FLOW METER GUIDE BOOK FOR INDUSTRY

VERSION 3.9

BY

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FOR

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Energy Solutions Center NOTICE

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OUR GOAL

The Energy Solutions Center, Inc. and our Industrial Energy Efficiency Consortium – a group of member companies – (collectively referred to as "ESC") engaged Bob Griffin, P. Eng., Industrial Energy Consultant, to develop a guide book to provide information and advice on the selection, installation, and cost of the major types of flow meters. For a facility to effectively reduce energy consumption (and thereby cost) it is very important to correctly select and use meters for monitoring the flow of process fluids such as natural gas, water, steam, compressed air, low pressure ducted air and combustion exhaust gases. In contracting with Bob Griffin to produce A Guide to Flow-Meters and Energy Management for Industrial Plants ("the Guide"), it is our goal to produce a Guide that will help our members work with their customers to select the correct flow meters for their energy management system thus enabling and enhancing their ability to analyze their data and take action to reduce energy consumption, thereby reducing cost and enhancing their corporate image.

OUR DISCLAIMER

ESC, the Consortium, the individual companies of the Consortium, and Bob Griffin ("Disclaiming Parties") shall not be responsible, collectively and/or individually, for errors or omissions in the Guide. Neither shall Disclaiming Parties be held liable for any claims or damages relating to the use of the Guide. None of the results, publications, outputs, or representations of the Guide, individually or collectively, in whatever form or format, shall constitute a recommendation, endorsement, approval, or guaranty of any product or service. All of the information generated is provided "as is" without warranty of any kind. Disclaiming Parties make no representations of any kind and disclaim all express, implied, statutory, or other warranties of any kind to the user and/or any other party, including, without limitation, any warranties of accuracy, timeliness, completeness, efficacy, merchantability, and fitness for any particular purpose. Disclaiming Parties shall have no tort, contract, or any other liability to users of the Guide and/or to any other party. Disclaiming Parties shall not be liable to users and/or any other party for any lost profits, lost opportunities, or any indirect, special, consequential, incidental, or punitive damages whatsoever, even if Disclaiming Parties have been advised of the possibility of such damages.

USER'S RESPONSIBILITY

If a specific meter is identified by the Guide, we specifically recommend that the end user seek advice from a qualified engineer, process analyst, or other appropriate professional before proceeding. Similarly, the user should understand that the lack of any specific finding by the Guide is not a guaranty that there is no meter available that might prove helpful to the facility. By using the Guide, the user acknowledges having read and agreed to the disclaimer above and to acknowledge their responsibility as discussed here.

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ABBREVIATIONS AND FLOW TERMS

% Accuracy AR = percent accuracy as read.
% Accuracy FS = percent accuracy at Full Scale.
% Repeatability = reliability of meter in repeating the same reading at a known flow rate.
CFH, Cubic feet per hour, **CFM**, Cubic feet per minute
BTU, British Thermal Unit
Beta Ratio, $\beta =$ the Ratio of the pipe diam. to the Orifice diam.
Cd, Discharge coefficient.
ρ = Density
D, Diameter, **I.D**., Inside Diameter, **O.D.,** Outside Diameter
DP, Differential Pressure (See Sec. 1.1)
Hz, Hertz (Cycles per second)
I.D., Inside pipe diameter
ISO, International Standards Organization
kHz, Kilo-Hertz (Thousand cycles per second)
m.a., Milli-amp
MW, Mega-watt
O.D.,Outside pipe diameter
P = Pressure, ΔP = Pressure differential
Pressure Inches of Water (w.c.) (1 inch w.c. = 0.0361 PSI)
PPL, Permanent pressure loss
PSIA, Pounds per square inch absolute pressure
PSIG, Pounds per square inch gage pressure
Qv, Flow Volume, **Qm** Mass Flow
Re, Reynolds Number (See Appendix A3)
RTD, Resistance temperature detector
T = Temperature
V = Flow Velocity
®, Registered Trademark

EDUCATIONAL WEBSITES

www.spitzerandboyes.com/downloads/ go to "Overheads"
www.flowresearch.com
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx
www.engineeringtoolbox.com
https://educationcenter.emersonprocess.com
www.tuvnel.com
www.omega.com/literature/transactions
www.asgmt.com (American School of Gas Measurement Technology)

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PURPOSE AND USE OF THE FLOW METER GUIDE BOOK

The **Energy Solutions Center** www.energysolutionscenter.org, has chosen to offer to its members, a guide book on the subject of flow meters and energy management. This book provides information and advice on the selection, installation and cost of 20 major flow meters. These meters are suitable for monitoring the flow of natural gas, water, steam, compressed air, low pressure ducted air, contaminated gases, slurrys, sludges and exhaust gases.

The purpose of the Flow Meter Guide Book is to guide the user in selecting a flow meter for his specific application, based on performance, technical specifications and cost criteria. Twenty different meters in three main categories have been chosen for comparison. The main attributes of each meter, advantages, disadvantages and approximate costs, are tabulated in a standard format for easy comparison. **Selection Tables (page 12 through 16)** gives the user a quick way to narrow down the choices based on his application.

Why Should an Industrial Plant, Commercial Building or Institution Install Flow Meters?

1. **Cost Reduction.** Industrial plants wishing to reduce costs must manage these costs. Flow meters are the key to understanding and managing the use of fuel, water, compressed air, steam and other utilities. Flow meters allow organizations to understand their costs on a daily basis and to take action to reduce the cost when required.
2. **Environmental Benefits.** The environmental benefit which comes with energy reduction is important socially, and helps to enhance the corporation's image.

Who Should Use the Guide Book?

1. The guide book is intended for use by **non-experts** in the field of flow meters.
2. **Plant operations personnel** including managers, engineers, supervisors, and anyone who has the task of selecting or purchasing a flow meter.
3. **Engineering Consultants.**
4. **Account Representatives** for Natural Gas Utilities.
5. **Contractors** who have the task of installing flow meters.
6. **Anyone who wishes to understand the basics of this subject.**

FLOW METER SPECIFICATIONS

Manufacturers of flow meters provide **physical and performance specifications** for their meters. Manufacturers sell flow meters through distributors and representatives who also give advice pertaining to their products. In general, the most import performance specifications for a flow meter are: the fluid to be metered, cost, pipe size, flow range, accuracy, repeatability, turndown ratio, permanent pressure loss (PPL), length of straight pipe required for installation.
Another very important factor is whether **correction of the meter reading** is required when fluid pressure or temperature varies from the nominal condition for which the meter has been calibrated.

The meter buyers must be careful to understand: 1.) the requirements of the application and 2.) the basis of performance specifications quoted.

1.) Purpose of Flow Meters:

Flow meter readings can be used for a number of purposes including:

- Utilities use meters for Custody Transfer and Billing. (eg. buying natural gas for your house or gasoline at the pump). The gas and oil industry uses meters to transfer ownership of the fluid from one company to another.
- Process Control. Metering a process or piece of equipment (eg. a boiler) in order to control it directly or indirectly. (Eg fuel to air ratio). Metering ingredients to the final product or metering production.
- Energy Management.

Typically, **energy management** does not require a level of accuracy as high as custody transfer or process applications. Energy Management does require good repeatability. Meter accuracy including the transmitter for energy management should be a minimum of 2.0 % **(AR)** or 0.5% **(FS)** with 0.25% repeatability.
By comparison meters used for **custody transfer** must meet specific standards, usually from AGA , API or other standards agency. Meters featured in this guide, meeting custody transfer standards are identified in **Table 3 of the Selection Tables.**

2.) Basis of Performance Specification

There are many reasons why a meter may deviate from specified performance.
For example, a manufacturer's data sheet for a "calibrated" orifice plate meter may specify an accuracy of **+/- 0.5% AR.** The same meter may show an accuracy of **+/- 2.0% to +/- 4.0% AR** when installed in a real application. The lower real accuracy is due to a range of real-world factors such as **installation variations, improper density correction, and poor meter maintenance.**

A question to ask before purchasing a meter is **what are the conditions for which it is designed, calibrated and specified?** Are these the conditions for which the meter operate? If not, the accuracy and repeatability of the meter may not be as expected.

FLOW METER SPECIFICATIONS

The flow meter buyer should become familiar with some of the terminology pertaining to performance and specifications. **See page 11** for a list common specifications.
One example of how misunderstandings about performance occur is around accuracy. **Accuracy** may mean the accuracy of the flow element only or the accuracy of flow element together with the transmitter. Accuracy could also mean accuracy at Actual Reading **(AR)** or at Full Scale **(FS).** These four different combinations of accuracy.
Performance data shown in sections 1.1, 1.2 and 1.3 is typical for each type of meter, not specific to a manufacturer or model. It is the seller's responsibility to specify conditions which apply to any given set of performance specifications. (eg. **The fluid is natural gas, the flow rate** is 10,000 to 20,000 CFH. Required accuracy **is +/- 0.5 % (FS)** at standard conditions **60 ^{O}F and 14.7 PSIA operating within the specified turndown ratio of 4:1**.

In most applications, there is more than one acceptable technical choice for a flow-meter. Furthermore, there are often variations of design within a specific type of meter which cause differences in performance. An example of this is the **conditioning orifice plate** which requires only **2 diameters** of straight pipe length up-stream compared with the standard orifice plate which may require **40 pipe diameters**. Another example is the **Multivariable Transmitter** which improves accuracy and turndown and is an option for most types of meters.

Initial Calibration
New Meters are calibrated by the manufacturer using one of two methods: (1) comparison to a master meter which has been calibrated by the U.S. National Institute of Standards and Technology **(NIST)** or (2.) by weighing the actual mass of fluid metered by an NIST approved scale for a period of time and comparing this to the meter mass flow reading.

For standard, off the shelf flow-meters, the normal practice of manufacturers is to calibrate a sample of flow-meters of a specific size, type and design but not all of those meters manufactured. Meters are calibrated for a specific set of conditions: pressure, Reynolds Number, etc. In reality, meters may operate outside these conditions. You can purchase a meter which is calibrated on request. This may cost extra.
In addition to meeting **NIST** standards, most U.S. meter manufacturers are certified to **ISO 9000** quality assurance standards and maintain the dimensions and other aspects of production for the flow elements and flanges.

Conclusion: It is the purchaser's responsibility to carefully specify the operating conditions. Selection of the meter is usually done by a process involving one or more potential suppliers. If the buyer is knowledgeable, he is equipped to ask the right questions and to make a good decision.

FLOW METER COSTS/PRICES

In the following **selection tables**, and in **Section 1**, **Flow Meter Description and Performance** which follow, you will see an estimate of the **cost** of each of the 20 different types of meters which are represented in the guide book. This is the price for an Industrial Grade flow meter of size 2 inch D to 8 inch or larger. You can find, by shopping on the internet, many cheaper meters which may be OK for your application, but they may not be suitable for use in your industrial application where a certain level of accuracy and meter life span are expected.

Furthermore, price may depend on numerous variations in the design of a specific meter and on options which are available. It's like buying a car.

Example-Cost Estimate for a Flowmeter: A high quality, flange mounted averaging **pitot tube** differential pressure meter available from an on-line distributor offering technical advice.

	Incl. in Base List Price USD	Extras at List Price	
1.) Basic Flow Element w/	$ 3,529 USD		
4 – 20 ma Transmitter	incl.		
Pipe line size 2 inch	incl.	Line size 3 inch	+ $ 262
Liquid or Gas metering	incl	Steam metering	+ $ 173
2.) Compression Mounting	incl.	Flange Mount	+ $ 477
3.) Material Carbon Steel	incl.	316 Stainless	+ $ 79
4.) No Temperature Sensor	incl.	integral RTD	+ $ 578
5.) Diff. Pressure (DP) range	0-250 "	low PPL loss	+ $ 335
6.) 4 to 20 ma xmitter communication		Profibus Digital	+ $ 143
Additional Options			
7.) Isolation Valve	None	Isolation Valve (ea.)	+ $ 467
8.) LCD Operator's display	None	LCD Display	+ $ 448
9.) 2 Yr Warranty	Incl.	5 Year warranty	+ $ 332
Total Basic meter	$ 3529	Total Extras and Options	$ 3,294

Total Meter Cost incl. Extras $ 6,823 USD excluding installation

The table above compares the base price of one flow meter with the extra cost for all of its possible options and extras. Every case and type of meter is different but it shows that in estimating a meter installation the buyer would be wise to understand exactly what is required. Furthermore does not include installation or start-up. **See Section 3, Installation and Maintenance.**

FLOW METER SELECTION TABLES
TERMINOLOGY OF FLOW METER SPECIFICATIONS AND PERFORMANCE

Section 1 of the guide includes a table like the one below for each of the 20 meters.

Application: **Typical Applications for this type of flow meter are described.**

1. Pipe diameter range: ¾ inch to 12 inch. ***Nominal Diameter not equal to inside diam.***

2. Accuracy : 1% to 3% ***Actual Reading (AR) specifies the lowest accuracy over the the whole flow range. Full scale (FS) specifies accuracy at the top of the flow range. The meter has lower accuracy at lower flow readings. See comments on Accuracy and Repeatability in Appendix A9.***

3. Repeatability: 0.25% ***this attribute is independent of accuracy. A meter may have an error of 5%, but be capable of producing the same erroneous reading within 0.25%, 95% of the time at the same flow rate.***

4. Turndown Ratio: 4 to 1. ***If the meter is sized for say a maximum flow of 1,000 Lb/Hr of steam, it will not give an accurate reading if the flow is below 250 Lb/Hr.***

5. Permanent Pressure Loss at maximum flow (PPL): eg. 60% of differential Pressure (DP) ***The meter causes a permanent drop in fluid pressure equal to 60% of the pressure differential across the meter. Additionally, PPL causes an energy loss.***

6. Length of straight pipe required: 30 D upstream, 5 D downstream. ***30 D means 30 pipe diameters. The straight length depends on the nature of the upstream disturbance and the fluid being metered. It also varies with the fluid being metered. The figure stated is conservative. (See Appendix A8)***

7. Operating temperature maximum: 500 °F. ***Fluid temperature. This specification applies to the primary element but not to the electronic transmitter.***

8.Reynolds number (Re) minimum: 20,000 If ***the Re is below this figure, the meter will not give accurate readings.***

9.Density compensation required: Yes. ***All meters except coriolis and thermal mass flow meters require density correction to give a correct mass flow reading if density of the fluid varies. (See Appendix A-4 for a discussion of pressure and temperature correction) Meters which have Multivariable Transmitters can calculate the corrected flow on-board and display the true mass flow.***

10.Approximate flow-meter cost estimate including transmitter: $ 4,000 to $6,500. ***Quotation required! The sample given includes a basic meter with a basic 4 to 20 ma transmitter. Supplier prices, quantity and options cause significant price variations.***

11.Cost of installation estimate: $ 3,500. ***This is rough estimate. Every project is different. In general, the cost represents the installation of a new meter and transmitter into an existing pipe. Installation of a new meter includes initial start-up and calibration. Wiring and electrical work are also required and included.***

FLOW METER SELECTION TABLES

Flow Meter Selection – Basic Questionnaire

The following questionnaire can be used by the purchaser as a starting point to asking for price quotes on a flow meter.
Most manufacturers have questionnaires of their own and can supply you with one.

1.) What fluid do you wish to meter? _

2.) Liquid, Gas or Two-phase flow? _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ **note:** 2-phase flow means that the primary fluid you are metering also carries along with it a secondary fluid eg. Steam with water.

3.) Is the fluid clean or dirty or corrosive? _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

4.) What is the minimum and maximum temperature at the flow meter? Give a Temp. Range.
_ _ _ _ _ _ _ _ _ _ _ _ _ _Min. To _ _ _ _ _ _ _ _ _ _ _ _ _ _Max. Temp. Units _ _ _ _ ^{O}F or ^{O}C

5.) What is the minimum and maximum pressure at the flow meter? Give a Pressure Range.
_ _ _ _ _ _ _ _ _ _ _ _ _Min. _ _ _ _ _ _ _ _ _ _ _ _ _ _Max. _ _ _ _ _ _ _ _ _ PSIG,

6.) What is approximate flow rate _ _ _ _ _ _ _ _Min. _ _ _ _ _ _ _ _ Max.
Enter Flow Units _ _ _ _ _ _ _ _ LB/Hr, CU Ft/Hr, KG/Hr, CU M/Hr. Other, state units

7.) What is the pipe size? Nominal. _ _ _ _ _ _ _ _ _ inches. I.D., _ _ _ _ _ _ _ _ _ inches

O.D., _ _ _ _ _ _ _ _ _ _ _ _ _ inches, Pipe Schedule _ _ _ _ _ _ _ _ _ _ eg. 40 ST

8.) What will the meter be used for? **(A)** Energy Management **(B)** Process control **(C)** Custody Transfer or **(D)** Other (state). Enter **A, B, C or D** _ _ _ _ _ _ _ _ _ _ _ _ _ _ _

9.) What is the required % accuracy over the operating range? _ _ _ _ _ _ _ _ + or - X%

10.) What is the total length of straight pipe available for installation? _ _ _ _ _ _inches
(Measure the distance from the meter location to the nearest upstream flow disturbance).

11.) What is the nature of the upstream disturbance? Enter A,B,C,D or E _ _ _ _ _ _ _ _ _ _ _
(A) Single elbow (B) double elbow (C) valve (D) pressure regulator or (E) other (state).

12.) Will the meter be mounted vertically, horizontally or other? _ _ _ _ _ _ _ _ _ _

13.) Is there any pipe vibration? _ _ _ _ _ _ _ _ _ _

14.) How will the flow data be displayed? **(A)** Local display on meter only **(B)** Chart recorder **(C)** communication to computer **(D)** other. Enter one or more of **A,B,C** and **D**. _ _ _ _ _ _ _ _ _ _

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FLOW METER SELECTION TABLES

DETAILED DESCRIPTIONS AND PERFORMANCE DATA FOR ALL FLOW METERS LISTED IN THE FOLLOWING TABLES IS PROVIDED IN <u>SECTIONS 1.1, 1.2 AND 1.3.</u>

How to Use the Selection Tables.
The selection tables in this section should be considered as a guide only. Typical performance for **each meter listed** in these tables can be found in the next **sections 1.1, 1.2, and 1.3.** The ratings given refer to the technical performance of the meter, compared to others. Meter cost is considered in **Table 4.**

General Recommendations
1. Fill out the flow meter selection checklist on **page 10.** Similar forms are supplied by most meter manufacturers.
2. Speak to several experienced meter suppliers about the application.

Step 1. Go to Table 1 – <u>Select the Fluid You Wish to Meter</u>
1. Select the fluid you wish to meter.
2. Table 1 may give you several possible meter choices for your application.

Step 2. Go to Table 2 -
1. This is where the purchaser must understand the specific requirements and physical details for installation of the meter. <u>Fill out the form **"Flow Meter Selection-Questionnaire**</u> on **page 12.**
2. **Go to Sections 1.1, 1.2 and 1.3** of the guidebook. **<u>Look up each meter which you selected in Step 1</u>** Compare the meter's performance with your requirements.
3. Narrow down the list until you have one or two or three acceptable choices.

Step 3. Go to Table 3- Evaluate Your Meter Selection from Step 2 according to it Main Advantages.
This table presents an assessment of your selection by its strong points including ease of installation and maintenance.

Step 4 Go to Table 4 – Estimate the Cost of Your Meter Selection
1. This gives an indication of cost for the meter and for installation. Note: the cost given is based on the purchase and installation of a single meter. This is a basic cost and can vary with quantity, special features or material.
2. Go to meter distributors and suppliers for a firm quotation.

Step 5. Request Quotes from Suppliers and Purchase a meter.

