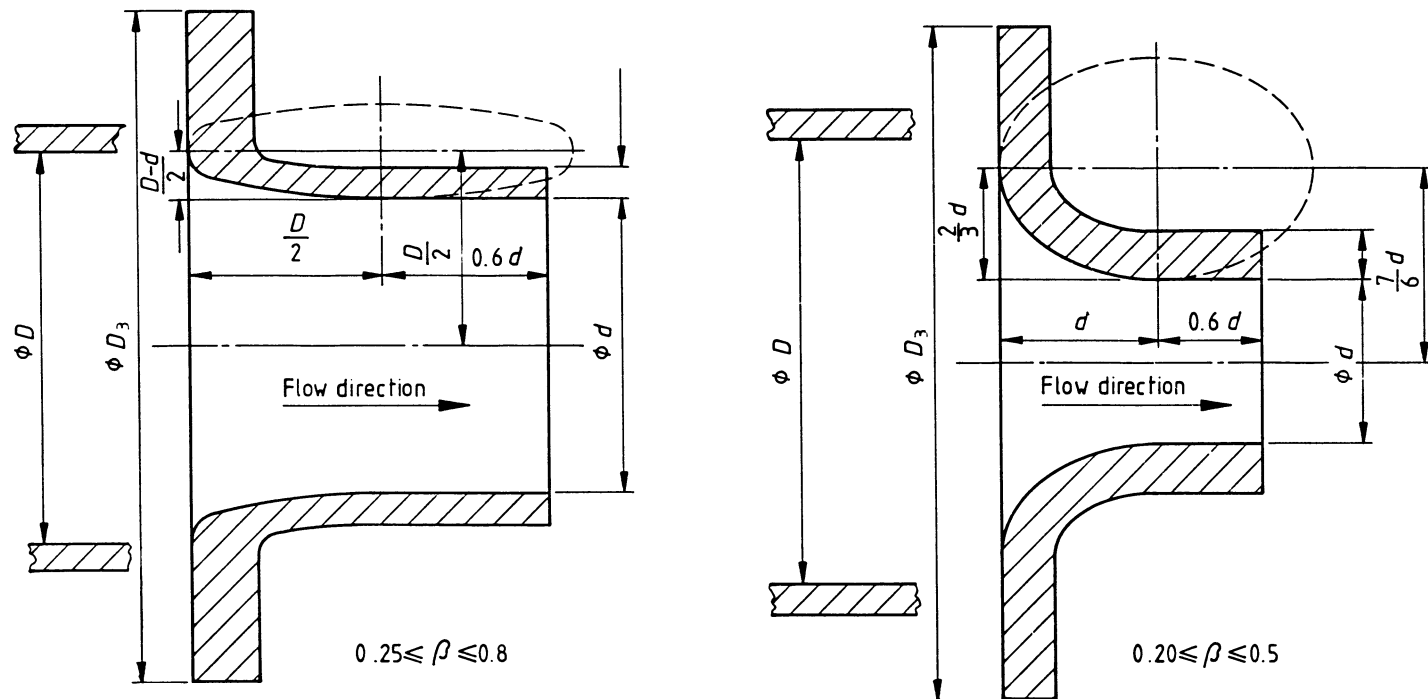


Figure 3.1.6 — Long radius flow nozzles