Rating System

☆ This means that the meter is probably a very good choice.
○ This meter may be the best choice when a specific attribute is important .
Blank Box = Not recommended or poor performance for this attribute.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

FLOW METER SELECTION TABLE 1

STEP 1 – SELECT THE FLUID YOU WISH TO METER, MAKE ONE OR MORE CHOICES

Type of Meter Refer to Meter section number	Natural Gas	Hot or cold Water	Steam	Compressed Air	Slurries, Waste Water	Air or Gas in large stack or duct	Other
DIFFERENTIAL PRESSURE 1.1	**Most DP Flow Meters can be upgraded from a.) a standard transmitter to b.) A Multivariable Transmitter. This improves flow meter performance. SEE SEC. 1.4, TRANSMITTERS**						
1.1.1 (a) Orifice (b) with MV transmitter	(a.) ○ (b.) ☆	○ ○	○ ☆	 ○			
1.1.2 Flow Nozzle	○	○	○		○		
1.1.3 Venturi Tube	☆	☆	☆	○	◊	◊	
1.1.4 Simple Pitot tube	○	○				◊	
1.1.5 Averaging Pitot Tube	○	○	○	○		◊ ☆	
1.1.6 Wedge		○			☆		
1.1.7 V-Cone	☆	○	○	○	◊		
1.1.8 VA Float meter- Rotameter		○					
1.1.9 TVA, Target Meter	Saturated or super-heated steam only		☆				**Incl. M.V. transmitter**
MECHANICAL 1.2							
1.2.1 Rotary Lobe	☆	☆					See sec. 1.2.1
1.2.2 Utility Turbine	☆	☆					See sec. 1.2.2
1.2.3 Industrial Turbine-in-line	○	○					See sec. 1.2.3
1.2.4 Insertion Turbine	○	○	○	○		◊	See Sec. 1.2.4
1.2.5 Diaphragm Meter	☆						
ELECTRONIC 1.3							
1.3.1 Vortex Shedding	☆	○	○	☆			
1.3.2 Electro-Magnetic		☆			☆ ◊		See sec. 1.3.2
1.3.3 Thermal Mass Flow	☆			☆		○ ◊ **Max temp.200F**	
1.3.4 Ultra-sonic Transit	☆	☆			◊		See fig.1.40
1.3.5 Ultra-sonic Doppler		○			◊		
1.3.6 Coriolis Mass Flow	☆	☆					Other liquids Eg. oil

☆ = probably a good choice, check application. ○= may be a good choice, check application
BLANK BOX = not recommended or poor performance for the specific attribute.
Unless stated otherwise, attributes for Meters are based on Standard Transmitter not Multivariable.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

FLOW METER SELECTION TABLE 2

STEP 2–COMPARE PERFORMANCE FOR YOUR SELECTION WITH YOUR REQUIREMENT

	Pipe Diameter Range (Inches)	Percent Accuracy (FS or AR)	Repeat-Ability %	Turn-down Range	Straight Length of Pipe in No. of Diameters	Permanent Pressure Loss
DIFFERENTIAL PRESSURE	**Most DP Flow Meters can be upgraded from a.) a standard transmitter to b.) A Multivariable Transmitter. This improves flow meter performance. SEE SEC. 1.4, TRANSMITTERS**					
1.1.1 (a) Orifice	2 inch to 48 inch. or larger **a.)**	2% to 4%FS	0.25%	4 to 1	40 D upstream	High
(b) With MV transmitter	**b.)**	**1% FS**	**0.10%**	**8 to 1**	**5 D upstream**	**High**
1.1.2 Flow Nozzle	2 inch to 48 inch +	2% FS	0.25%	4 to 1	15 D upstream 7D downstream	Medium
1.1.3 Venturi Meter	2 inch to 180 inch.	2% AR 0.5% FS	0.1%	10 to 1 to 100:1	5 D upstream 0 D downstream	Very Low
1.1.4 Simple Pitot tube	4 inch to 72 inch.	1.5% to 3% FS	Not specified	3 to 1	20 D upstream	Very low
1.1.5 Averaging Pitot Tube	2 inch to 48 inch.	1.0%AR	0.1%	10 to 1 or greater	20D upstream 4D Downstream	Low
1.1.6 Wedge	1 inch to 48 inch.	3% FS 0.5% if cal.	2%FS 0.2% cal	8 to 1	5 D upstream	Low
1.1.7 V-Cone	1 inch to 120 inch.	0.5%FS	0.1%	10 to 1	3D upstream 1D downstream	Low
1.1.8 VA Float meter- Rotameter	1/8 inch to 4 inch	3% FS	0.5%	10 to 1	None required.	Medium
1.1.9 TVA, Target Meter for Steam	2 inch to 4 inch	2% AR 0.2% FS	NA	Up to 100 to1	6D upstream 3D downstream	High
MECHANICAL						
1.2.1 Rotary Lobe	2 inch to 6 inch.	0.5% AR	0.1%	80 to 1 or greater	None required	Low
1.2.2 Utility Turbine	1 inch to 12 inch	0.25% AR	0.1%	10 to 1 or 100:1 lower accuracy	None required Internal flow straighteners	Low
1.2.3 In-line industrial	1/2 to 12 inch.	0.5% AR	0.2%	10 : 1 to 50:1	None required	Low
1.2.4 Insertion Turbine	1 inch to 72 inch	1.0% AR	0.5%	50 to 1	30 D upstream 5 D downstream	Low
1.2.5 Diaphragm meter	½ inch to 4 inch	1.0% AR	0.5%	100 to 1	None required	Low
ELECTRONIC						
1.3.1 Vortex Shedding	½ to 16 inch. Insertion 96 inch	1.0% FS	0.2%	25 to 1	20 D upstream 10D downstream	Low
1.3.2 Electro-magnetic	½ inch to 12 inch or larger	0.25% FS	0.1%	10 to 1	5D upstream 5D downstream	Zero
1.3.3 Thermal Mass Flow	½ to 12 inch Insertion 96 inch	1.0% AR 0.2% FS	0.2%	100 to 1	30 D upstream 5 D Downstream	Low
1.3.4 Ultrasonic - Transit	1 inch to 12 inch clamp up to 160	1.0% AR	0.2%	100 to 1	15 D upstream	Very low
1.3.5 Ultrasonic - Doppler	1 inch to 160 inch	2% to 5% FS	0.1%	100 to1	15D upstream	Zero
1.3.6 Coriolis Mass Flow	1/8inch to 12 inch	0.05% AR to 0.5% AR	0.025% to 0.25%	20:1 to 100:1	None Required	High

FLOW METER SELECTION TABLE 3
STEP 3 – EVALUATE YOU METER SELECTION BY ITS MAIN ADVANTAGES

	Easy to Install	**Low Mtce.**	**Resists dirt, and Fouling.**	**Low PPL**	**High Turndown 10:1 or better**	**No Density Correction Required**	**Nat .Gas Custody Transfer Approval**
DIFFERENTIAL PRESSURE	**Most DP Flow Meters can be upgraded from a.) a standard transmitter to b.) A Multivariable Transmitter. This improves flow meter performance. SEE SEC. 1.4, TRANSMITTERS**						
1.1.1 (a) Orifice (b) With Multi-variable Xmitter	O O	O O			 O	 ☆	AGA report 3
1.1.2 Flow Nozzle	O	O	O	O			AGA report 3
1.1.3 Venturi Tube	O	☆	☆	☆	☆		AGA report 3
1.1.4 Simple Pitot tube	☆	☆		☆			
1.1.5 Averaging Pitot Tube	☆	O		☆	☆		
1.1.6 Wedge	O	☆	☆	O			See sec. 1.1.6
1.1.7 V-Cone	O	☆	☆	☆	☆		Canada NOA-AG-0428
1.1.8 VA Float meter- Rotameter	O	O	O	O	☆		
1.1.9 TVA, Target Meter for Steam	☆	O	O		☆	☆	Includes multi-var. xmitter
MECHANICAL							
1.2.1 Rotary Lobe	O	O		O	☆		Ansi/ASC B109.3
1.2.2 Utility Turbine	O	O		O	☆		AGA report 7-
1.2.3 In-line industrial Turbine	O	O		O	☆		
1.2.4 Insertion Turbine	☆	☆	O	O	☆		
1.2.5 Diaphragm meter		☆		O	☆		
ELECTRONIC							
1.3.1 Vortex Shedding	☆	☆	☆	O	☆		API draft report 2007
1.3.2 Electro-magnetic	O	☆	☆	☆	☆		
1.3.3 Thermal Mass Flow	☆	☆	O	☆	☆	☆	
1.3.4 Ultrasonic Transit Time	☆ O Clamp-on	☆	☆	☆	☆		AGA report 9
1.3.5 Ultrasonic Doppler	☆ O Vs. in-line	☆	☆	☆	☆		
1.3.6 Coriolis Mass Flow	O	☆	☆	O	☆	☆	AGA report 11

☆ = probably a good choice, check application. O = may be a good choice, check application
BLANK BOX = not recommended or poor performance for the specific attribute.

FLOW METER SELECTION TABLE 4
STEP 4 – ESTIMATE THE COST in US $ OF YOUR METER SELECTION

	Meter Cost for 2 inch and 6 inch D	Installation - Cost for 2 and 6 inch D	Total Installed Cost 2 inch and 6 inch D	Comments
DIFFERENTIAL	**DP Flow Meters can be upgraded from a.) standard transmitter to b.) Multivariable Transmitter. This improves flow meter performance. SEE SEC. 1.4, TRANSMITTERS**			
1.1.1 (a)Orifice	$ 2,500 to $ 3,400	$ 1,500	$ 4,500 to $ 5,400	Includes T
(b)Multivariable	**$ 4,700 to $ 6,600**	$ 800	**$ 6,000 to $7,900**	xducer @ $ 500
1.1.2 Flow Nozzle	$ 3,000 to $ 4,000	$ 1,500 Flanged mtg.	$ 5,000 to $ 6,000	Includes T xducer @ $ 500
1.1.3 Venturi Meter	$3,000 to $ 7,300 2 inch to 6 inchD	$ 1,500 Flange	$ 5,000 to $ 9,300	Includes T xducer @ $ 500
1.1.4 Simple Pitot tube	$ 1,000 to $ 1,500 to $ 2,500	$ 800 4 inch, 8 inch, 36 inch	$ 2,300 to $ 2,800 to $ 3,800	Includes T xducer @ $ 500
1.1.5 Averaging Pitot Tube	$ 3,500 to $ 5,000 4 inch and 8 inch	$800 insertion Mtg.	$ 4,800 to $ 6,300	Includes T
		$ 1,500 Flange Mtg.	$ 5,500 to $ 6,000	xducer @ $ 500
1.1.6 Wedge	$ 4,000 to $ 7,000 2 inch to 6 inch	$ 1,500	$ 6,000 to $ 9,000	Includes T xducer @ $ 500
1.1.7 V-Cone	$ 4,000 to $ 6,000 2 inch to 4 inchD	$ 1,500	$ 6,000 to $8,000	Includes T xducer @ $ 500
1.1.8 VA Float meter- Rotameter	$ 1,000 to $ 3,000 ½ inch to 4 inch	$ 800 ½ inch to 4 inch	$ 1,800 to $ 3,800	No electronic correction.
1.1.9 TVA, Target Meter for Steam	$ 5,000 to $ 7,000 2 inch to 4 inch D	$ 1,500 2 inch to 4 inch	$ 6,500 to $ 8,500	Includes multi-Variable xmitter
MECHANICAL				
1.2.1 Rotary Lobe	$ 3,900 to $ 4,500	$ 3,000	$ 6,900 to $ 7,500	Incl. by-pass + T correction
1.2.2 Utility	$ 9,500 **low P**	$ 3,000	$ 12,500	Incl. by-pass +
Turbine 6 " D	$ 18,300 **high P**	$ 3,000	$ 21,300	P,T correction
1.2.3 In-line industrial Turbine	$ 3,000 to $ 8,000 2 inch to 6 inch	$1,500	$ 5,000 to $ 10,000 Gas	2 in. and 6 in. Includes T xducer @ $ 500
1.2.4 Insertion Turbine	$ 3,800 to $ 4,600 1 inch to 36 inch D	$ 800 insertion	$ 4,600 to $ 5,400	Std. 4-20 ma Xmitter
1.2.5 Diaphragm meter	$ 200 to $ 2,500 1-1/4 inch D	500 to $ 1,500	$ 700 to $ 4,000	P correction, regulator
ELECTRONIC				
1.3.1 Vortex Insertion type	$ 3,700 to $4,700 2 inch + 4 inch D	$ 1,500 Wafer mount.	$ 6,200 to $ 7,200	P + T xducer incl. @ $ 1,000
1.3.2 Electro-magnetic	$ 3,000 to $ 9,000 4 inch + 8 inch D	$ 1,500	$ 5,000 to $ 11,000	T transducer incl. @ $ 500
1.3.3 Thermal Mass Flow	$ 4,250 to $ 5,000 2 inch & 4 inch D	$ 800 insertion	$ 5,050 to $ 5,800	Mass Flow reading
1.3.4 Ultrasonic Transit Time	$ 3,000 to 9,000	$ 1,500 permanent flanged spool version	$ 5,000 to $ 11,000	Add $500 for temp Correction
1.3.5 Ultrasonic Doppler	$ 2,200 to $ 2,200	$ 500 strap-on only available	temporary installation	No temperature correction
1.3.6 Coriolis Mass Flow	$ 12,000 to $ 30,000 2 inch to 6 inch	$ 2,000	$ 14,000 to $ 32,000	Incl Xmitter Mass flow reading

Note re Cost/Price: Prices are approximate List Prices in U.S. $ for Qty 1 standard meter. Prices include 4-20 m.a. transmitter unless otherwise stated.

SECTION 1. FLOW METER DESCRIPTION AND PERFORMANCE

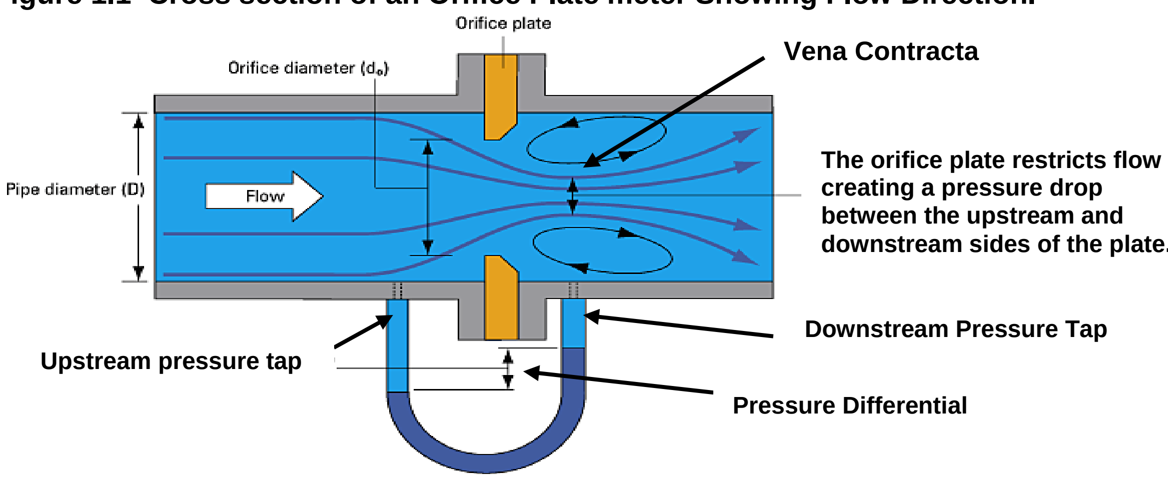
1.1) Differential Pressure (DP) Meters Basics - Correcting for Fluid Density Variation

Orifice Plates, Flow Nozzles, Venturi Tube Meters, Pitot Tubes, Annubars, V-Cone and Wedge meters all belong to a category known as **differential pressure (DP) meters.**

The objective in metering the flow of a fluid is to determine its corrected mass flow Qm. That is, the meter reading is corrected for fluid conditions-Pressure or Temperature variations, which are outside the specification for which the meter is calibrated and specified.

Most flow meters do not measure mass flow **Qm,** directly. They measure some other flow variable such as pressure differential ∆**P**, velocity **V,** or Volume flow **Qv**. In order to determine the mass flow, a series of calculations is performed. These calculations are based on the metered variable (eg. ∆**P**) Additionally, specific data about the application is required. This includes the fluid's characteristics, pipe size and the meter's coefficients and performance.
Of the more than 20 types of meters described in the guidebook, only two measure mass flow directly. These are: <u>The Thermal Mass Flow Meter</u> and <u>the Coriolis Meter.</u>

Figure 1.1 Cross section of an Orifice Plate meter Showing Flow Direction.



Figures 1.1, Image Courtesy of Spirax Sarco Steam Engineering Tutorials http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

1.1) Differential Pressure (DP) Meters- Correcting for Fluid Density Variation

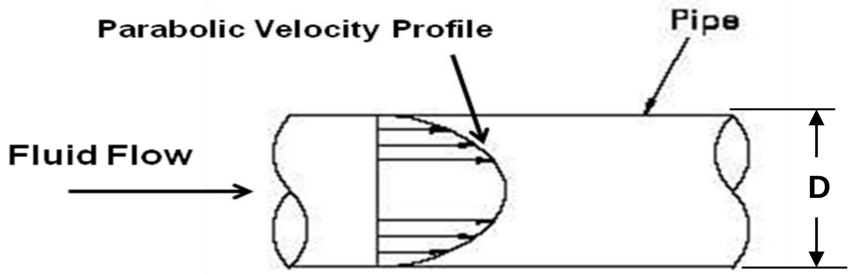
Correction Calculation: 1.) **DP** flow meters directly measure the **pressure drop (ΔP)** across an orifice or other restriction in the flow. They do **<u>not measure mass flow directly</u>.** Therefore, the **(ΔP)** reading must be converted to mass flow to be meaningful.
This is not so easy. We need to know the relationship between **(ΔP)** and velocity, and next, the relationship between velocity and mass flow. We also need to know the fluid density **ρ.**

2.) The meter is calibrated for a specific fluid at a specific temperature **T** and pressure **P.** Most industrial applications involve variations in fluid **T** or **P** or both.

Therefore, in order to convert the metered variable, **(ΔP)** to mass flow, **Qm** a complex formula is required.
This formula relates the metered pressure drop **(ΔP)** to the velocity of the fluid, Then, density **ρ** is used to calculate the mass flow. Density is corrected to account for the difference in T and P (actual) compared to the values for T and P for which the meter is calibrated**. (See page 20 also see Appendix B, P. 137 for a detailed example)**

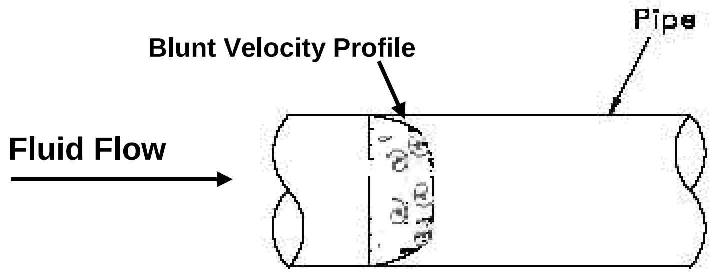
Other flow concepts to be familiar with are Flow Velocity Profile, Turbulent and Laminar flow and Reynolds number. The specific application and meter selection are made with these flow variables in mind.

Laminar Flow Velocity Profile, Reynolds No. < 4,000



See Appendix A3 for an explanation of Reynold Number (Re)

Turbulent Flow Velocity Profile, Reyolds No. > 4,000



Most industrial applications have turbulent flow. Turbulent flow occurs at a Reynolds number **(Re)** greater than 4,000. (**See Appendix A3** for details pertaining to Reynolds number).

1.1) Differential Pressure (DP) Meters Basics- Correcting for Fluid Density Variation
The following is a brief description of the measurements and calculations necessary to convert the differential pressure **ΔP** reading from the meter, to a mass flow **Qm** reading. A detailed example calculation is shown **in Appendix B.**

Step 1.) The density of the fluid is corrected for variations in P and T. When **P** or **T** vary from the base case condition, the **density** of the fluid changes. The change in density is proportional to the new Temperature **T** divided by the new pressure **P** or **T/P**. For gases, this relationship comes from the fundamental gas formula **PV = nRT**. **See Appendix B** of the guidebook.

$$\rho_{corrected} = \rho_{nominal} \times T/P$$

Step 2.) Flow Velocity is calculated. V is proportional to ΔP as in this formula:

$$V \; \alpha \; \sqrt{\frac{2\,\Delta P}{\rho_{corrected}}}$$

Where: **V**=Velocity, **ΔP** = pressure difference, **ρ** = fluid density
α means "proportional to":

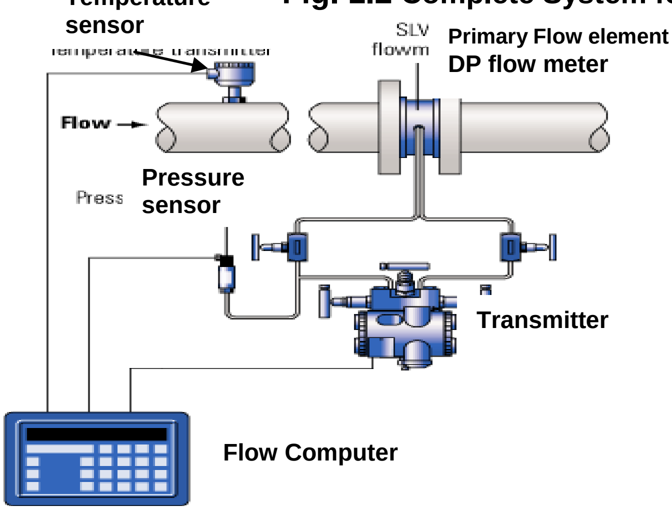
Step 3.) The corrected mass flow (Qm) is calculated

$$Qm = V \times \rho_{corrected} \times A$$

where: **V =** the fluid velocity from Step 2
$\rho_{corrected}$ = corrected fluid density
A = Internal Pipe Area

Appendix B, p. 145 provides a detailed example of how the mass flow of steam is calculated using the principles shown above.

Fig. 1.2 Complete System for Metering Mass Flow.



For the flow meter (Primary flow element) to provide a continuous output signal or visual display representing true mass flow, additional hardware is required. A pressure P sensor and a temperature T sensor are needed. A flow computer must do mass flow correction calculation following the steps shown (next page). Recent developments have made it possible to package the pressure sensor, temperature sensor and flow computer into the transmitter. This is called a Multi-variable Transmitter (MVT). See FIG. 1.3

Figure 1.2, Image Courtesy of Spirax Sarco website "Steam Engineering Tutorials"
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

1.1.1) Orifice Plate Flow Meters

Orifice plate meters are the most common flow-meter in use worldwide.
The standard orifice plate comprises a centered, round concentric orifice which is supported by an approved flange. (ANSI B16.36, API14.3.2/AGA Report 3 or other). The basic material of the plate itself is usually stainless steel but may also be manufactured from carbon steel or even plastic, depending on the application. It has a 45 ^{O} angle beveled edge and is called a sharp-edged orifice. The thickness of the plate is specific to the application. Its exact design depends on the pipe size, process temperature, pressure, differential pressure and type of fluid etc.

Various configurations of hole and plate are available. (eg. segmental and eccentric orifice plates) **(See figure 1.4).**
As fluid flows through the plate, its flow lines converge. Its velocity increases, and its pressure decreases to a minimum at a point called ***vena contracta.*** **(See Figure 1.1**). **See Appendix A.** for a more detailed description of how DP meters work.

Pressure taps are usually located in the flanges and the meter is calibrated based on these locations. At times, taps are located in the pipe, up-stream and downstream of the meter. This is standard practice in Europe but it requires accuracy by the installer and may be a source of reading error if done improperly.
A factory calibrated orifice plate may have accuracy as high as +/- 0.5%.

1.1.1) Orifice Plate Flow Meters

Fluid Applications – Orifice Plates-Standard Transmitter

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries	Contaminated or corrosive liquids	Com-pressed Air
○	○	◊	○	○				

☆ =probably a good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard materials.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.1.1) Orifice Plate Meters with Multivariable Transmitters (MVT).

The **multivariable transmitter** ("smart" transmitter) is a relatively recent development. The **MVT** is in fact a **flow computer** having all of the calculation and communication capability as the discrete system shown in Fig. 1.2 built in to a single device. The MVT receives three fluid measurements: pressure **P,** differential pressure **ΔP**, and fluid temperature **T**. The primary element is which provides **ΔP** in this case, is an orifice plate. Ideally, the **MVT** mounts directly on to the orifice plate block, measuring temperature at the orifice. The **MVT** has an on-board microprocessor which compensates for density variations and calculates mass flow directly without the need for a remote computer or PLC. (**See Sec. 2.1, Flow Transmitters**)

The flow inputs to the transmitter are upstream and downstream pressure as well as fluid temperature. Fluid temperature is supplied by a sensor Knowing these variables, the transmitter continuously calculates, **Δ P** fluid velocity and mass flow. The mass flow is corrected for pressure and temperature variation. The transmitter then communicates the mass flow to a data system. Multivariable transmitters will be discussed in **Section 2.1.**

Fig. 1.3

MultivariableTransmitter

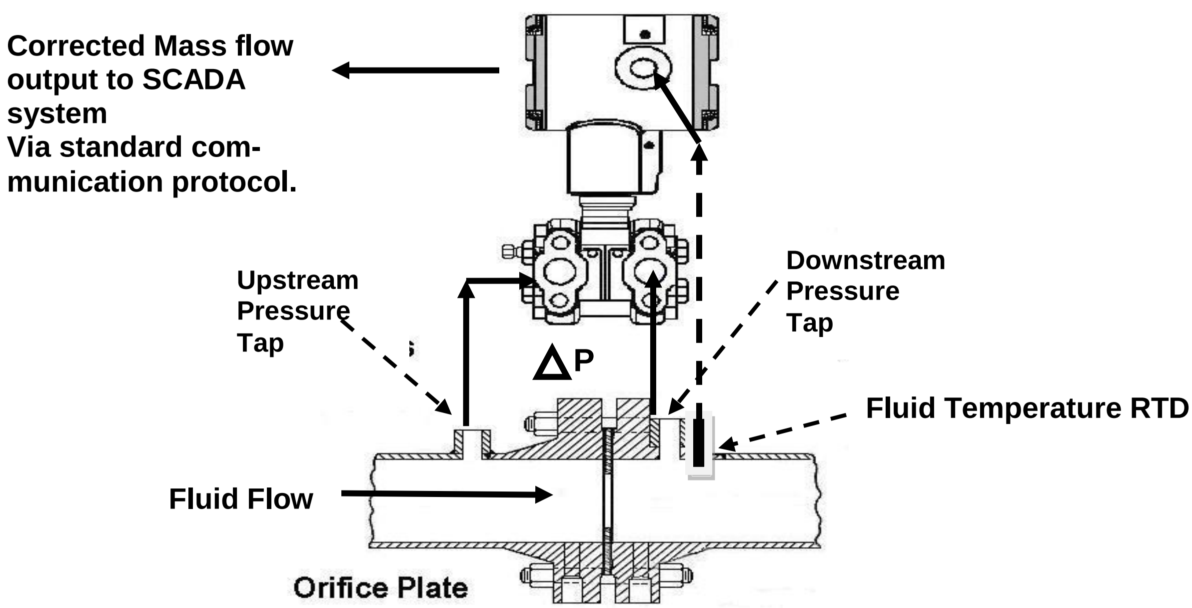


Figure 1.1 (b), Multivariable Transmitter receives inputs , performing mass flow calculations without the need for a remote flow computer.

MVT's improve the performance of the flow meter
Orifice Plate Performance Comparison, Standard vs. Multivariable Transmitter

	Flow Turn-down	Accuracy	Repeatability
Standard transmitter	4 to 1	+/– 2% to 4%	0.25%
Multivariable transmitter	10 to 1	+/– 1%	0.10%

1.1.1) Orifice Plate Flow Meters

Performance Characteristics

1. Applications: Clean liquids, natural gas, steam, compressed air and other gases.
2. Pipe Diameter Range: 2 inch to 48 inch
3. Accuracy at Max. Flow: +/- 2.0% to 4.0% FS standard transmitter
   +/- 1% Multivariable Transmitter
4. Repeatability: +/- 0.25% AR standard transmitter
   +/-0.1% Multivariable Transmitter
5. Turndown Ratio: 4 to 1 standard transmitter
   8 to 1 Multivariable Transmitter
6. Length of straight pipe required : 40D. upstream, 10D downstream
   2 D with conditioning Orifice Plate
7. Operating temperature range: 600 ^{O} F max. higher for High temp.
8. Discharge Coefficient Cd: Low (0.6 Approximately)
9. Permanent pressure Loss High: 75% of Pressure Differential at 0.5 Beta Ratio.
10. Minimum Reynolds Number: **5,000** (AGA Standard)
11. Pressure and temperature correction required: Yes
12. Cost of Meter Including Transmitter: **$ 2,500 to $ 3,400** 2 inch and 4 inch.D
    Add **$ 500** for Temp., transducer
13. Cost of Installation: **$ 1,500** **<u>14.)Total: $ 4,500 to $ 5,400</u>**

Note- Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in irem 12.) = $ 1,500

Advantages and Disadvantages - Orifice Plate Flowmeters

Advantages

- Available from many suppliers with a wide choice of approved flange mountings and options. Options include liquid drain holes for gas applications and gas vents for liquid applications..
- Maximum pressure applications as high as 1500 PSIG. (Depends on the flange rating).
- Inexpensive.
- Acceptable for horizontal, vertical or angle installation.
- Approved for **Custody Transfer**. **AGA Report 3 parts 1, 2, 3 and 4.**

Disadvantages

- Proper installation is critical to accuracy. Attention must be paid to tap location, straight runs, alignment of pipe, flange and orifice plate.
- Standard concentric orifice plate is not recommended for two-phase flow (eg. Steam with water). This causes a problem with accuracy in many boiler plants and steam distribution systems. Use a segmental orifice with flow directed to bottom of pipe. **(See fig. 1.4).**
- Narrow operating range, 4:1 turndown.
- Subject to wear of the primary element depending on fluid and orifice material.
- Debris collects at orifice if fluid is dirty.

1.1.1) Orifice Plate Flow Meters

Figure 1.4 Additional Orifice Plate Configurations

Image Courtesy of Emerson Automation Solutions www.emerson.com

The Conditioning Orifice Plate Flow-meter
This version of the orifice plate flow-meter has greater accuracy and reduces the required straight pipe run to 2D upstream and 2D downstream. The orifice plate conditions the fluid flow as it passes through the specially designed orifice configuration. There is no sacrifice in accuracy.

Figure 1.5, Conditioning Orifice Plate

Image Courtesy of Emerson Automation Solutions
www.emerson.com

1.1.1) Orifice Plate Flow Meters

Advantages – Conditioning Orifice Plate

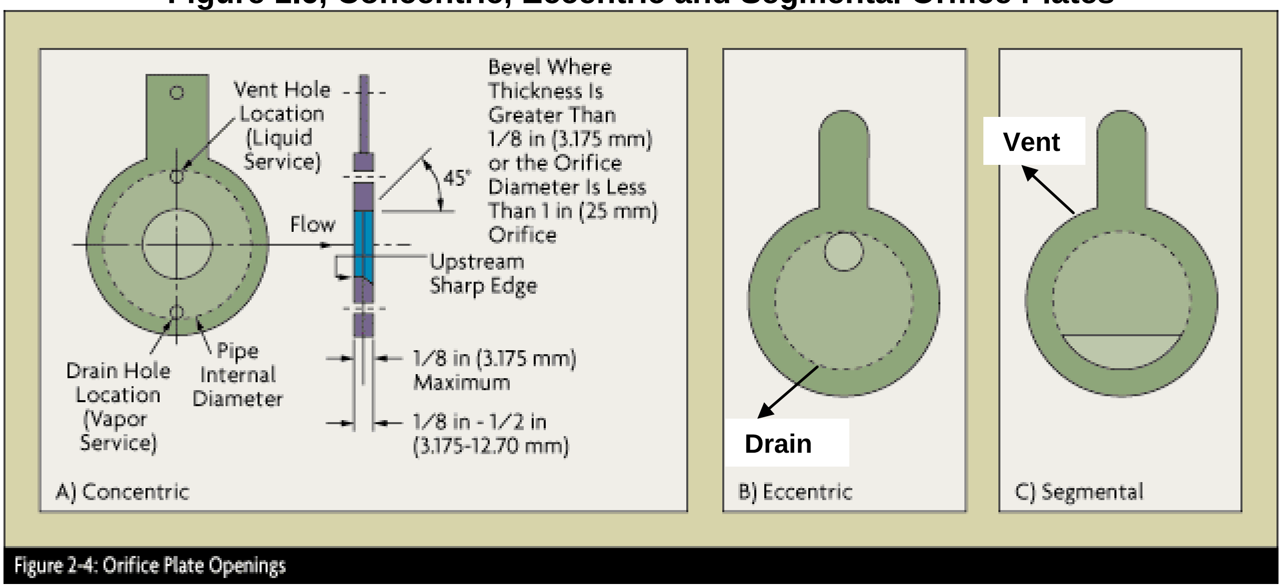
- Much shorter straight pipe runs required. 2D upstream and 2D downstream depending on nature of flow disturbance.
- Higher accuracy +/- 0.5% of FS rather than 1% to 4%.
- Easier installation, no Impulse lines, Lower cost installation.

Disadvantages:

- 4 to 1 turndown.

Other Variations of the Orifice Plate Meter

Figure 1.6, Concentric, Eccentric and Segmental Orifice Plates



Eccentric and Segmental orifice plates are used in two-phase flow applications. These applications may be for measuring gas with a liquid secondary flow (eg. steam with water) or liquid with a secondary gas flow (eg. water with steam).

Eccentric and segmental orifice plates may have the openings located at the bottom of the pipe or the top, depending on the application.

When the primary phase is a gas, the opening is located at the bottom of the pipe to allow water to escape through drain-holes. In primary phase liquid applications, the opening of the orifice is at the top to allow un-wanted gases to escape through vent holes.

1.1.2 Flow Nozzle Meters

The principle of operation of a flow nozzle is identical to that of an orifice plate. The flow volume through the meter is proportional to the pressure drop across the nozzle. The fluid being measured passes through the nozzle creating a pressure differential between the inlet and outlet of the primary element. The flow volume can be calculated using the basic formulae described in **Appendix A:**

$$V \propto \sqrt{\frac{2\,\Delta P}{\rho}}$$

The flow nozzle is more dimensionally stable than the orifice plate and better suited to **high temperature and pressure** applications. It has a longer lifespan than an orifice plate.

Because of its geometry it is more difficult to remove and replace and is often supplied as part of a spool section. It is available in a range of Beta ratios from 0.2 to 0.8.
(See Appendix A5 for the definition of Beta Ratio and Discharge Coefficient Cd).

Because of the smooth, tapered flow path through the nozzle, it has a slightly higher coefficient of discharge **(Cd)** and is less subject to wear than the orifice plate.

Pressure taps are made in the pipe one diameter upstream and ½ a diameter downstream. If the meter is supplied as a single unit in a pipe spool-piece, taps are pre-installed.

Fluid Applications – Flow Nozzles

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries	Contaminated or corrosive liquids	Com-pressed Air
○	○	◊	○	○	◊		◊	

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard materials.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.1.2 Flow Nozzle Meters

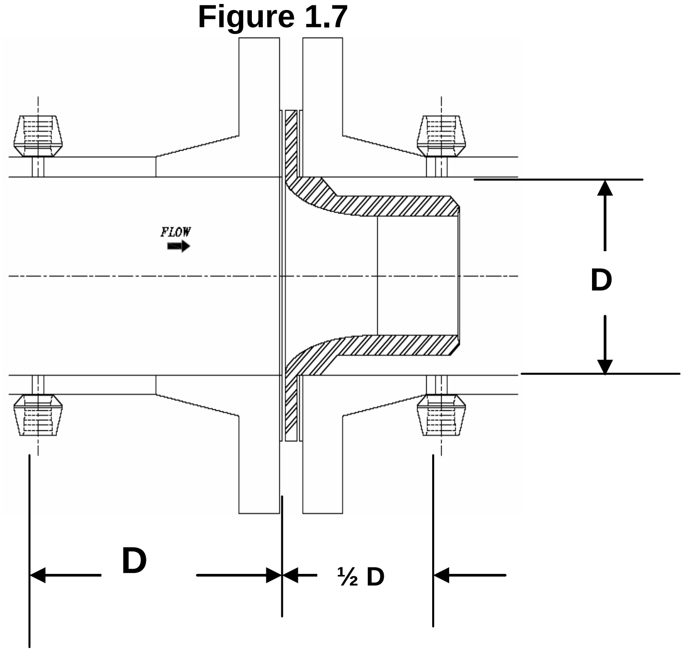
Typical Performance Characteristics – Flow Nozzle Meters

1. Applications: Clean liquids, natural gas, compressed air, steam, superheated steam and fluids including corrosive fluids. Not recommended for dirty fluids or slurries.
2. Pipe Diameter Range: 2 inch to 48 inch or larger as special.
3. Percent Accuracy at Max. Flow: +/- 2.0%, FS typical
4. Repeatability: +/- 0.25% AR
5. Turndown Ratio: 4.0 to 1
6. Length of straight pipe required: 15D to 7D. upstream
   Depends on the type of restriction and Beta ratio.
7. Operating temperature range: As high as 1200 ^{O} F
8. Discharge Coefficient Cd: High (0.90 to 0.99) depending on Re
9. Permanent pressure Loss: 60% of Pressure Differential at 0.5 Beta Ratio.
10. Minimum Reynolds Number: 10,000
11. Pressure and temperature correction required : Yes
12. Cost of Meter incl. transmitter: $ 3,000 and $ 4,000 for 2 inch and 6 inch. D
    Add $ 500 Temp. transducers
13. Cost of Installation: 2 " and 6" D $ 1,500 **<u>14.) Total $ 5,000 to $ 6,000</u>**

Note - Prices are approximate in U.S. $ for standard meters.
Typical cost for basic 4-20 m.a. transmitter included in item 12.) = $ 1,500

Fig. 1.7, Flow Nozzle Drawing Showing Standard ASME pipe taps

Figure 1.7



Drawing Courtesy of Primary Flow Signal Inc., www.primaryflowsignal.com

1.1.2 Flow Nozzle Meters

Advantages and Disadvantages of Flow Nozzles.

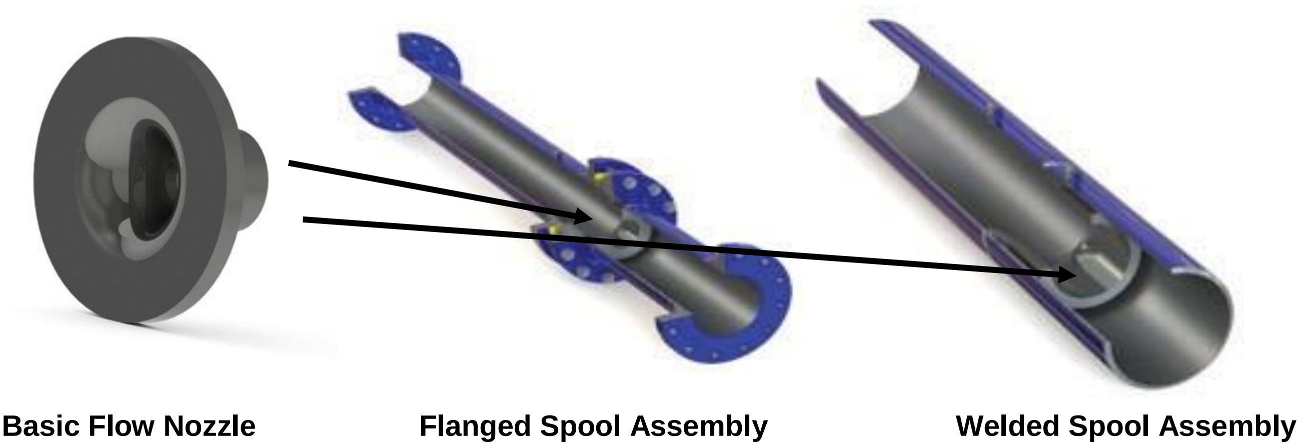
Advantages

- A flow nozzle has a higher discharge coefficient **(Cd)** and a somewhat lower permanent pressure loss **(PPL)** than an orifice plate.
- A flow nozzle can handle approximately 30% greater flow with the same meter diameter as an equivalent diameter orifice plate.
- A flow nozzle is more rugged than an orifice plate and suited for high temperatures and pressures. Less susceptible to wear by steam.
- Lower upstream and downstream straight pipe required than orifice plates.
- Approved for **Custody Transfer**. **AGA Report 3 parts 1, 2, 3 and 4.**

Disadvantages

- Flow nozzles are difficult to install and to remove for inspection or cleaning unless they are supplied as an integral meter and **pipe spool assembly.**

Figure 1.8, Flow nozzle assembled with pipe sections for easier installation, removal



1.1.3 Venturi Meters - Basics

The Venturi tube is a **DP** flow meter having three sections, a tapered inlet, a center throat, and a diverging outlet. The pressure differential DP is measured at the inlet and at the throat by pressure taps. A venturi tube meter is designed to measure flows with higher accuracy and **much lower PPL than either the orifice plate or the flow nozzle**. One variation of the design is an annular ring at each pressure measurement location, rather than a single point tap. This provides an average pressure over the circumference of the inlet and throat and thus greater accuracy than a single point measurement.

Figure 1.9, Venturi Meter

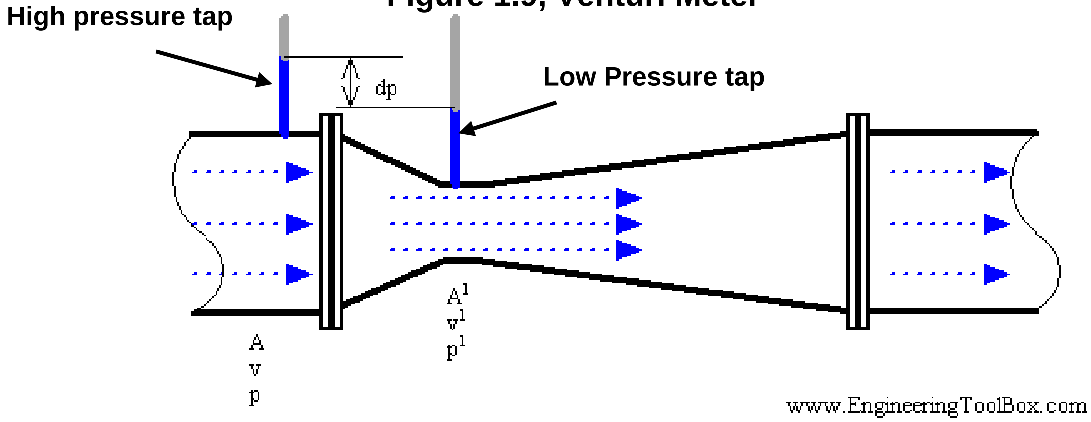


Image Courtesy of Engineering Toolbox, www.engineeringtoolbox.com

Fluid Applications – Venturi Meters

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated liquids	Com-pressed Air
☆	☆	◊	☆	○	◊	◊	◊	○

☆ **= good choice, check performance and cost.**
○ **= may be a good choice, check performance and cost.**
BLANK BOX = Not Recommended for standard materials.
◊ **Caution: Special meter design or materials may be required. Consider the fluid's characteristics.**

1.1.3 Venturi Meters

Figure 1.10, Modified "Halmi" Short form Venturi Meter

Primary Flow Signal Inc. **Model HVT-FV** fabricated venturi meter for metering clean or solids-bearing gases and liquids. **The HVT-FV Halm**i is a modified, short form venturi. Materials include a wide range of carbon steel, stainless steel, titanium and special steels for extended temperature range up to **1250 ^{O}F** and for resistance to abrasion. Pipe size **ranges from 1 inch D to 180 inch D. Th**is meter **has very low permanent pressure loss** and meets or exceeds performance standards such as **ISO 5167 or ASME . It has a cost advantage** compared to the standard venturi meters. The short length Is also an **advantage for installation.**

Fig. 1.11, Modified "Halmi" multiple piece Short From Venturi Meters

Fig. 1.11 (A) Full Body

Fig. 1.11 (B) Short Body

Primary Flow Signal Inc. Full body venturi flow meter model HVT-Halmi. Fig. 1.11 (A)
A range of **full body type** meters are available in sizes 0.25 inch to **180 inch D** and beyond. Materials can be whatever is suitable for the service, pressure and temperature and the meter can be equipped with plain ends for field welding, flanged ends (any pressure rating), mechanical coupling ends and many others. The meter can be provided in multiple pieces to assist field installation in tight places.

The **Halmi model HVT-FIF (Fig. 1.11 (B)) short body meter** is designed for installation between two pipe flanges and has a profile complete inside the pipeline except for the center flange. This meter is less expensive than the full body design, it is ideal for measuring clear liquids, steam and all types of gasses. It offers the same basic accuracy and PPL as the full body design, weighs less and is less expensive.

Images Courtesy of Primary Flow Signal Inc., www.primaryflowsignal.com

1.1.3 Venturi Meters

Typical Performance Characteristics – Venturi Meters

1. Applications: Clean liquids, clean gases, chilled water, hot water, natural gas, compressed air, Combustion air for boilers. Special Designs: Oil, Crude oil, slurries, municipal wastewater.
2. Pipe Diameter Range: 2 inch to 180 inch or larger.
3. Percent Accuracy : +/- 0.5% FS to 2.0% AR depends on design
4. Percent Repeatability: +/- 0.1% depends on design
5. Turndown Ratio: 10:1 to 100:1
6. Length of straight pipe required: 5 upstream, zero downstream
   depends on meter Beta ratio
7. Operating temperature range: As high as 1250 ^{O} F (special materials required)
8. Discharge Coefficient Cd: High (0.9 to 0.99) depending on Re
9. Permanent pressure Loss: Low, 3% of Pressure Differential depending on Beta ratio.
10. Minimum Reynolds Number: 50,000
11. Pressure and temperature correction required : Yes
12. Cost of Meter c/w transmitter: $ 3,000 to 7,300. 4 inch and 8 inch D
    $ 500. temp., transducer
13. Cost of Installation: (flange mtg.) $ 1, 500. 14.) **<u>Total $ 5,000 to $ 9,300</u>**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 12.) = $ 1,500

Advantages and Disadvantages – Venturi Flow Meters

Advantages

- High Turn-down ratio. Up to 100:1
- Short straight pipe lengths upstream and downstream. 5 upstream,0 downstream depending on nature of interference and Beta Ratio.
- Higher accuracy than orifice plate +/- 1% AR typical.
- Low permanent pressure loss**. (See figure 1.12)**
- **Low energy loss due to pressure loss.**
- Approved for **Custody Transfer**. AGA Report 3 parts 1, 2, 3 and 4.
- Able to handle a wide range of liquids and gases.

Disadvantages

- Higher cost than Orifice meter or Flow Nozzle.
  However, the higher cost may have a financial payback in terms of energy savings caused by a much lower PPL.
  .

1.1.3 Venturi Meters

Figure 1.12, Permanent Pressure Loss Compare Venturi Meters vs. Other DP Meters

The Wyatt Engineering model LVM is a proprietary design Venturi meter having high flow accuracy (0.5% measurement uncertainty). and very low permanent pressure loss (PPL). This meter requires short upstream straight pipe and no downstream straight pipe i.e., valves, pipe fittings etc. can be directly connected to the outlet. The LMV is available in sizes from 1 inch to 96 inch.

<u>Permanent Pressure Loss (PPL)</u>
The basic principle of operation of a DP meter is that flow through the reduced throat diameter accelerates the fluid with a resultant drop in pressure; comparison of the inlet-to-throat pressure is the DP and is proportional to flow velocity. The DP inherently incurs an un-recoverable pressure loss or PPL downstream of the throat. In a Venturi, the downstream re-covery section keeps this loss to a minimum and is many times more efficient than an Orifice Plate which has no transition area. PPL robs the process of energy with associated costs every minute of operation.

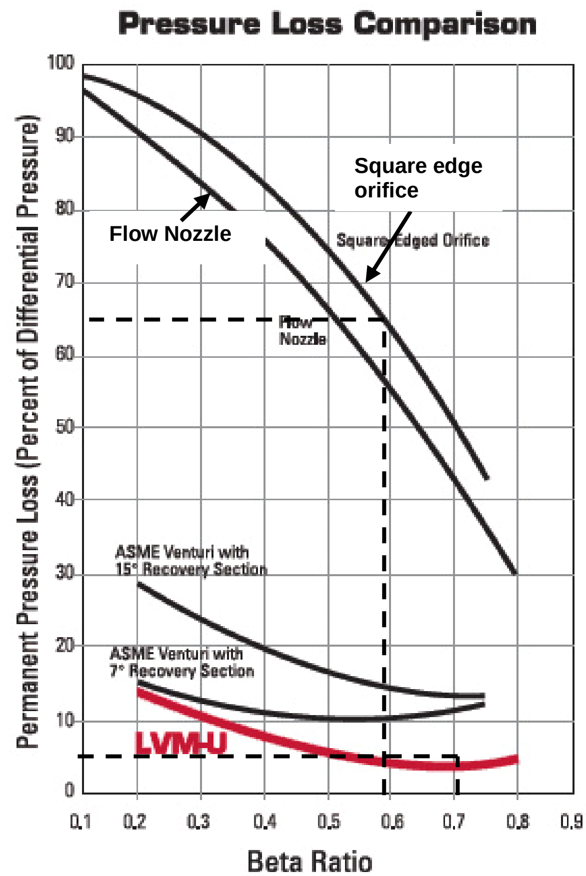


Figure 1

The graph above shows the Permanent Pressure **(PPL)** loss as a percentage of the Differential Pressure **DP** across various DP meters. In this <u>real example</u>, a 12 inch **orifice plate** is compared to a 12 inch **LVM venturi meter**. Steam at 300 PSIA is being metered. Both meters have <u>identical **DP**</u> across the meter, **DP= 200 in. W.C. or 7.2 PSI.** The orifice meter has a higher **Beta ratio (0.71)** compared to **(0.58)** for the venturi meter. The graph shows that the **PPL for the Orifice plate** is approximately **64% of the DP or <u>4.6 PSI.</u>** The **PPL for the LVM venturi meter** is much lower, about **5% of the DP or 10 in. W.C. or 0.4 PSI. Note:** Each situation is specific to the meter, the fluid, pressure and other variables. Depending on the fluid flow and operating hours per year, **lower PPL** of the Venturi meter can results in energy savings of **several thousand dollars per year,** depending on steam flow and operating hours.

Images Courtesy of Wyatt Engineering LLP, <u>www.wyattflow.com</u>

Beta Ratio β = d/D is the ratio of the orifice diameter to the inside Pipe diameter.
in. W.C. = inches of Water Column 1 PSI = 27.68 in. W.C.

1.1.4 Simple Pitot Tube Meters - Basics

The pitot tube is a simple flow measuring device. It was invented in 1732 by the Frenchman Henri Pitot. The main difference in the principle of operation of the pitot tube and other differential pressure measuring meters is that the fluid does not flow through the pitot tube. The fluid impacts the tube in two locations measuring two variables, the static and dynamic pressure caused by the flow.

The operating principle of a pitot tube is based on Bernoulli's equation, the basis of all differential type flow-meters**, (see appendix A-1.1).**

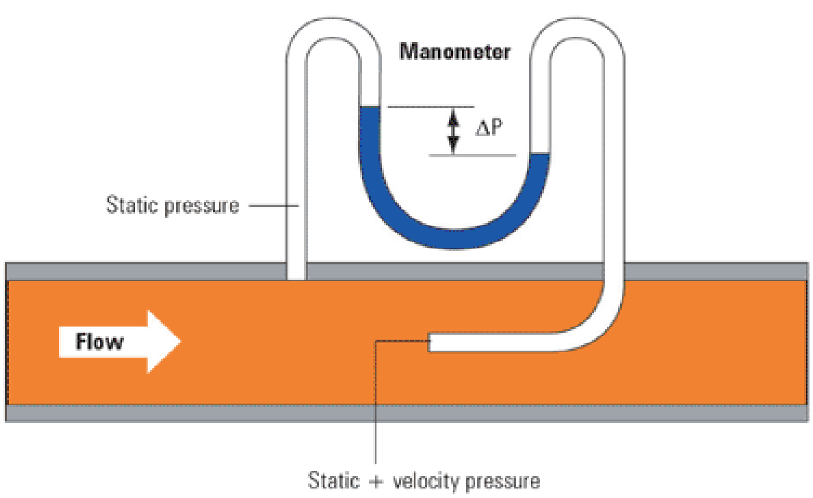
The total energy (**E_T**) of a flow-stream = (**E_K**) the kinetic energy plus (**E_P**) the potential energy due to the static pressure of the fluid plus (**E_E**) the potential energy due to change in elevation. The third term is usually ignored in meter applications because **E_p** is small.

A pitot tube directly measures the pressure associated with **E_T** the total and Item **E_P** static pressure energy. Item (1.), kinetic energy is determined by subtracting static from the total. The relationship between the two pressures can be used to determine the velocity flow as follows:

$$P_T = P_P + \left(\frac{\rho V^2}{2}\right)$$

Where: **P_T** = Total Pressure
P_P = Static Pressure
$\{\rho V^2 / 2\}$ = Dynamic Pressure

Figure 1.13, The Principle of Measurement for a Simple Pitot Tube



Drawing Courtesy of Spirax Sarco Website: "Steam Engineering Tutorials"
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

1.1.4 Simple Pitot Tube Meters - Basics

The Pitot Tube has multiple applications in industry including the measurement of air flow in round or square pipes and ducts, clean liquids and gases in pipes, and the measurement of water in open channels.
A Pitot tube can be applied in high temperature applications such as the measurement of boiler flue gas and dryer exhaust air. Pitot tubes are often used for portable or temporary measurements as well as in permanent installations. They are helpful as portable units in **Energy Management** assessments.

The usual mechanical configuration is an L-shaped tube having two internal pressure tubes which transmit the fluid pressure to taps.
For accuracy, it is critical to position the tube at the correct pipe depth to detect the average flow, and to make sure the end of the tube is parallel to flow.

Figure 1.14, Configuration of a Pitot Tube

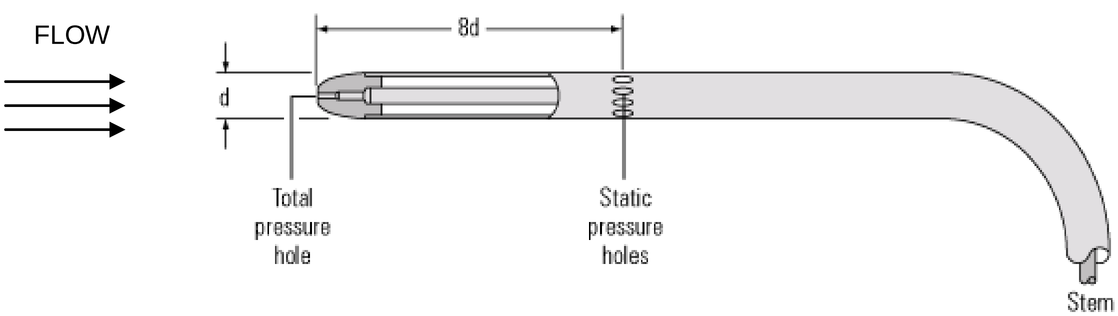


Image Courtesy of Spirax Sarco Inc., www.spiraxsarco.com/resources/steam-engineering-tutorials/flowmetering.asp

Typical Performance Characteristics – Simple Pitot Tube

1. Applications: Clean liquids, clean gases, low pressure air in ducts, hot air in ducts, water in pipes and open channels, gases in pipes, high temperatures.
2. Pipe Diameter Range: up to to 72 inch
3. Percent Accuracy at Full Span: +/- 1.5% to 3.0% FS typical. Position in pipe is critical.
4. Turndown Ratio: 3:1
5. Length of straight pipe required: 20 D, upstream depending on disturbance.
6. Operating temperature range: Up to 500 ^{O} F typical, Higher for special.
7. Discharge Coefficient Cd: not applicable, no flow through meter.
8. Permanent pressure Loss: very low
9. Minimum Reynolds Number: can be used in laminar flow < 4000 Re
10. Fluid Density correction required : Yes
11. Cost of Meter: $ 2,000 to $ 2,500 for 4 inch and 12 inch D
    c/w transmitter add $500 Temp transducer.
12. Cost of Installation: insertion mtg.. $ 800. 13.) **Total $ 3,300 to $ 3,800**

Note – Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 11.) = $ 1,500

1.1.4 Simple Pitot Tube

Fluid Applications

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Water, Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
○	○			○				

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard materials.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

Advantages and Disadvantages of the Simple Pitot Tube.

Advantages

- Low cost
- Low installation cost, can be inserted into pipe.
- Can be hot tapped without shutting down the process for some applications.
- Multiple applications including low pressure air, ducts, liquids or gases in pipes, high temperatures.
- Portable hand-held version available for temporary installation and testing.
- Large Diameter Pipes O.K., Up to 72 inch.

Disadvantages

- Low Accuracy, single point measurement in flow stream.
- Low turn-down ratio, 3:1
- Plugging may be a problem with dirty fluids.

1.1.5 Averaging Pitot Tube Meters or Annubars ®

Basics

The averaging pitot tube or Annubar **®,** operates on the same principle as the simple pitot tube, namely; by measuring the total pressure and the static pressure (Upstream and Downstream) through multiple ports, or slots in a bar which extends across the flow profile. The accuracy is much higher than that of a simple pitot tube or orifice plate because the profile of the flow stream is more reliably represented with multiple total pressure readings. The total pressure readings are "averaged". The static pressure reading is taken in the side-wall of the tube through one or multiple ports. The annubar® is available in insertion, wafer or hot tap mounting formats.

Averaging pitot tubes are capable of metering a wide range of gases, steam and liquids. They are especially suited to large pipes such as process and combustion stacks, up to 8 M in diameter.

Fig. 1.15 Averaging Pitot Tube Torbar ®, ABB Model FPD 350
Meters a wide range of gases, steam and liquids.

Image Courtesy of ABB, www.abb.com/flow

ABB manufactures a wide range of flow meters including Venturi meters, Orifice plates, Vortex Shedding, Coriolis and Thermal mass flow meters.

Fluid Applications – Averaging Pitot Tube

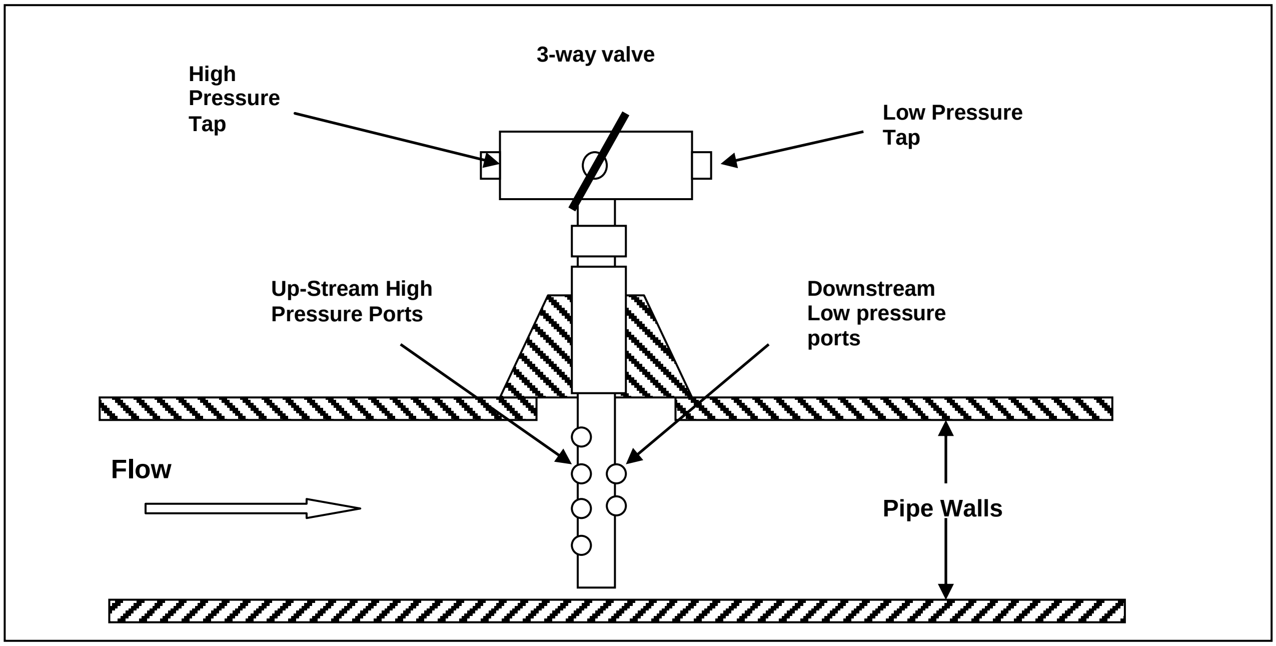
Natural gas	Other gases	Contaminat-ed Gases Large stacks	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
○	○	◊ ☆	○	○				○

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.
BLANK BOX = Not Recommended for standard meters.

1.1.5 Averaging Pitot Tube Meters (Annubar ®)

Annubar is a registered trademark of Emerson Process (www.emersonprocess.com)

Figure 1.16, Averaging Pitot Tube-Insertion type mounting



Typical Performance Characteristics – Averaging Pitot Tube

1. Applications: Clean liquids, clean gases, steam, low pressure air in ducts, hot air in ducts, water, high temperature gases such as boiler flue gas, dryers, large smoke stacks.
2. Pipe Diameter Range: 2 inch up to several meters.
3. Percent Accuracy at Full Scale: +/- 1.0% typical. Position in pipe is critical.
4. Repeatability: +/- 0.1% typical.
5. Turndown Ratio: 10:1
6. Length of straight pipe required: 18 D upstream, 4D downstream.
7. Operating temperature range: Up to 700 ^{O} F typical, much higher for special.
8. Discharge Coefficient Cd: not applicable, no flow through meter.
9. Permanent pressure Loss: very low, 3% to 6% of DP
10. Minimum Reynolds Number: greater than 12,000 Re
11. Fluid Density correction required : Yes
12. A Cost of Meter: $ 3,500 to $ 5,000, 4, and 8 inch
12. B Alt. Cost – Multivariable Xmitter. $ 4,700 to 5,400, 4 inch and 8 inch D
13. Add for Temp transmitter $ 500
14. Cost of Installation: Insertion $ 800 **15.) Total $ 4,800 to $ 6,300** (12A)

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Meter cost incl. typical cost for basic 4-20 m.a. transmitter included in item 12A.) = $ 1,500

1.1.5 Averaging Pitot Tube Meters

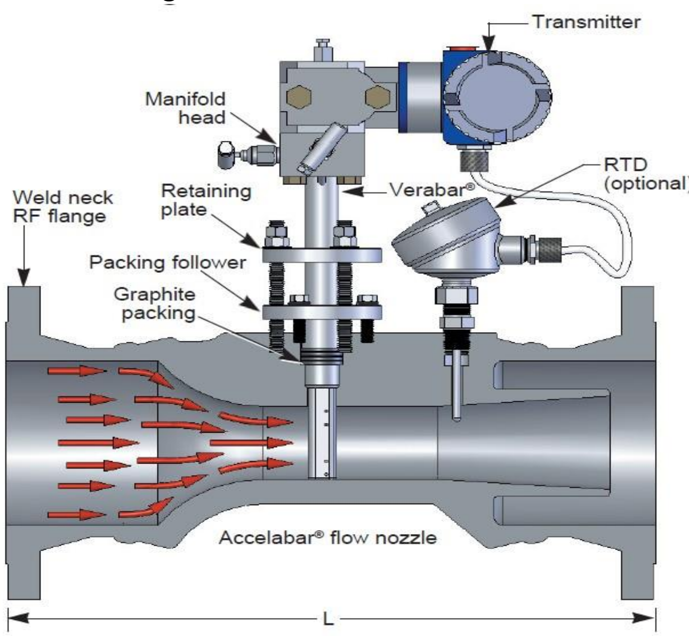
Advantages and Disadvantages – Averaging Pitot Tube.
Advantages

- Multiple applications, very flexible. Special designs available for very large diameter pipes and very high temperature applications.
- Insertion into pipe makes installation cost low. Easy removal for inspection.
- High accuracy, high turn-down ratio. One model claims a 17:1 turndown.
- Low cost units available from some distributors.
- Low permanent pressure loss.

Disadvantages:

- Susceptible to plugging of pressure ports in dirty fluid applications.
- The primary element is subject to vibration in dynamic environments. If this is problematic,the annubar can be supported at both ends.

Figure 1.17, Veris Acclebar ®



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www.armstronginternational.com/products-systems
www.armstronginternational.com

The Veris Accelebar ® has a unique design comprising a patented torroidal nozzle at the inlet of the meter which **stabilizes the fluid velocity profile.** The fluid differential pressure **ΔP** is then sensed by the **Verabar ®** multi-port primary element. Temperature and pressure correction can be implemented as required. Combined with a multivariable transmitter, the flow meter can produce a mass flow reading with accuracy of **+/ – 0.50% AR.** This design also permits the meter to be installed with very short straight pipe runs.

1.1.6 The Wedge Meter for Liquids, Gases and Slurries - Basics

The wedge flow-meter is used to measure the flow of a wide range of fluids including high viscosity liquids, clean liquids, slurries, corrosive liquids, gases.
It is used in the oil and gas industry for many applications such as liquid or gas **custody transfer**, oil blending and heavy oil metering. It can be used successfully to handle particulate laden liquids and slurries for industrial applications. It is capable of measuring at a very low Reynolds number < 500.

A V-shaped wedge is inserted into the pipe section at right angles and acts as a restricting orifice, creating a pressure differential between up-stream and down-stream measurement points. The shallow slope of the wedge surfaces prevents fouling.

Figure 1.18, Wedge Flow-meter

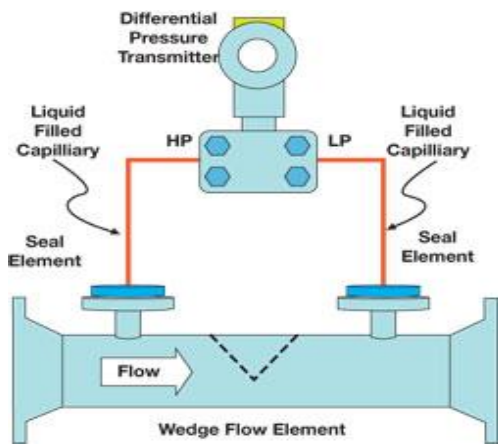


Image Courtesy of ABB, www.abb.com/flow

Fluid Applications – Wedge Meters

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
		◊		○	◊	☆ ◊	☆ ◊	

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.1.6 The Wedge Meter

Typical Performance Characteristics – Wedge Meter

1. Pipe Diameter Range:	1 inch to 48 inch.
2. Percent Accuracy at Full Span:	+/- 0.5% if calibrated. +/- 3% if un-calibrated
3. Repeatability:	+/- 0.2% if calibrated +/- 2% if un-calibrated
4. Turndown Ratio:	8:1
5. Length of straight pipe required:	as low as 5D upstream.
6. Operating temperature range:	Up to 700 ^{O} F typical.
7. Discharge Coefficient Cd:	0.7 depending on Beta Ratio
8. Permanent pressure Loss:	low
9. Minimum Reynolds Number:	can be used in laminar flow < 500 Re
10. Fluid Density correction required :	Yes
11. Cost of Meter:	$ 4,000 to $7,000 for 4 inch to 8 inch D Add $ 500 for Temp. Transducer
12. Cost of Installation: flange mtg.	$ 1,500 **13.) <u>Total</u>: <u>$ 6,000 to $ 9,000</u>**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 11.) = $ 1,500

Advantages and Disadvantages-Wedge Meters

Advantages

- Meters a wide range of liquids and gases.
- Available for a wide range of pipe diameters.
- Extremely Rugged.
- Corrosion resistant.
- No Moving Parts.
- Can achieve high accuracy and repeatability when calibrated for the application.
- Approved for **Custody Transfer** in some applications.
- High turndown ratio 8:1
- Low straight pipe upstream required depending on application.

Disadvantages

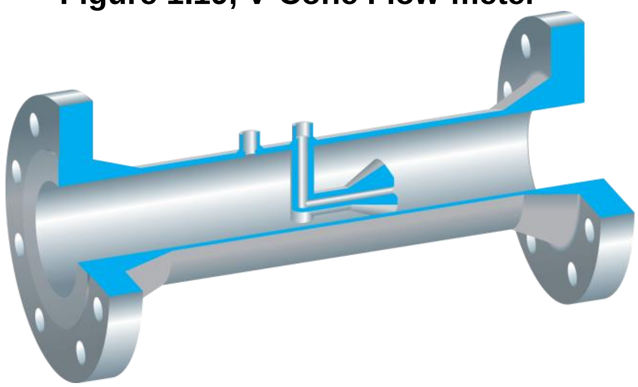
- High cost.

1.1.7 The Venturi-Cone (V-Cone) Flow meter – Basics

The V-cone meter has a wide variety of applications including gases, water and oil. It can also handle fluids with particulates and solids as well as low Re number flow. It is used widely in the oil and gas industry. The V-cone is often applied where there is minimal straight length of pipe available. It has an internal flow conditioning action which straightens out disturbances from upstream and downstream elbows and valves and normalizes irregular flow profiles. The V-cone meter has been used for steam billing in district heating.

A cone is inserted inside the meter tube, restricting fluid flow. As the fluid flows a low pressure region forms down-stream of the cone. The pressure differential is measured up-stream (static pressure) and down-stream (dynamic pressure) and the difference is sensed in the same way as with other DP meters. The V-Cone is suited for steam application because it passes moisture without blocking flow.

Figure 1.19, V-Cone Flow-meter



Drawing courtesy of Emerson Automation Solutions
https://educationcenter.emersonprocess.com

Fluid Applications – V-Cone Meters

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquids +Hydro-carbon	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
☆	☆	☆ ◊	O	☆	◊			O

☆ = good choice, check performance and cost.
O = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.1.7 The Venturi-Cone (V-Cone) Flow-meter

Typical Performance Characteristics – V-Cone Meter

1. Pipe Diameter Range:	½ inch to 48 inch or larger
2. Percent Accuracy at Full Span:	+/- 2.0 %. FS
3. Repeatability:	+/- 0.1%
4. Turndown Ratio:	10:1
5. Length of straight pipe required:	3 D upstream, 1D downstream depending on disturbance and Beta Ratio
6. Operating temperature range:	Up to 720 ^{O} F.
7. Discharge Coefficient Cd:	Beta Ratio, 0.2 to 0.5
8. Permanent pressure Loss:	low
9. Minimum Reynolds Number:	8,000 or lower with flow profile correction.
10. Fluid Density correction required :	Yes
11. Cost of Meter:	$ 4,000 to $ 6,000 2 inch and 4 Inch D.
Add	$ 500 temp transducer
12. Cost of Installation:	$ 1,500 13.) Total: **$ 6,000 to $ 8,000**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 11.) = $ 1,500

Advantages and Disadvantages – V-Cone Meters

Advantages

- Applicable to a wide range of fluids and applications.
- Up to 120 inch pipe Diameter.
- High accuracy and repeatability. Can be used for **custody transfer**.
- Short length of straight pipe up-stream and downstream required. Flow conditioner not required.
- High turn-down ratio.
- Low viscosity fluids including oils.

Disadvantages

- Higher cost.

1.1.8 Variable Area (VA) Flowmeters - Float Type

Target Flow Meters are generally categorized as variable area flow meters. Target meters work on the common principle that a flowing stream of clean **liquid, gas or steam** impinges on a **target.** The target is a **cone or plate** placed in the flow stream. The moving components (cone or plate) are usually spring-mounted. The fluid flow deflects the target against the spring and moves its position back and forth. The amount of deflection is proportional to the flow velocity and fluid density (momentum). The variation in the target position is sensed by a electronic detectors (transducers) and the position is converted to an electrical signal output and transmitted to a display or converted to 4 to 20 m.a. format.

The simplest **variable area (VA) float meter** comprises: **a.)** a measuring tube which is tapered and installed vertically large end up and **b.)** a specially shaped float which moves freely inside the tube.
This meter can be used to meter a wide range of liquids or gas. The fluid flowing upward through the tube raises the float until the gap between the float and tube walls increases to the point where the buoyancy of the float reaches equilibrium with the force of the fluid. The flow marking on the side of the tube indicate the flow rate at its equilibrium position. As flow rate changes, the float moves up or down to indicate the new rate.

The design of the system is specific to the fluid, the buoyancy of the float and the expected flow rate. It is also specific to the shape of the float relative to the tube walls. Various materials and shapes are used in the construction of both the tube and the float. Tubes and floats may be metal, plastic or glass, depending on application.

Figure 1.20, Glass, Plastic or Metal Tube Variable Area Flow Meter

Stainless Steel Design
Designed for Harsh Applications
Borosilicate Glass
Easy to Read, install and Maintain
Optional Limit Switches
0.04 - 44 GPM Water
0.09 - 90 SCFM Air

Turn Down Ratio 10 - 1

Photo courtesy of Yokogawa Corporation of America,
www.Yokogawa.com/us/products/field-instruments

1.1.8 Variable Area (VA) Flowmeters - Rotameters.

An enhanced version of the float type VA flow meter is the **Rotameter,** a float type VA flow meter with a display dial on the outside for easy reading. The indicator needle on the display dial is magnetically coupled to a magnet on the float causing it to rotate with the float position. The Rotameter can also be fitted with an electronic transducer.

Figure 1.21, Rotameter

316L Stainless Steel Construction
2% Full Scale accuracy
4-20ma output
Hart Protocol Available
Adjustable Limit Switches
0.95 to 550 GPM
0.42 to 1050 SCFM

Turn down ration 10 - 1

Photo courtesy of Yokogawa Corporation of America
www.Yokogawa.com/us/products/field-instruments

Fluid Applications –Variable Area Flow Meter (Target Meter or Rotameter)

Natural gas	Other gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Corrosive liquids	Com-pressed Air
	○ ◊			○	◊		◊	

☆= good choice, check performance and cost. ○= may be a good choice, check performance/cost.
BLANK BOX = Not Recommended.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.1.8 Variable Area (VA) Flowmeters – Float Type and Rotameters

Typical Performance Characteristics – Variable Area Flow Meter and Rotameters

1. Pipe Diameter Range:	1/8 inch to 4 inch
2. Max. flow rate:	600 US gpm water, 1200 SCFM gas.
3. Percent Accuracy at Full Span:	+/- 3.0%. FS
4. Repeatability:	+/- .5%
5. Turndown Ratio:	10:1
6. Length of straight pipe required:	No up-stream straight pipe required.
7. Operating temperature range:	Up to 700 ^{O} F
8. Operating Pressure Range:	Up to 1000 PSIG (stainless steel)
9. Discharge Coefficient Cd:	not applicable
10. Permanent pressure Loss:	low
11. Minimum Reynolds Number:	laminar range.
12. Fluid Density correction required :	Yes
13. Cost of Meter: (no transmitter)	$ 500 to $ 2,000 ½ inch to 4 inch.
14. Cost of Installation:	$ 800. Vertical Pipe only.
15.) Total Cost: (no transmitter)	**$ <u>1,300 to $ 2,800</u>**

16.) Add 4-20 ma transmitter to rotameter $ 1,500 17.) Total Cost: **<u>$ 2,300 to $ 3,800</u>**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 11.) = $ 1,500

1.1.8 Variable Area Flow-meters - Float Type and Rotameters

Advantages and Disadvantages Variable Area

Advantages

- Low Cost
- Easy to read, direct read-out with pre-calibrated flow scale.
- Electric Power not required, depending on model.
- Compact installation, no upstream piping required.
- Can be equipped with electronic output for remote metering.

Disadvantages

- Vertical mounting only- may make installation cost high.
- Low flow projects.
- Low accuracy.

1.1.9 Target Variable Area (TVA) Flow Meters for Steam and other Fluids.

The TVA flow meter is designed for **saturated and superheated steam**. It operates on the principle that a cone shaped target in the flow stream is displaced by the pressure drop across the cone. This creates a strain on the target which produces a signal output which is then converted to a mass flow within the multivariable transmitter.
The TVA has a 50:1 turndown ratio and comes **complete with a multivariable transmitter** as a standard feature**.** The corrected mass flow communicates via an RS 232, RS 485, Modbus or 4-20 m.a. output. The transmitter also provides a local display reading of steam flow and other the parameters.

Fig. 1.22, Target Variable Area (TVA) Flow Meter for <u>Steam</u> with 50:1 turndown

Steam Flow

Image Courtesy of Spirax Sarco website "Steam Engineering Tutorials",
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

1.1.9 TVA Target Variable Area Flow Meter for Saturated Steam

Applications – TVA Variable Area Flow Meter

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
Note: Saturated and Superheated steam only			☆					

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.1.9 Typical Performance Characteristics – TVA Variable Area

1. Pipe Diameter Range: 2 inch, 3 inch and 4 inch.
2. Accuracy: 2% AR over the range of 100:1, 0.2% AR over the range of 10:1
3. Repeatability (Uncertainty) : 2% over range of 10:1
4. Turn-down Ratio: 50 to 1
5. Straight Length Pipe Diameters: 6 D upstream, 3 D downstream. Sched. 40 pipe is standard. Other schedules on request.
6. Operating Pressure Range: up to **464 psig** horizontal flow, up to **101 psig** vertical.
7. Operating Temperature Range: varies with pressure eg. **100 psig = 320 ^{O}F**
   290 psig = 390 ^{O}F
8. Permanent Pressure Loss: for 4 inch meter, 7.22 psi
9. Pressure Temperature Correction Required: No
10. Cost of Meter: $ 5,000 for 2 inch, $ 6,000 for 3 inch and $ 7,000 for 4 inch D. Price includes multi-variable transmitter,
11. Cost of installation: $ 1,500 to $ 3,000. May require steam separator upstream.

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. This meter is purchased complete with multivariable transmitter.

Advantages and Disadvantages Target Variable Area (TVA) Flow Meters

Advantages

- High turndown ratio for steam. 50:1.
- Low Cost when the standard Multivariable Transmitter is included

Disadvantages

- High permanent Pressure Loss (PPL)

1.1.9a The Gilflo Target Variable area Flow Meter for Steam and other Fluids

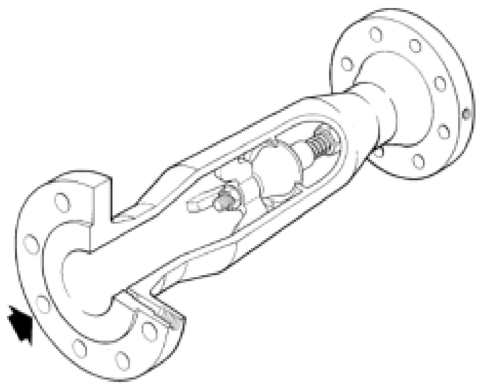
Spirax Sarco manufactures a range of target variable area flow meters primarily used **for steam flow measurement** but also applicable to other gases and liquids. The metering principle is as described above. The **Gilfo** range of meters is available in several sizes :

- Gilflo “B” with Pipeline Flanges from 2” to 18” for utility and industrial metering.
- Gilfo ILVA In-line-wafer mount from 2” to 12”.
- Gilfo TVA wafer mount with MV transmitter included, 2” to 4 “.
- Gilflo TFA wafer mount and MV transmitter included, 1 “ to 2”.

The Gilfo B ® meter is a variable area flow meter designed for utility **pipeline applications.** It is available in a size range from 2 inch to 16 inch and capable of metering flow rates accurately with a turn-down of **100:1**. The Gilflo B can meter steam, water or natural gas but is mainly used in steam applications. The required length of straight pipe for severe upstream disturbance is much shorter than for most DP meters.

1.1.9a Gilflo -Target Variable area Flow Meter for Steam and other Fluids

Figure 1.23, Gilflo B ® High Turn-down Target Flow Meter



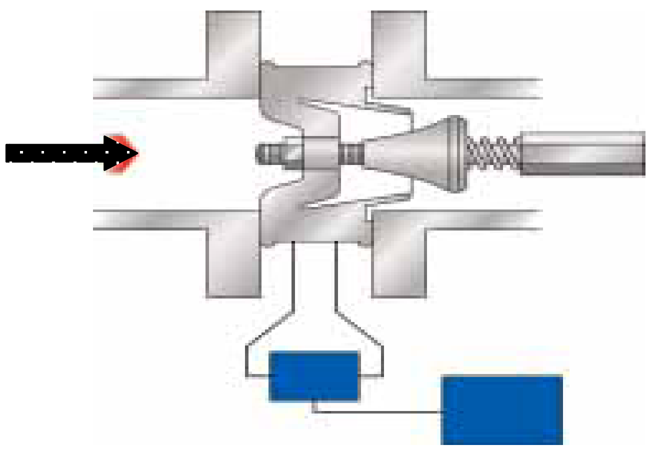
Gilflo B Variable Area Flow Meter
For Pipeline applications.

2 inch to 16 inch pipe diameter
100:1 Turndown.

May be used in custody transfer applications.

Image Courtesy of Spirax Sarco website "Steam Engineering Tutorials".

http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx



Gilflo B variable area flow meter cross section Illustrating the principle of operation.

Fluid Flow displaces the cone which is spring mounted. The position of the cone is proportional to the flow rate.
The position of the cone is detected electronically and the signal is processed by a transmitter.

Image Courtesy of Spirax Sarco Website, "Steam Engineering Tutorials"
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

Applications – Gilflo "B"® Variable Area Flow Meter

Natural gas	Other clean gases	Contaminat -ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam- inated or corrosive liquids	Com- pressed Air
○	○		☆	○				

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.1.9a Gilflo - Target Variable area Flow Meter for Steam and other Fluids

Typical Performance Characteristics – Variable Area (Gilflo ® Meter)

1. Pipe Diameter Range: 1 inch to 16 inch.
2. Accuracy: 1% (AR) for 20:1 turn-down, Reduced accuracy for 1% Max. flow.
3. Repeatability: 0.25%
4. Turn-down Ratio: 100 to 1
5. Straight Length Pipe Diameters: 6D upstream, 3D downstream depending on disturbance.
6. Operating Temperature Range: to 600 ^{O}F .
7. Permanent Pressure Loss: High
8. Pressure Temperature Correction Required: Yes
9. Minimum Reynolds Number: Operates at Low Re, Not specified by manufacturer.
10. Cost of Meter: **$ 6,400 to $ 9,900** for 4 inch an 8 inch D.
    add $ 500 for Temp., transducer.
    Add $ 4,000 Multivariable Transmitter
11. Cost of installation: $ 1,500 **12. Total Cost: $ 12,400 to $ 15,900**

Advantages and Disadvantages of the Variable Area (Gilfo ®) meter

Advantages

- High Accuracy
- Custody Transfer Approval(s)
- High Turn-down
- Good for steam and saturated steam.
- Short straight pipe length required.
- Wide range of clean gases and liquids. 2-phase flow O.K.

Disadvantages

- High Permanent Pressure Loss.
- High cost

1.2) Positive Displacement Flow Meters

INTRODUCTION

The Positive Displacement **(PD)** category of flow-meter includes various types of meters as follows:

Meter Type	Typical Applications
1.) Nutating Disc (Not discussed in flow meter guide)	Residential Water Meters
2.) Rotary Lobe	**Utility billing meters for large volume natural gas customers. Sub-meters for energy management. Batch metering for liquids and various gases in industry.**
3.) Gear Meters (Not Discussed in flow meter guide)	Precision metering in industrial plants. Special applications such as liquids, oils. Hydraulic oil system metering.
4.) Diaphragm meters	**Small volume natural gas (eg. Residential billing meters) Small Industrial Metering Projects.**
5.) Piston Meters (Not Discussed in flow meter guide)	High viscosity liquids eg. oils and liquid resins.
6.) Turbine Meters.	**Utility and Industrial Applications including gas, water and other liquids.**

Positive Displacement Meters – Basics

Positive Displacement meters (PD) measure flow by mechanically displacing a moving part in the meter, then counting the number of displacements per unit of time. Each count represents a **volumetric amount** of fluid. At each count, the fluid passes through the meter. The energy required to drive the moving parts of the meter is supplied by the pressure of the fluid being metered. **In this section 1.2, we discuss Rotary Lobe, Diaphragm and Turbine meters.**

1.2.1 Rotary Lobe Meters - Basics

Applications

Rotary lobe meters are used mainly for natural gas billing for commercial and industrial customers when loads exceed 1,000 Cubic Feet per Hour (CFH). They are mainly used for gases and liquids in industry and in oil and gas production. They have also been used in industrial sub-metering applications for **energy management**. The main reason for their use is high accuracy, and ruggedness. ANSI/ASC B 109.3 approves these meters for **custody transfer.**

A Rotary Lobe flow-meter **directly measures the actual volume of fluid** which passes through it, at the actual operating pressure.
Two counter-rotating lobed impellers rotate within a casing. (**See figure 1.24**). Gas or liquid flowing through the meter drives the impellers which trap a know volume of gas in the inter-space. The flow volume is proportional to the speed of rotation.
The volume is measured by counting revolutions and multiplying the count by the known volume displaced with each revolution. Counting can be accomplished mechanically or electronically. The most common arrangement is to embed magnets in the lobes. These are sensed by proximity switch “pick-ups” mounted in the meter casing. Switches driven by the magnets activate local digital displays or are input to an integral electronic system for processing, correction and remote communication.

1.2.1 Rotary Lobe Meters

Fluid Applications – Rotary Meters

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquid Hydro-carbons	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
☆	☆			○				

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid’s characteristics.

1.2.1 Rotary Lobe Meters

Figure 1.24
Rotary Lobe Gas meter

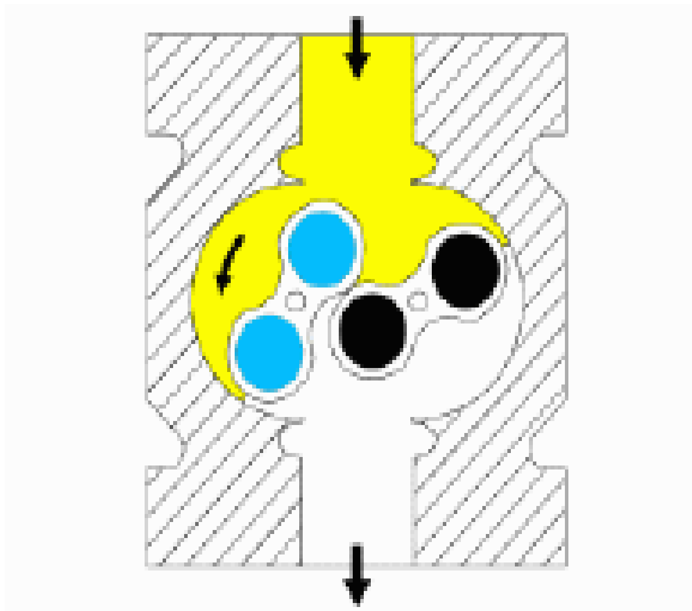


Image Courtesy of Romet International, www.rometlimited.com

Typical Performance Characteristics of Rotary Lobe Meters.

1. Pipe Diameter Range:	2 inch to 6 inch
2. a Flow rate at 14.7 PSIA 60^{O} F:	627 SCFH smallest to 58,000 SCFH largest.
2..b Flow rate at 50 PSIG 60^{O} F	2,623 SCFH smallest to 150,000 SCFH largest.
3. Percent Accuracy % AR:	+/- 0.5% AR
4. Repeatability:	+/- 0.1%
5. Turndown Ratio:	80:1 or better
6. Length of straight pipe required:	No up-stream straight pipe required.
7. Operating temperature range:	- 40^{O} F to + 140^{O} F
8. Operating Pressure Range:	Up to 175 PSIG
9. Discharge Coefficient Cd:	not applicable
10. Permanent pressure Loss:	low
11. Minimum Reynolds Number:	laminar range.
12. Fluid Density correction required:	Yes
13. Cost of Meter: (temp. comp.)	\$ 3,900 to \$ 4,500 for model 3000 and 5000 SCFH
14. Cost of Installation:	\$ 3,000 with by-pass

Note: item 2.) Flow ratings for rotary meters for natural gas billing duty are typically rated at standard conditions, but usually operate at pressures and temperatures outside the standard range. Therefore, when sizing a meter it is important to provide the actual operating conditions to the manufacturer.

1.2.1 Rotary Lobe Meters

Advantages and Disadvantages of Rotary Lobe Meters

Advantages

- High Accuracy
- Low cost due to large production quantities.
- Very low turn-down ratio.
- Able to meter fluids with low Reynolds Number.
- Reliable and Rugged. Low maintenance costs.

Other Factors

- The volume flow must be corrected to standard conditions when operating at fluid temperatures and pressures outside the calibration range. This function is done automatically when the meter is used as a billing meter.
- A by-pass with manual isolation valves is recommended in case of mechanical failure.

On-Board Electronic Density (Pressure, Temperature) Compensation

Gas density compensation can be achieved using the meter manufacturer's optional features supplied with the meter. Compensation for temperature and pressure variation and super-compressibility are available with rotary gas meters. Contact outputs for local use (Energy Management) are available. This meter, having advanced electronics, has a range of 200:1 with less than 1% error.

Figure 1.25, Rotary Lobe Meters

The advanced electronic module (AdEM) can be adapted to existing rotary meters providing high rangeability and accuracy as well as gas data logging and communications.
Image Courtesy of Romet Meters, www.rometlimited.com

1.2.1 Rotary Lobe Meters-Electronic Density (Pressure, Temperature) Compensation

Microprocessor based electronic gas volume correction systems perform the functions of correcting gas volume for temperature and pressure. They provide a local display of all gas readings, and communication through serial port or by phone line to the gas utility. For a cost of approximately $ 1,500, some of these systems can be retrofit with a pulse output circuit board which can supply the gas customer with his own real-time gas flow signal. This will require the agreement and cooperation of your local gas utility.

As an industry standard, billing gas meters are calibrated for standard inlet conditions of **14.73 PSIA and 60^{O} F**. The standard temperature is **60 ^{O}F or 520 ^{O}R**. In service, these meters operate at temperatures and pressures which vary from this standard.
Volumetric flow readings are converted by the electronic flow computer to mass flow and corrected for density variation caused by pressure and temperature operating conditions. The example below shows the calculation involved:

Density Correction for Billing Purposes – Example
Note: Assume the meter is calibrated at a standard pressure of gas at 14.73 PSIA (0 PSIG) and a standard temperature of 60 ^{O}F (520 ^{O}R)

Example 1: Correct for Pressure Variation only.
The actual flow reading is **100 CFH at 10 PSIG**
Correct flow reading at the actual pressure of 10 PSIG 0 PSIG or 14.73 PSIA.
Actual flow = **100 CFH X (10 + 14.73) / 14.73 = 167.8 SCFH**
Note: Pressure variation is usually not a factor with small installations when the meter has an upstream pressure regulator.

Example 2: Correct for Temperature Variation Only
The actual flow reading at 90 ^{O}F is 100 CFH.
Correct flow reading to 60 ^{O}F
Actual flow = **100 SCFH X (460 ^{O}F + 60 ^{O}F) / (460^{O}F + 90 ^{O}F) = 94.5 SCFH**

Example 3: Correct for both temperature and pressure variation. The actual Temperature is 90 ^{O}F and the actual pressure is 10 PSIG:
Correct the flow reading at actual pressure and temperature to standard.
Actual flow = **100 X ((10 + 14.73)/14.73 X (460 ^{O}F + 60 ^{O}F)/(460^{O}F + 90^{O}F**) = **158.6 SCFH**

Note: Standard pressure conditions vary with the altitude of the location. In Toronto, for example, the standard pressure is **14.55** PSIA. In this location, **14.55** would replace **14.73** in the numerator of the equation to give the standard pressure correction factor.

Utility meters come equipped with integral gas pressure and temperature sensors which continually supply these signals to an electronic computer which calculates the corrected flow values.
Standard Rotary Lobe meters are available in ratings up to 175 PSIG and in sizes up to 60,000 SCFH through-put. Special meters can handle higher pressures.

1.2.2 Axial Turbine Flow Meters – Utility Billing Meters

Turbine flow meters are available in a very wide range of sizes types and prices. Turbine meters are used in many applications in industry and for billing purposes by water and gas utilities.

Utility type Turbines for metering gas and water are approved for custody transfer. Turbine meters are approved by **AGA report 7.** They are normally supplied with corrected mass flow reading electronic outputs and communication capability. A prominent use of turbine meters is metering and billing **large volume customers**.

Fig. 1.26, Turbine Meter-Utility Type for Natural Gas Custody Transfer

Turbine Gas Meter for custody transfer (Billing Meter)

Image Courtesy of Enbridge Gas Distribution Inc.

www.enbridgegas.com/contact-us

Typical Performance Characteristics – Turbine Meters – Utility Billing Meters

1. Pipe Diameter Range:	up to 12 inch.
2.a Flow rate at 14.7 PSIA 60^{O} F:	84 SCFH smallest to 51,000 SCFH largest.
2.b Flow rate at 50 PSIG 60^{O} F	364 SCFH smallest to 220,000 SCFH largest.
3. Percent Accuracy % AR:	+/- 0.25%.
4. Repeatability:	+/- 0.05%
5. Turndown Ratio:	10:1 up to 100:1 with lower accuracy
6. Length of straight pipe required:	No up-stream straight pipe required. Internal flow straighteners
7. Operating temperature range:	- 450^{O} F to + 570^{O} F for gases (excludes electronics).
8. Operating Pressure Range:	Up to 1350 PSIG 4 inch diam. Lower for larger meters.
9. Discharge Coefficient Cd:	not applicable
10. Permanent pressure Loss:	1.8 PSI at max. flow. Varies with gas density.
11. Minimum Reynolds Number:	can measure in laminar range.
12. Fluid Density correction required :	Yes
13. Cost of Meter:	8 inch $ 9,500 Low Press., $ 18,300, High Press.
14. Cost of Installation:	$ 3,000

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters.

1.2.3 Industrial Turbine Meters, In-Line and Insertion Type

Industrial turbine Meters are available as, **in-line** and **insertion** type meters.
Insertion turbine meters are available in a wide range of sizes, and materials from ½ inch to 36" and larger. Because of their ability to meter large pipe flows, they are often used for stack gas monitoring. They cover a **wide range of applications** in industry for metering steam, water, air flow and other gases.

Typically, depending on size, the price for standard industrial turbine meters varies from a few hundred dollars to $ 7,000 or more.

Fig. 1.27, Industrial Turbine Flow Meters – Insertion and In-line type

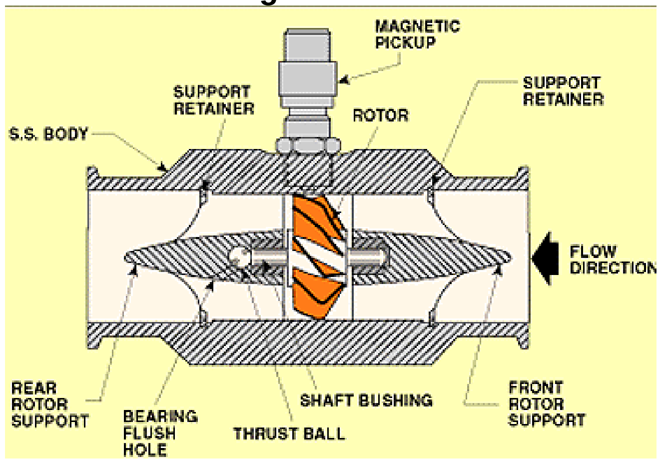
ONICON model F-1500 insertion turbine meter measures steam, gases and high temperature hot water. Pulse output for totalization and 4-20 mA analog output for flow rate.

ONICON F-1300 in-line turbine flow meters measure water and water/glycol mixtures in ¾ inch and 1 inch pipes.
+/- 0.5% of reading accuracy at the calibrated (typical) HVAC flow velocity and within +/- 2% of reading over a 50:1 flow range. May be connected to a display or BTU meter.

Images Courtesy of ONICON incorporated, www.onicon.com

1.2.3 Industrial Turbine Meters – In-Line Type

Figure 1.28, Cross section drawing of an industrial in-line axial turbine flow-meter



Reproduced with permission of Plant Engineering Magazine.
Image Courtesy of Omega Engineering Inc.
www.omega.com

Industrial Turbine flow meters directly measure the velocity of the fluid stream. **Qv.** Together with the velocity measurement, the mass flow can be calculated with **P** and **T** inputs. A flow computer **or** multi-variable smart transmitter at the meter is required. (see **appendix A**).
A rotor with attached blades is suspended in the fluid stream on free running bearings. **(See figure 1.28).** The rotational speed (RPM) of the rotor is directly proportional to the fluid velocity. There are a number means of counting rotations of turbines including from magnetic and electrical transducers embedded in the rotor or blades. These transducers produce a weak pulse or sine wave electronic output which is converted electronically to a flow velocity **Qv**, then to a 4-20 m.a. output signal from the **transmitter**.
The **mass flow** is calculated by multiplying the volumetric flow by the fluid density.
Mass flow = Flow Velocity X Density X Pipe Area. **Qm = Qv x ρ x A**
A corrected mass flow requires additional inputs including pressure and temperature.

Fluid Applications – Industrial In-Line Axial Turbine Meters.

Natural gas	Other clean gases	Contaminat-ed gases	Steam	Clean Liquid Hydro-carbons	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
○	○			☆	◊			

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.2.3) Industrial Turbine Flow Meters – In-Line Axial Turbine

<u>Typical Performance Characteristics</u> – Varies widely with meter type and application. Check all applications and performance specifications with your supplier.

1. Pipe Diameter Range:	1/2 inch to 12 inch (in-line)
3. Percent Accuracy % AR:	varies from 0.5% to 2% AR
4. Repeatability:	+/- varies
5. Turndown Ratio:	10:1 up to 50:1 with lower accuracy
6. Length of straight pipe required:	None
7. Operating temperature range:	- 100^{O} F to + 450^{O} F
8. Operating Pressure Range:	Up to 500 PSIG. (extra cost for high press.)
9. Discharge Coefficient Cd:	not applicable
10. Permanent pressure Loss:	Varies with gas or water density and flow.
11. Minimum Reynolds Number:	Not applicable
12. Fluid Density correction required :	Yes for gas and liquids
13. Cost of Meter : Incl 4-20 m.a xmitter	$ 2,500 to $ 7,000, 2 inch to 6 inch
Add temp tranducer:	$ 500
14. Cost of Installation:	$ 1,500 **15.) Total cost $ 4,500 to $ 9,000**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 13.) = $ 1,500

Advantages and Disadvantages of Industrial, in-line Turbine Meters

In-line industrial turbine meters are available in a very wide range of sizes, flow rates, and fluids which they can handle.

These meters are suited to **energy management** applications because they are available in a wide range of diameters, and are lower in cost.

Advantages

- Good accuracy and repeatability.
- Wide Size Range
- Minimal upstream straight lengths of pipe required.
- May be low cost
- Low installation cost - InsertionType

Disadvantages

- High installation cost – in-line type.
- Moving Parts-susceptible to contaminants.

1.2.4 Industrial Turbine Meters – Insertion Type

Natural gas	Other clean gases	Contaminat -ed gases	Steam	Clean Liquid Hydro-carbons	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
○	○		○	☆	◊			

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.2.4 Industrial Turbine Meters- Insertion Type

Typical Performance Characteristics – <u>Insertion Type Turbine Meter</u>

1. Pipe Diameter Range:	2 inch to 36 inch or larger.
2. Percent Accuracy % AR:	+/- 1.0%. AR depends on operating range
3. Repeatability:	+/- 0.5%
4. Turndown Ratio:	50 to 1
5. Length of straight pipe required:	30 D upstream, 5 D downstream, for severe disturbances.
6. Operating temperature range:	- 40^{O} F to + 450^{O} F depending on materials (excludes electronics)
7. Permanent pressure Loss:	Low
8. Fluid Density correction required :	Yes
9. Cost of Meter: 2 inch + 6 inch D	$ 3,800 to $ 4,600 (No T or P correction)
10. Cost of Installation:	$ 800
11. Total Cost	**$ 4,600 to $ 5,400**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 9.) = $ 1,500

Advantages and Disadvantages of Insertion Turbine Flow Meters

Advantages
- Low initial cost, especially for large pipe diameter applications.
- Low installation cost. Can be hot-tapped. Good for temporary installations and Energy studies.
- Can be hot-tapped depending on fluid and pressure.
- Easy to service and calibrate.
- Good accuracy.
- Portable Test Version available for temporary installation and energy studies
- Able to meter large diameters at low cost.
- Turbine impeller can be changed out for new flow conditions.

Disadvantages
- Susceptible to vibration especially if secured only at one end.
- Lots of straight pipe required, depending on severity of up-stream disturbance.

1.2.4 Installing Insertion Type Flow Meters-Insertion Type – General

Because of their relative ease of installation and removal (for maintenance), insertion meters are an attractive alternative to in-line flow meters for many applications including **Energy Management** . Several different types of insertion flow-meters are available including **Turbine, Vortex, and Thermal Mass Flow meters.**
Their main advantage is **that installation time and cost is significantly less** than for in-line meters which require cutting and welding or threading pipe.
Insertion meters can also **be hot-tapped** in some applications depending on pressure and the fluid being metered. With natural gas, hot tap drilling is by hand (the gas code does not allow electric drills).
The meters are inserted through a ball valve and can be removed for calibration or replacement without shutting down the process. This depends on the fluid being measured and the pressure. Removal and re-insertion have to be done very quickly.

Figure 1.29, Contractor hot-tapping a 30 PSIG natural gas line to prepare for insertion of a flow meter.

Photo by B. Griffin, P.Eng., grgriffin@hotmail.com

Hot tapping for installation of the meter should only be done when process shut-down is impossible or very costly. Check your local **Gas Code**. No electric drills allowed.

1.2.4 Diaphragm Meters – Basics

Diaphragm flow meters are ubiquitous. There are tens of millions of this type of meter installed in the U.S., Canada and worldwide in residential and commercial service. Large diaphragm meters are also installed in smaller industrial sites as billing meters. Diaphragm meters are manufactured in pipe connection sizes from 1/2 inch to 4 inch diameter.
They are available for inlet gas pressures from 5 psig to 100 psig. Their capacity ranges from 150 CFH to 5000 CFH at a pressure differential across the meter of ½ inch W.C. The main attributes of diaphragm meters are **low cost, high accuracy and reliability**

Small diaphragm meters for natural gas metering require 5 to 10 PSIG inlet and meter up to 250 CFH or natural gas. Large diaphragm meters operating up to 100 psig are capable of measuring over 11,000 CFH of natural gas. Small diaphragm meters can be purchased for as little as **$ 100 on line**.

Large diaphragm meters for industrial and large commercial applications can be supplied with pulse output and communication features as optional equipment. A diaphragm meter having a 1-1/4 inch threaded connection operating at 10 psig with pulse output feature will cost approximately **$ 2,500.**

Figure 1.30, Diaphragm Gas Meter for Residential billing.
Photo Courtesy of Enbridge Gas Distribution Inc.

www.enbridgegas.com/contact-us

A large majority of diaphragm meters are sold to gas utilities for residential use and most of those in the field are smaller units. They can be purchased very inexpensively because they are manufactured in large volumes.

Manufacturers include:
www.elster-americanmeter.com, www.sensus.com, www.ge-energy.com,
A brief history of the diaphragm meter is mentioned in an article “Fundamental Principles of Diaphragm Displacement Meters” by Mr. Robert Bennett of the American Meter Company. www.asgmt.com. This history goes as far back as 1823 when The New York Light Company first began to meter gas to customer sites.

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1.2.4 Diaphragm Meters – Basics

How Diaphragm Meters Work

A diaphragm meter comprises an outside casing which is charged with natural gas (or other gas) and which houses two gas bellows (diaphragms). Each diaphragm has a slide valve which alternately opens and closes the inlet valve and the outlet valve to each diaphragm.

As gas flows into the meter the bellows fill up and empty alternately by means of slide valves which act as counters. As each valve closes and then opens, one known volume of gas is counted. A mechanical linkage connects each valve to a counter which registers a count and a display which shows it on a dial. The gas is discharged into the meter casing and to the outlet of the meter.

The two sets of bellows and valves operate alternately in order to provide a continuous flow of gas.
The mechanism is driven by gas pressure on the bellows and the result is a small pressure drop across the meter.

Diaphragm meters employed in billing applications for natural gas are installed with a pressure regulator upstream in order to maintain constant pressure. This eliminates the need for a pressure correction transmitter. Temperature variations can cause error however, in practice, the temperature changes are minor when gas is supplied via underground piping.

A detailed description of the operation of a diaphragm meter can be found in the article: **"Fundamental Principles of Diaphragm Meters"** by Robert Bennett of the American Meter Corporation. www.asgmt.com

Fluid Applications – Diaphragm Meters

Natural gas	Other Clean gases	Contaminat-ed gases	Steam	Clean Liquid Hydro-carbons	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
☆	☆							

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.2.5 Typical Performance-Diaphragm Meters

1. Pipe connection diameter:	1/2 inch to 1-1/4 inch. (residential) Up to 4 inch (Commercial/Industrial)
2. Standard Pressure Max. Rating:	5 or 10 PSIG. (residential), 100 PSIG (commercial Industrial)
3. Operating line Pressure Range:	0.25 PSIG to 10 PSIG (residential) Up to 100 Psig (industrial)
2. Flow rate gas:	150 CFH to 250 CFH (residential) Up to 11,000 CFH (commercial/Industrial)
3. Percent Accuracy % AR:	less than +/- 1.0%. (AR)
4. Repeatability:	+/- 0.2%
5. Turndown Ratio:	25 to 1
6. Length of straight pipe required:	not required.
7. Operating temperature range:	- 30^{O} F to + 150^{O} F
9. Discharge Coefficient Cd:	not applicable.
10. Permanent pressure Loss:	½ " W.C. ANSI Standard
12. Fluid Density correction required :	Inlet Pressure is regulated
13. Cost of Meter:	$ 150 to $ 2,500 includes pressure compensation.
14. Cost of Installation:	$ 200 to $1,500
15. Total Cost:	**$ 350 to $ 4,000**

Note - Cost of Meter No transmitter: Prices are approximate in U.S. $ for standard meters.

Advantages – Diaphragm Meters

- Inexpensive and Accurate
- Can be used for small Energy management projects.
- Pulse output and communications capability available.

Disadvantages

- Clean gases only
- Large Heavy and expensive in large sizes.

1.3) ELECTRONIC FLOW METERS

In the past 25 years, a range of flow meters which employ electronic, rather than mechanical means to measure flow velocity or mass have been developed. The fundamental principles of fluid dynamics are still the basis of the measurement, but means of detecting the flow velocity have moved from Pressure Differential, and Mechanical Volume measurement, to other technologies which rely on electronics to detect and interpret an electrical output signal.

The Main Types of Electronic Flow Meter

Meter Type	Typical Applications
1.) Vortex Shedding Meter	Gases, water, steam.
2.) Electromagnetic Meter	Liquids
3.) Thermal Mass flow Meter	Gases
4.) Ultrasonic Flow Meter (Transit Type)	Liquids, Gases
5.) Ultrasonic Flow Meter (Doppler Type)	Liquids, Gases
6.) Coriolis Mass Flow Meter	Liquids, Gases – Batch Control, Blending and Process Control.

The above table shows the main types of electronic flow meter found in industrial facilities.

1.3.1 Vortex Shedding Meter - Basics

The principle of operation of a vortex shedding flow-meter is the phenomenon of the formation of eddy currents (vortices) downstream of a sharp edged object (called a bluff body or a shedder bar) immersed in a flowing stream of fluid. As the fluid flows past the stationary body, it begins to form alternating vortices which separate and flow down stream. The example of a flag waving in the breeze is often given in the literature on this subject.

Figure 1.31, Basic Principle - Vortices Shedding from Flow past a Bluff Body

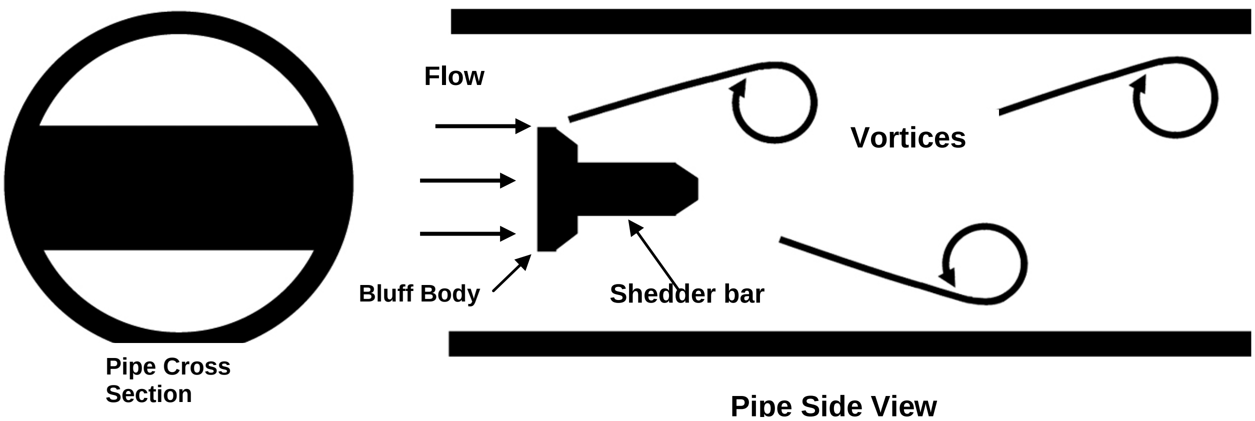


Image Courtesy of CB Engineering Ltd., Calgary, AB, www.cbeng.com

Typically the bluff body occupies 35% of the pipe cross sectional area however; newer materials have made it possible to reduce this to approximately 10%, reducing the pressure loss through the meter element.
The vortex shedding meter has the property that the frequency with which the vortices are shed is directly proportional to the Velocity of the flow as follows:

$$\mathbf{F = V / 2\pi w}$$

Where: F = the frequency of vortex shedding
V = the fluid velocity
w = the width of the bluff body

One limitation is that the Reynolds Number (Re) should be greater than 10^4 for consistent and reliable vortex formation.

The formation of the vortices causes pressure pulsations in the fluid. These pulsations are transferred through the fluid. They are detected by various types of sensors. The frequency of the pressure pulses is **dependent only on fluid velocity** and independent of pressure, temperature and viscosity. Thus, **the vortex shedding meter measures velocity and volume flow.**

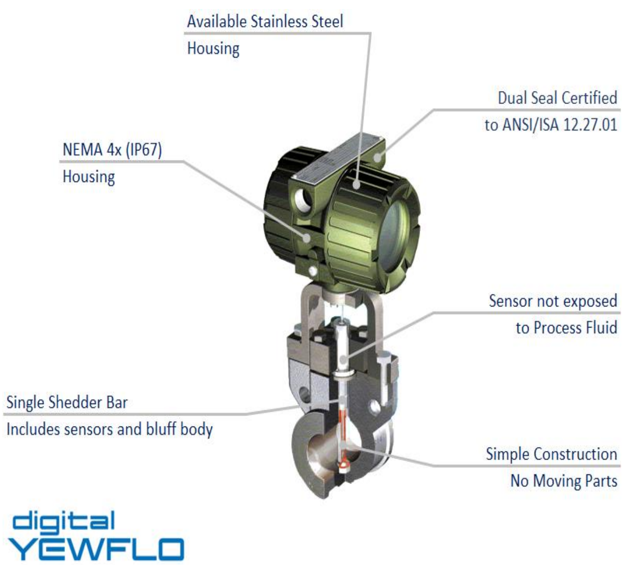
1.3.1 Vortex Shedding Meters - Basics

Electronic frequency detection systems vary among different manufacturers. All of these methods convert pressure variations (vortex frequency) to an electrical voltage signal which in turn produces a flow reading. The means of detecting the vortex pressure pulsations include for example:

- **Piezoelectric sensors** are located inside the shedder bar. These sensors detect the flexing of the shedder bar as pressure pulsations are generated by the vortices. This is the most common arrangement available and it employs two sensors which operate in such a way as to verify the pulse.
- The pulses are detected by the meter's transmitter and converted to a displayed value or communicated to a flow computer.

One **caution** is that vortex meter frequency detection systems can be influenced by external pipe vibration, picking these vibrations up and generating an erroneous reading. Some electronic systems have filtering capabilities which minimize this. This factor should be included in your discussions with suppliers if your application may involve pipe vibration. Another limitation of the vortex shedding meter is that it requires 20 straight pipe diameters up stream and 5 diameters down stream unless a flow straightener is installed.

Figure 1.32, Vortex Shedding Meter



The digital YEWFLO vortex flow meter combines the field proven sensor and body assembly used in more than 400,000 units installed worldwide with a unique and powerful digital technology (SSP) The digital YEWFLO vortex flow meter is accurate and stable, even in harsh process conditions, and has a highly reliable and robust design that delivers improvements in plant efficiency and reduced operating costs

Image Courtesy of Yokogawa
www.Yokogawa.com/us/products/field-instruments

1.3.1 Vortex Shedding Meters

Fluid Applications – Vortex Meters

Natural gas	Other Clean gases	Contaminat -ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam- inated or corrosive liquids	Com- pressed Air
☆	☆	◊		○				☆

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

Typical Performance Characteristics – Vortex Shedding Meters

1. Pipe Diameter Range (in-line):	½ inches to 16 inches.
1.b Pipe Diameter Range (insertion):	4 inches to 16 inches.
2. Flow velocity rate (gas):	0.4 to 600 feet per second (flanged)
2.b Flow rate (liquids):	2 to 18 feet per second.(flanged)
3. Percent Accuracy % AR:	+/- 0.75% for liquids, 1.0% for gases and steam.
4. Repeatability:	+/- 0.2%
5. Turndown Ratio:	range from 25 to 1 or better.
6. Length of straight pipe required:	20 D upstream, 5 D downstream, for severe disturbances.
7. Operating temperature range:	- 40^{O} F to + 500^{O} F depending on materials (Excludes electronics)
8. Operating Pressure Range:	Up to 2000 PSIG depending on model.
9. Discharge Coefficient Cd:	Not applicable.
10. Permanent pressure Loss:	Low (discuss with manufacturer)
11. Minimum Reynolds Number:	10,000
12. Fluid Density correction required:	Yes
13. Cost of Meter:	$ 3,700 to $ 4,700 for 2 inch to 4 inch D
Add	$ 1,000 for P + T transducers
14. Cost of Installation:	$ 1,500 wafer mounting.
15. Total Cost	**$ 6,200 to $ 7,200**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 13.) = $ 1,500

1.3.1 Vortex Shedding Meters

Advantages and Disadvantages – Vortex Shedding Meters

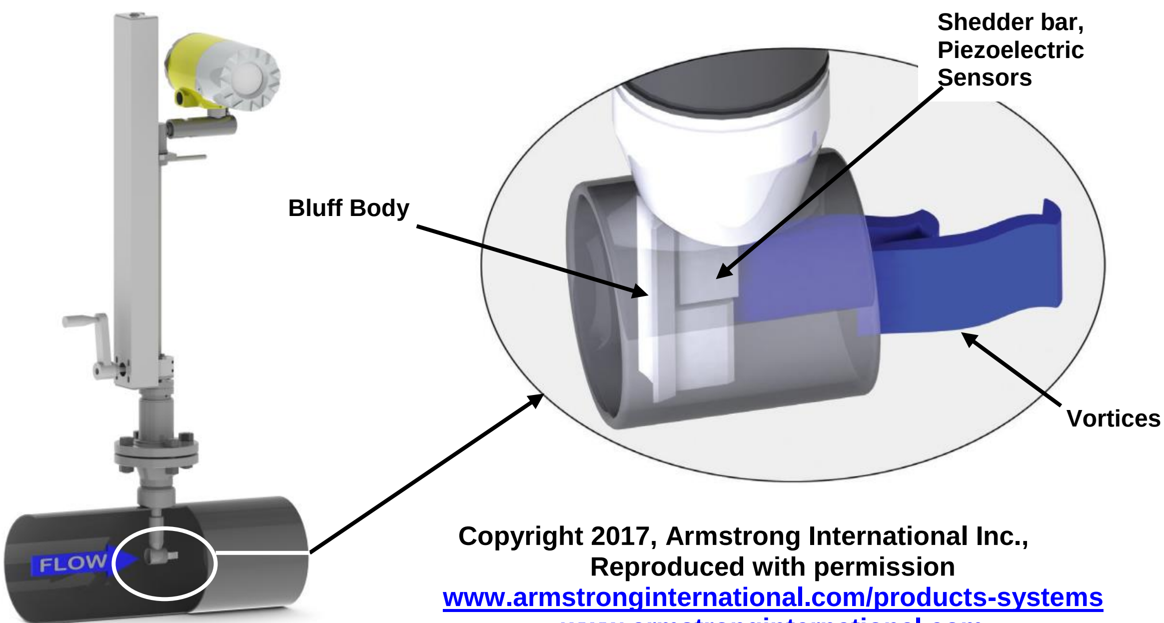
Advantages

- No moving parts.
- O.K. for low viscosity fluids (greater than Re of 10,000).
- Low wear on edges of shedder bar. Dimensional stability over life of meter.
- High accuracy and repeatability.
- Low cost for large pipe diameters.
- Very low maintenance.
- Insertion Type Vortex Meter has lower cost of installation approx. $ 800.
- Available in Wafer, Spool in-line and Insertion mounting.
- Approved for custody transfer by API Draft Report 2007.

Disadvantages

- Susceptible to pipe vibration which causes spurious readings.
- Straight pipe requirements. Possible to use a flow straightener.

Figure 1.33, Insertion Mounted Vortex Shedding Meter



The insertion mounted vortex shedding meter **Model AVI** is an innovation which provides the advantages of insertion mounting to vortex technology. (Ease and low cost of installation, ease of removal for inspection). Accuracy is +/- 2% AR. This meter is available with a multivariable transmitter having on-board mass flow correction as well as ModBus, Hart and BACnet communication protocols.

Fig. 1.34, Swirl Flow Meter

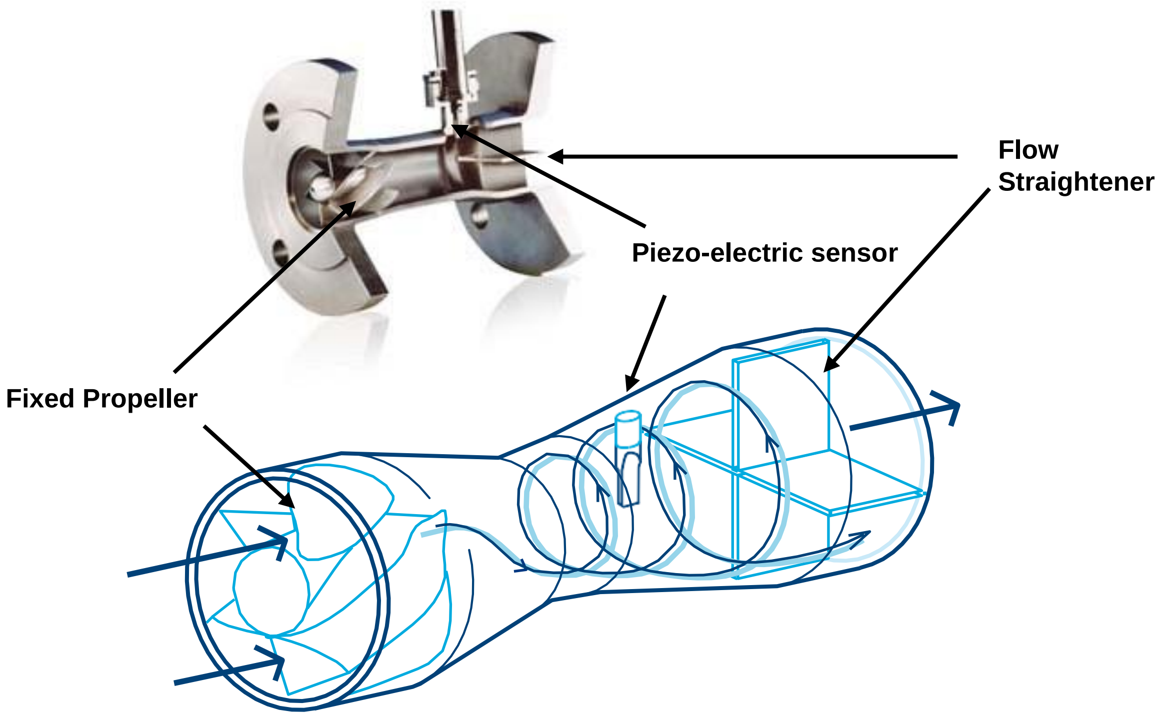


Image Courtesy of ABB, www.abb.com/flow

The ABB SwirlMaster FSS 450, for **Volume, Mass** and **Energy** flow. This meter can be used to meter liquids, steam and gases.
The swirl flow meter comprises a **fixed propeller** at the inlet, together with a tapered meter body. The propeller causes the fluid to swirl in rotational velocity which is proportional to the fluid velocity V. At the outlet of the meter a de-swirler straightens out the rotating flow stream.

The swirl meter can be compared to the vortex shedding meter in the sense that they both disturb the flow stream creating a regular oscillating flow pattern which can be used to determine flow velocity. The swirl meter creates a more stable oscillating pattern than the vortex meter which uses a bluff body in the flow stream to create vortices.

The rotational speed of the fluid in a swirl meter is detected by a piezoelectric sensor located downstream of the propeller, producing a modulating signal which is proportional to velocity and is detected by the transmitter.
This meter has a **low upstream straight pipe requirement (3D)** and is available for pipe diameters **½ inch to 16 inch**. Accuracy is **0.5% A.R**. Standard temperature operating range is **– 55^{O}C to + 280 ^{O}C.** A version or the **SwirlMaster** is available for temperatures up to **400 ^{O}C.** An internal RTD eliminates the need to install a separate temperature transducer. A transmitter with LCD display is included.
Communication alternatives are 4-20 m.a. analog and HART digital.
Approximate cost: **$ 6,000 US** including multivariable transmitter.

1.3.2 Electromagnetic Flow Meters - Basics

Electromagnetic flow meters were first invented in the 1930's and 1940's and implemented in the medical field. Foxboro patented the concept in the U.S. in 1952 for industrial applications.

The principle of operation is as follows:
An alternating magnetic field is applied by a coil, to a moving, conductive liquid (eg. water with dissolved solids). The fluid flows through the metering tube (which is non-magnetic). The magnetic flux from the coil penetrates the fluid inducing an electrical voltage. The induced voltage is proportional to the strength of the magnetic field and the velocity of the liquid for a given liquid.

A set of electrodes which are located on opposite sides of the metering tube detect the voltage induced in the liquid. This voltage is measured by the Transmitter continuously.

Voltage induced. $\textbf{Volts} \;\alpha\; \textbf{B X D X Vel}$ Where: **Volts** = the voltage induced
B = magnetic field strength.
Vel = velocity of liquid.
D = Diameter of tube

Velocity of liquid. $\textbf{Vel} \;\alpha\; \dfrac{\textbf{Volts}}{\textbf{B X D}}$

D=Pipe Diameter, Es = voltage detected, V = Velocity of Liquid.

Figure 1.35, Magnetic Flow Meter Basic Operating Principle

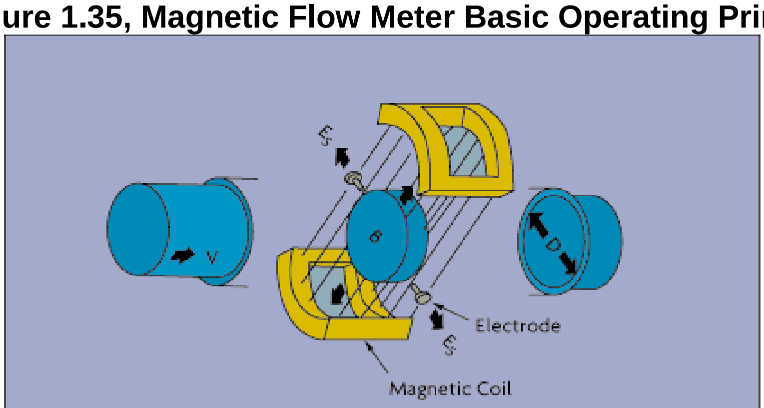


Figure 4-1: The Magmeter and Its Components

www.omega.com/literature/transactions

1.3.2 Electromagnetic Flow Meters - Basics

The voltage which develops at the detection electrodes is a low milli-volt signal. This is converted to a 4 to 20 milli-amp. or to a frequency signal output by the transmitter.
There are two main methods of exciting the main coil, namely, by AC sine wave current or by Pulsed D.C. D.C. is predominant because it results in a less "noisy" flow signal output from the electrodes.

The flow-tube of the meter is non-magnetic, usually a plastic material such as neoprene or Teflon, depending on the liquid being metered. The tube may also be non-magnetic stainless steel. The electrodes are embedded in the flow-tube and contact the liquid directly.
The meter reading is unaffected by changes in conductivity of the liquid, unless these changes are very large. There is however a minimum requirement for conductivity of approximately: 5 micro-siemens per centimeter (**5 µ S / cm)**. (Tap water has a conductivity of approximately **100 µ S / cm).**
There is a new type of electrode called a capacitance sensor which is embedded in the metering tube and does not contact the liquid. This unit can operate with liquids having lower conductivity of approximately **0.1 µ S / cm.**

Figure 1.36. Electromagnetic Flow Meter

The Hoffer Nor-Mag series electromagnetic flow meters are suited for electrically conductive fluids in water heating systems and diverse applications in manufacturing plants and large buildings where hydronic heating is present.
Electromagnetic flow meters can measure flow in both directions. There are no moving parts making them very low cost in terms of maintenance. There **is no pressure loss** through the meter since there are no mechanical parts in contact with the fluid, thus they are energy efficient. These meters are available with flanged or wafer mounting.
Pipe Size range is **½ inch to 12 inch D**. A flow transmitter is available in 4-20 m.a, USB or R 485

Image Courtesy of Hoffer Flow Controls Inc. www.hofferflow.com

1.3.2 Electromagnetic Flow Meters

Fluid Applications - Electromagnetic Flow Meters - Conductive Liquids Only

Natural gas	Other Clean gases	Contaminat-ed gases	Steam	Clean Liquids (conduct-ive)	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
				☆	☆	◊ ☆	◊	

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

Clean water, hot water, waste water, acids or bases (depending on meter tube material), slurries, pulp, juices.

Typical Performance Characteristics – Electromagnetic Flow Meters

1. Pipe Diameter Range **(in-line flanged):** ½ inch D to 12 inch D standard meters. Larger D for special designs.
1.b Pipe Diameter Range **(insertion)**: Up to 100 inch D.
2. Flow velocity rate (gas): Not applicable.
2.b Flow rate (liquids): 3 to 30 feet per second.
3. Percent Accuracy % AR: +/- 0.25% for liquids
4. Repeatability: +/- 0.1%
5. Turndown Ratio: range from 10 to 1 depending on Application.
6. Length of straight pipe required: 5 D upstream, 5 D downstream, more for severe disturbances.
7. Operating temperature range: up to + 300^{O} F depending on tube material.
8. Operating Pressure Range: Up to 200 PSIG depending on diameter.
9. Discharge Coefficient Cd: Not applicable.
10. Permanent pressure Loss: Very low
11. Minimum Reynolds Number: Low. Can handle laminar flow
12. Fluid Density correction required: No for pressure. Yes for large T variation
13. Cost of Meter: incl. 4-20 ma : $ 3,000 to $ 9,000, 4 inch to 8 inch D.
Add $ 500 for T transducer .
14. Cost of Installation: $ 1,500 **15.) Total cost: $5,000 to $11,000.**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 13.) = $ 1,500

1.3.2 Electromagnetic Flow Meters

Advantages and Disadvantages of Electromagnetic Flow Meters

Advantages

- No restriction in pipe, very low permanent pressure loss.
- Wide range of liquids can be accommodated.
- **Insertion type** available for larger pipe diameters, **(lower installation cost).**
- High accuracy - can be used for custody transfer for clean water.
- Low maintenance.

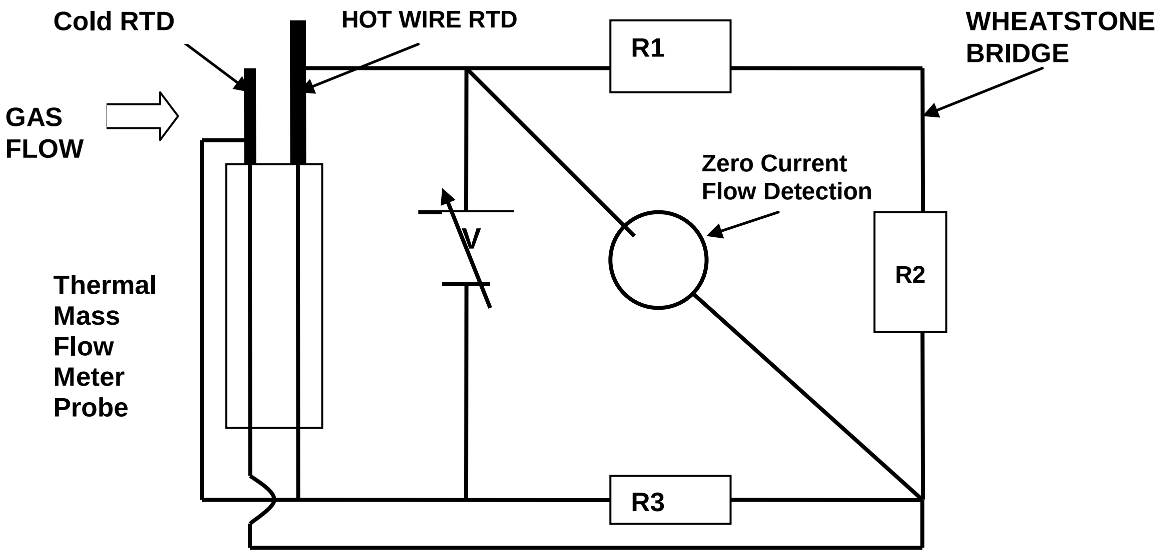
Disadvantages

- High initial cost for In-line type.
- Air bubbles entrained in liquid may cause erroneous readings.
- Coating of electrodes could be a problem. Capacitance type electrodes may be the solution.
- Pipe must be full.

1.3.3 Thermal Mass Flow Meters – Basics

Thermal mass flow meters directly measure the mass flow **Qm** of a gas. The advantage of the **direct measurement of mass flow** is that the flow reading **does not have to be corrected for pressure and temperature** variation of the fluid being measured.

Figure 1.37, Basic Circuit for a Thermal Mass Flow Meter



Principle of Operation:
A probe has two Resistance Temperature Detectors **RTD's** embedded in it. The probe is inserted into the flow stream. The upstream (cold) **RTD** measures the temperature of the incoming gas and the downstream probe (**hot wire**) is heated by an electric current. The bridge resistors R1, R2 and R3 are fixed values, which depend on the application. The current flow in the hot RTD is controlled by the voltage **V** which is applied to the hot wire in such a way as to maintain zero current across the bridge detector.

As the mass flow **Qm** of the gas increases, more heat is transferred to the fluid from the hot wire reducing its resistance. More power is then required to increase its resistance and to maintain the constant temperature difference between the two RTD's. The amount of current applied to the bridge detector increases or decreases in proportional to the mass flow of the fluid.

In order to design this system, the thermal characteristics of the gas must be known, that is, the rate of heat transfer from the hot wire to the moving stream is related to the type of gas (air, natural gas, nitrogen etc.). The set-up calibration of the meter is for a specific gas. The mass flow reading is independent of variations in gas temperature and pressure.

1.3.3 Thermal Mass Flow Meters – Applications

Thermal mass flow meters can be applied to a wide range of gases and over a very large flow range including laminar flow at the low end of the range and as high as 750 feet per second maximum flow rate.

Gases which can be measured include air, natural gas, and industrial gases such as nitrogen, oxygen, argon, carbon dioxide etc. Thermal mass meters have also been used in environmental monitoring applications such as landfill gas, digester gas, flare gas, and boiler exhaust gas. (Note, there is a gas temperature maximum of approximately 200 ^{O}F).

A caution in the use of this type of meter pertains to wet (saturated) gases. Condensate forming on the probe produces erroneous readings and potentially, corrosion.

Fluid Applications – Thermal Mass Flow Meters

Natural gas	Other Clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
☆	☆	◊						☆

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.3.3 Thermal Mass Flow Meters

Figure 1.38, Thermal Mass Flow Meters

Image Courtesy of ONICON Incorporated, www.onicon.com

Thermal Mass Flow Meter available as an insertion type or in-line meter.

In addition to being suited to permanent installation, having a low PPL, thermal mass flow meters are ideal for **energy management studies** because they are easy to install and they avoid the complexity of a flow computer or multivariable transmitter. Furthermore, there is no need to supply Pressure or Temperature Transducers.

Thermal Mass Flow meters can also be used as part of a system for **combustion control.** By providing accurate and reliable metering of the gas and air supply to a burner a special system can provide output signals to control actuators for industrial combustion equipment such as boilers and furnaces.

1.3.3 Thermal Mass Flow Meters – Applications

Typical Performance Characteristics – Insertion Thermal Mass Flow Meters

1. Pipe Diameter Range (flanged):	½ inch to 12 inch for most standard meters.
1.b Pipe Diameter Range (insertion):	Up to 80 inch or greater.
2. Flow velocity rate (gas):	Maximum 400 feet per second.
2.b Flow rate (liquids):	Not applicable.
3. Percent Accuracy % AR:	+/- 1.0% (AR), 0.2% of Full Scale (FS)
4. Repeatability FS:	+/- 0.2%
5. Turndown Ratio:	Greater than 100 to 1
6. Length of straight pipe required:	up to 30 D upstream, 5D downstream.
7. Operating temperature range:	- 40 ^{O}F to + 200 ^{O}F excluding electronics.
7 b. High temperature versions:	up to 700 ^{O}F
8. Operating Pressure Range:	maximum to 300 PSIG.
9. Discharge Coefficient Cd:	Not applicable.
10. Permanent pressure Loss:	Low
11. Minimum Reynolds Number:	Low. Laminar flow o.k...
12. Fluid Density correction required:	No, Mass Flow directly measured.
13. Cost of Meter:	$ 4,250 to $ 5,000 4 inch and 8 inch D.
14. Cost of Installation:	$ 800. (Insertion Type Only)
15.) Total Cost:	**$ 5,050 to $ 5,800**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters.

Advantages and Disadvantages – Thermal Mass Flow Meters

Advantages

- Easy and low cost to install and remove. Insertion type.
- Relatively low cost especially for large pipe diameter meters. (up to 72 inch)
- No correction or calculation required for mass flow. Mass flow is directly measured.
- In-line version pre-mounted in pipe available in diameters up to 4 inches.

Disadvantages

- Range of fluids limited to dry gases.
- Condensed water in wet gases forms on the thermal elements causing false readings and potentially corrosion.
- Thermal mass meters are not suitable for saturated steam metering.
- For compressed air applications the meter should be downstream of the air dryer.
- Straight Pipe Lengths Required up to 30 D.

1.3.4 And 1.3.5 Ultrasonic Flow Meters, Transit time and Doppler

There are over 100 companies listed in the Global Spec index (www.globalspec.com) as suppliers of ultrasonic flow meters having a presence in the U.S. market. Ultrasonic meters have developed significantly over the past 20 years to the point where they are reliable and accurate if properly applied. Their attraction is linearity, and the absence of obstruction to flow. The **clamp-on** version also features very low installation cost because it does not involve any pipe work.

Ultrasonic meters are primarily **used to measure liquid flow**. The liquid may be clear or it may have entrained particles or gas bubbles. Ultrasonic meters can also be used to measure the flow of gases. In the gas industry, they are now used routinely on larger pipe diameters. They are used for **custody transfer under AGA report 9.**

For **industrial energy management** applications, liquid flow is presently the most practical proven application. The **portable clamp-on** version is ideal for doing energy studies on hot or chilled water flow and for BTU measurement.

There are two main technologies which are prominent in the market:

- Transit Time
- Doppler

1.3.4 Transit Time Ultrasonic Flow Meters - Principle of Operation

Transit time ultrasonic low meters operate on the principle that a sound introduced into a flowing stream of liquid (or gas) takes longer to travel a known distance upstream, than it takes to travel the same distance in a downstream. A sound wave is sent in each direction, and the transit time is measured. The small difference in time that it takes for the sound to travel in each direction can be used to calculate the **flow velocity.**

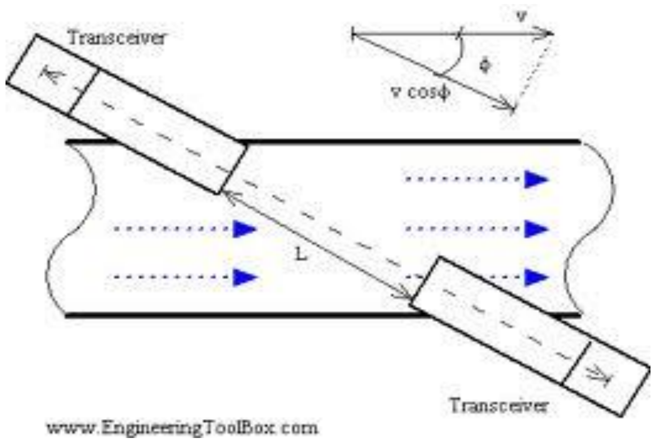
In practical example, a 2-inch pipe flowing water has transceivers installed up-stream and down-stream. (Note: Transceivers perform the dual function of transmitting and receiving). A burst of sound about ten cycles long having a frequency of approximately 1 MHz and a wavelength of around 1.5 mm, is sent alternately in each direction. Two transducers are located approximately 100 mm distance apart, and usually on opposite sides of the pipe at an angle to the center line. (**See figure 1.38**).
The speed of sound in water is approximately 1400 M/Sec. The speed of sound in air is approximately 350 M/Sec.

The operating frequency depends on the speed of sound in the fluid being measured and pipe diameter. Therefore, the meter must be calibrated for a specific fluid and pipe diameter.

1.3.4 Transit Time Ultrasonic Flow Meters

Principle of Operation

Figure 1.39, Arrangement of Transducers for a Transit-time Ultrasonic Flow-meter



Courtesy of the Engineering Tool Box, www.engineeringtoolbox.com

The sound bursts going in each direction are generated by piezoelectric crystals which vibrate at the required frequency specific to each application and meter size.

The development of electronic systems to measure the small difference in transit time between the up-stream and down-stream sound bursts has been a major technical achievement. The system must measure time difference in the order of 1 nano-second. The system contains on-board computers which calculate the flow velocity, and volume based on the relationship between the time differences every few milliseconds.

Applications for Transit Time Ultrasonic Flow Meters

Transit time flow meters in flanged, in-line configuration have been used with clean liquids or liquids with minor particles. Examples: city water, chilled water, hot water, grey-water, process liquids, clear oils and chemicals.

Fluid Applications – Transit Time Ultrasonic Flow Meters

Natural gas	Other Clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
☆	☆	◊		☆	◊	◊	◊	

☆ = good choice, check performance and cost. NOTE:☆ Four-Path ultrasonic meter, see fig. 1.40
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.3.4 Transit Time Ultrasonic Flow Meters

Figure 1.40, Transit Time Ultrasonic Flow-meter with In-line Flange Mounting.

The **Hoffer Transi-FLO I** Ultrasonic flow meter is available as a single beam or dual-beam meter. It is intended for flow measurements of conductive and non-conductive and aggressive liquids.

The electronic unit is available integral to the meter (as pictured) or as a remote unit. Transi-FLO I can be programmed to directly meter mass flow. Communication is via RS 485
Pipe size availability is 1 ¼ inch to 12 inch.
Liquid temperature range is 32^{O}F to 311^{O}F.

Courtesy of Hoffer Flow Controls Inc. www.hofferflow.com

Typical Performance Characteristics – Transit Time Ultrasonic Flow meters.
Specification and cost is for a typical a one-path transit meter.
Spool piece with flanges, for permanent installation, not strap-on version

1. Pipe Diameter Range (flanged):	1 inch to 12 inch standard meters.
1.b Pipe Diameter Range (clamp-on):	greater than 200 inch.
2. Flow rate (gas):	not available.
2.b Flow rate (liquids):	10,000 gpm for 12 inch diameter pipe.
3. Percent Accuracy % AR:	+/- 1.0% AR
4. Repeatability FS:	+/- 0.02%
5. Turndown Ratio:	100 to 1
6. Length of straight pipe required:	up to 15D upstream.
7. Operating temperature range:	up to 300 ^{O}F excluding electronics.
7 b. High temperature versions:	not applicable.
8. Operating Pressure Range:	maximum to 2,000 PSIG.
9. Discharge Coefficient Cd:	Not applicable.
10. Permanent pressure Loss:	Very Low.
11. Minimum Reynolds Number**:**	Approximately 10,000.
12. Fluid Density correction required:	Gas Yes, Liquid No.
13. Cost of Meter: Spool/w flanges	$ 4,000 to $ 9,000 4 inch and 8 inch D
14. Cost of Installation:	$ 1,500.
Add	$ 500 for P correction transducer.
15. Total Cost:	**$ 6,000 to $ 11,000**

Note – Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters. Typical cost for basic 4-20 m.a. transmitter included in item 13.) = $ 1,500

1.3.4 Transit Time Ultrasonic Flow Meters

Ultrasonic flow meters approved for **custody transfer** require multiple sonic paths to assure required accuracy. The unit shown is for natural gas custody transfer. Liquid versions are used to meter oil and hydrocarbons in pipelines.

Fig. 1.41, Four Path Transit Time Ultrasonic Flow Meter for Custody Transfer

Daniel SeniorSonic™ model 3414, 4-path ultrasonic gas flow meter,
Coutesy of Emerson Automation Solutions
www.emerson.com

This meter has accuracy of **+/- 0.05% AR** and a turndown of **100:1.** It can provide density corrected mass flow readings and communicate using HART communication protocol by means of its multivariable transmitter. Pipe size range is 4 inch to 42”. This meter has the capability can be managed by MeterLink™ software which diagnoses and detects flow disturbances in real time.

1.3.4 Transit Time Ultrasonic Flow Meters

Ultrasonic Meter Configured as a BTU Meter
BTU or Energy Meters are primarily used to meter the energy delivered to a hot water heating system. Much of this is done in commercial buildings but there are many applications in industrial processes.
Most types of water meters, can be used as a **BTU meter** for permanent installation or for energy studies of hot water heating systems. They may also be used in cold water delivery systems for building or process cooling.

Resistance temperature detectors **(RTD's)** are installed on the supply and return loops of hydronic heating system. The BTU flow to the heat load is calculated by metering the mass flow (using an ultrasonic flow meter). The **delta T** is measured by the two RTD's which measure the supply and return hot water temperatures. The heat (BTU's) delivered to the load is the product of the water mass flow **Qm** multiplied by the temperature difference:

Energy BTU α Qm X (Ts – Tr). **Ts** = Supply temperature and **Tr** = Return temperature.

Figure 1.42, Flow Meter Arrangement for BTU Metering of a Water Heating Loop.

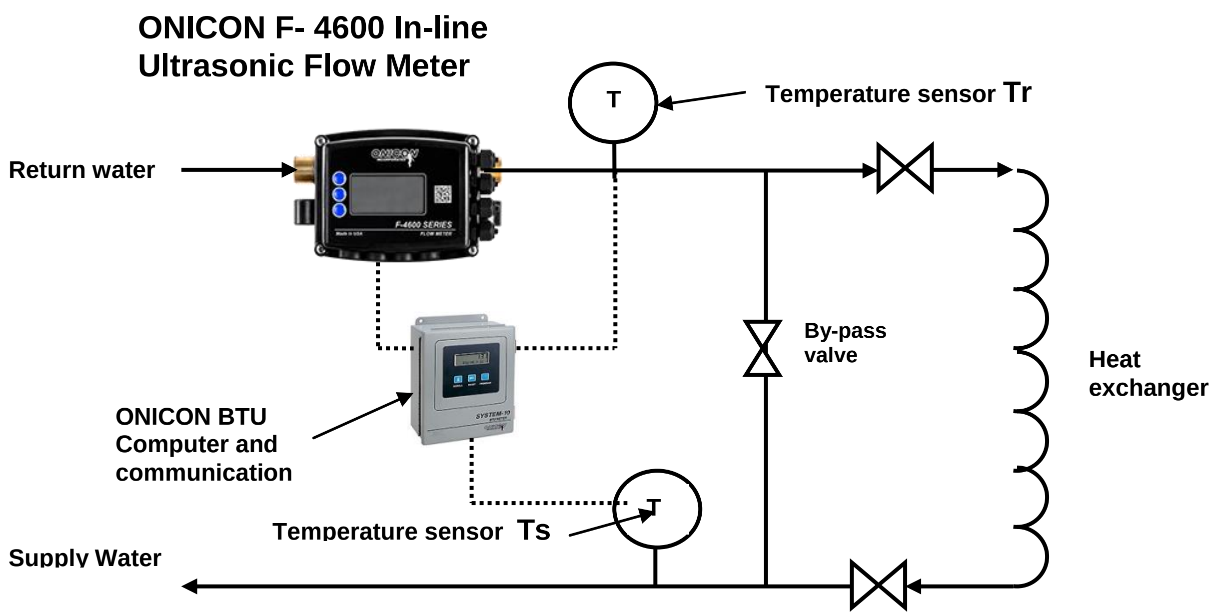


Image Courtesy of ONICON Incorporated , www.onicon.com

An ultrasonic flow meter can be used in a BTU water metering system by integrating it with temperature sensors and a BTU computer. The computer calculates BTU flow to a heating or cooling load. This is the difference in energy between the return and supply water to the load. The BTU computer is a special purpose computer/transmitter. This system is available to large or small users and can be economically employed with a wide range of large or small water flows and for various pipe sizes from ½ inch D to large diameter pipe.

1.3.4 Transit Time Ultrasonic Flow Meters

Advantages and Disadvantages of Ultrasonic Transit-Time Flow Meters

Advantages

- **Low Cost for larger diameters.** Strap on version
- No flow obstruction, low pressure loss across the meter.
- Low maintenance.
- High turn-down.
- Ease of installation (strap-on version).
- Low Installation cost approx. $ 500 for strap-on version.
- Portable, temporary test version available for energy management studies.

Disadvantages

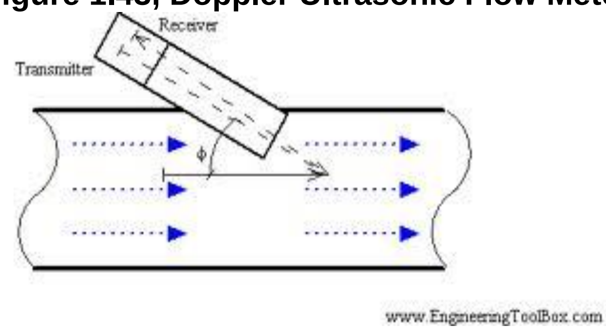
- Main use is water and liquid flow measurement but applications for gas measurement are developing with improvements in the technology. Use by natural gas utilities for custody transfer (in larger sizes) has increased in the past two years. Smaller units are beginning to be installed for residential and commercial customers.
- 15 D of Straight pipe up-stream or flow straightener is required unless pressure regulators are installed up stream.
- Pipe must be full of liquid for good reading. Mount vertically with liquid flow upward if possible.

1.3.5 Ultrasonic Doppler Flow Meters

The Doppler flow meter operates on the principle that when sound reflects from a moving object, a frequency shift in the sound occurs, and when detected, this shift is proportional to the velocity of the moving object.
This type of meter is applicable only to liquids having a minimum of 100 ppm of particulates or particulates or air bubbles having a minimum size of 100 microns.
The most common arrangement is a transducer and receiver (transceiver) located in a single head, clamped on to the exterior of the pipe.

A piezoelectric crystal **transmitte**r generates continuous sound of 0.5 to 1.0 M Hz and transmits in the upstream flow direction. The reflected sound frequency is detected by the **receiver** located in the same position and the velocity of the flow is calculated based on the frequency shift. Other variables included in this calculation are the pipe geometry as well as the base velocity of sound in the liquid. There is another configuration of transducers in which a separate receiver and transmitter are on opposite sides of the pipe.

Figure 1.43, Doppler Ultrasonic Flow Meter



Courtesy of Engineering Toolbox, www.engineeringtoolbox.com

The Doppler flow meter relies on a strong acoustic connection between the transmitter and the exterior of the pipe. Positioning of the transducers in relation to each other and the pipe center line is also important. Typically, straight pipe length required is 20D.
While the accuracy of these units is relatively low (2% to 5%) they are excellent as portable units for doing short-term energy studies of hot or chilled water systems.

Fluid Applications – Doppler Ultrasonic Flow Meters

Natural gas	Other Clean gases	Contaminat-ed gases	Steam	Clean Liquids	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
				☆	◊	◊	◊	

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

1.3.5 Ultrasonic Doppler Flow Meters

Typical Performance Characteristics – Doppler Flow Meters.

1. Pipe Diameter Range (flanged):	Not Applicable-clamp-on meters only
1.b Pipe Diameter Range (clamp-on):	one inch to 12 feet.
2. Flow rate (gas):	not available
2.b Flow rate (liquids):	minimum 1 fps.
3. Percent Accuracy % FS:	+/- 2.0% to 5.0% FS
4. Repeatability AR:	+/- 0.1 %
5. Turndown Ratio:	100 to 1 (approximately)
6. Length of straight pipe required:	up to 15D upstream depending on type of obstruction.
7. Operating temperature range:	minus 10 ^{O}F to 300 ^{O}F excluding electronics.
7 b. High temperature versions:	not applicable.
8. Operating Pressure Range:	limited only by pipe application.
9. Discharge Coefficient Cd:	Not applicable.
10. Permanent pressure Loss:	Significant for bent tube type. Low for straight tube type.
11. Minimum Reynolds Number**:**	**Caution!** Some manufacturers' literature indicates o.k. for laminar flow; other literature indicates minimum Re of 10,000
12. Fluid Density correction required:	Gas Yes, Liquid No. Velocity is measured
13. Cost of Meter:	$ 2,500 to $ 5,000 for 4 inch to 8 inch D
14. Cost of Installation:	$ 500, strap-on.
15. Total Cost:	**$ 2,900 to $ 5,500**

Note - Cost of Meter and Transmitter: Prices are approximate in U.S. $ for standard meters.

Advantages and Disadvantages of Doppler Flow Meters.

Advantages

- Lower cost than transit time ultrasonic.
- Strap-on easy to install. Low cost for installation approx. $ 500 or less
- Excellent for short term energy studies (portable test version available)

Disadvantages

- Fluid must have minimum particle or bubble content.
- Problematic with some types of pipe material and scaled pipe.
- Low accuracy. 2% to 5% (FS)
- Pipe Scale inside interferes with reading – no reading results.
- Pipe must be full for operation. Mount vertically fluid flow upward if possible.
- Diameter limited to 6 inches. Twelve inch D meter is available but cost is very high.

1.3.6 Coriolis Mass Flow Meter – Basics

One of the first references to the Coriolis mass flow meter was in a paper in the ASME transactions 75:835-41, in 1953 by Y.T. Li and S.Y. Lee. The first practical Coriolis flow meter was developed and commercialized by Jim Smith, founder of **Micro Motion**, in Boulder Co., in 1977. Early installations were for the measurement of liquid flow. Recent developments have provided meters with increased sensitivity, greater noise immunity and lower pressure drop. This has opened the door for their use in gas and two-phase flow applications. The market for Coriolis meters for both liquids and gases is growing fast.

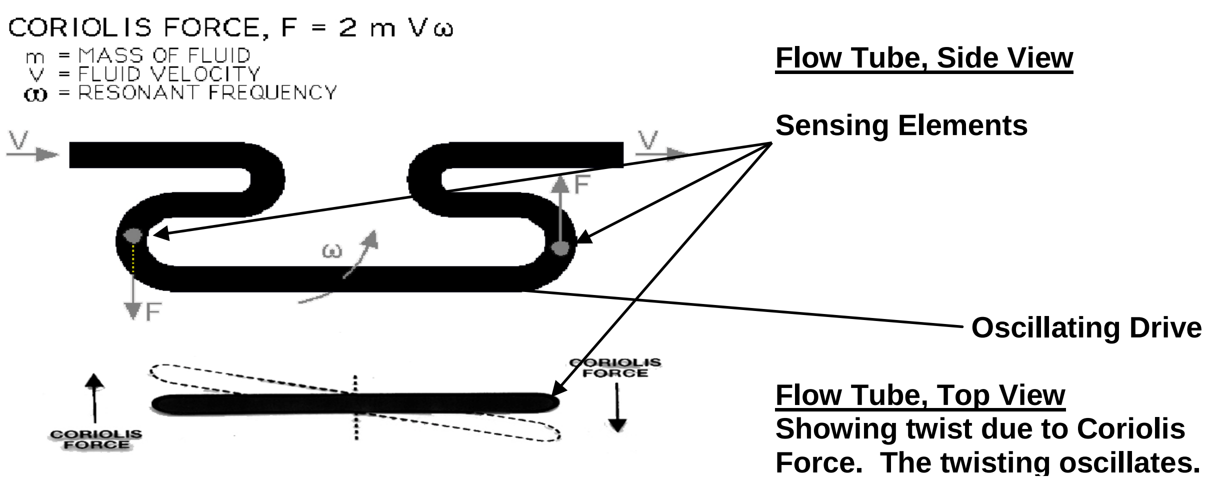
The principle of operation of this meter relies on the Coriolis force which is present in rotating and oscillating systems. See: www.wikipedia.org/wiki/Coriolis_effect.

Coriolis meter technology provides direct mass flow measurement which is independent of changes in pressure, temperature, density and fluid viscosity. Meters come in a variety of configurations including U-tube, twin U-tube, bent tube and straight tube designs. They all operate on the following principle:

1.) The fluid to be measured enters one end of the flow tube which is subjected to an external oscillating drive. This is an electro-mechanical oscillator which vibrates at the natural frequency of the tube at about ten kilohertz (kHz) depending on the tube design and the fluid density. Flow tubes are commonly made from 316 stainless or other metals (eg. titanium) depending on the application.

2.) As the fluid flows through the flow tube it is subjected to an upward or downward force caused by the external oscillation driver. The Coriolis force opposes the driving force, pushing upward on the tube on the in-flow side and downward on the outflow side of the tube, causing the tube to twist. The twisting motion is also an oscillation.

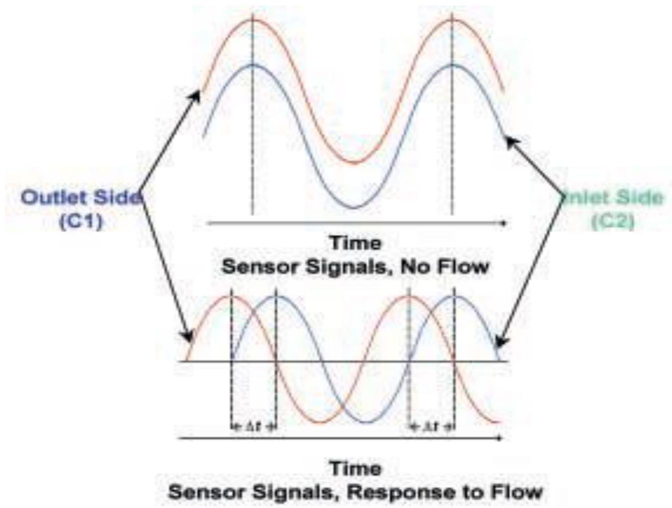
Figure 1.44, The Coriolis Flow Metering Principle-Bent Tube Type



1.3.6 Coriolis Mass Flow Meter – Basics (Continued)

3.) Sensors which are located on each leg of the flow tube detect the position and frequency of the tube as it twists. There is a phase shift between the two sensors as mass flow changes. **This phase shift is directly proportional to the mass flow of the fluid.**

Figure 1.45



Courtesy of Emerson Automation Solutions, www.emerson.com,

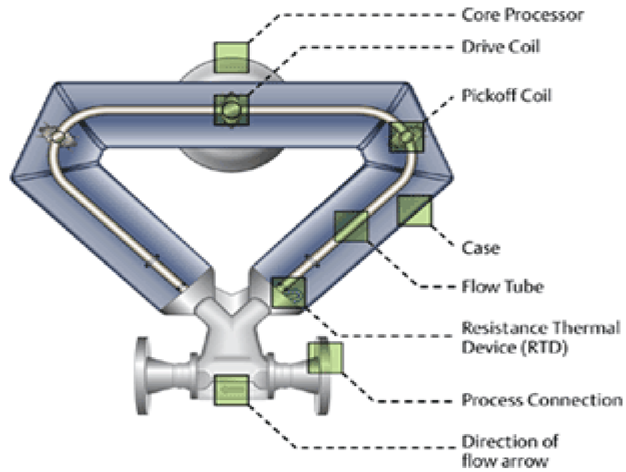
4.) The Coriolis meter is equipped with a microprocessor based signal processing system which interprets the raw signals from the sensors and the frequency shift which is being measured, converting these to signals which can be used by standard instrument and data systems eg. 4 to 20 M.A., pulse and voltage outputs.

5.) **Figure 1.45** (next page) shows the design of a commercial, double tube Coriolis meter including

- An outer containment casing which protects the surrounding area in the event of tube failure. This enclosure also ensures that the internal components are dry. It is filled with argon gas and sealed. Some meters have a secondary housing with ASME B 31.3 pressure rating.
- An RTD temperature sensor which allows for compensation of the flow reading caused by heating and expansion or contraction of the flow element itself.
- A double U-tube which splits the flow of the fluid into two separate tubes. This improves accuracy and resistance to outside vibration sources.

1.3.6 Coriolis Mass Flow Meter – Basics

Figure 1.46, Main parts of a commercial double U-tube, Bent Tube Coriolis meter.



Courtesy of Emerson Automation Solutions, www.emerson.com

6.) Density Variation.
For liquids, variations in density caused by temperature change can be directly measured. The frequency of vibration of the tube(s) changes as the total mass of fluid and tube changes the natural frequency of the system. The liquid density is in direct proportion to the natural frequency and this is measured, becoming an output from the flow transmitter or flow computer.

Fluid Applications-Coriolis Meters-Bent and Straight Tubes

Natural gas Custody	Other Clean gases Custody	Contaminat-ed gases	Very Low Temp. Liquid Gases	Clean Liquids Custody	Viscous Liquids	Slurries/ Waste Water	Contam-inated or corrosive liquids	Com-pressed Air
BENT ☆	☆	◊	☆	☆	○ ◊			
STRAI	GHT ○	◊	○	○	☆ ◊		◊ ☆	

☆ = good choice, check performance and cost.
○ = may be a good choice, check performance and cost.
BLANK BOX = Not Recommended for standard meters.
◊ Caution: Special meter design or materials may be required. Consider the fluid's characteristics.

Due to high meter cost, most suitable applications for Coriolis meters are Large Volume Custody Transfer and Critical process batch mass metering.

1.3.6 Coriolis Mass Flow Meter – Basics

The Coriolis meter has a wide range of applications.

The first applications for the Coriolis meter were in the petroleum and chemical industries measuring all kinds of liquids, mainly for process control purposes. Because of its high accuracy it is also used for **custody transfer** in the oil and gas industry. **AGA report 11.** Coriolis meters have been used to measure high viscosity fluids, slurries and mixed phase fluids. (eg. oil and water, water with bubbles, pulverized coal in air etc.)

Compatible fluids include: crude oil, cryogenic liquids, polymers, asphalt, fuel oil, paints, nitric acid, phosphoric acid, molten sulphur, sodium hydroxide, tar sands.
Food products include: beer, fruit juices, milk, pie fillings and peanut butter (no kidding).

More recently, design improvements and increased precision have made Coriolis meters a candidate for metering gases. They are capable of metering **industrial gases** and are have been used for customer transfer of natural gas for large users. They can also be applied to low temperature gaseous or liquid **Oxygen, Nitrogen and CO2**.

Fig. 1.47, Compact Coriolis Straight-tube Mass Flow Meter

ABB Coriolis Master Flow Meter. Model FCH 400 and FCH 450
Designed for hygienic applications
Low permanent pressure loss (PPL)
Multi-variable Transmitter-Included
Fieldbus and Hart Communications

Image Courtesy of ABB, www.abb.com/flow

1.3.6 Coriolis Mass Flow Meter

Performance Characteristics – Coriolis Mass Flow Meters
Note: All specifications should be checked for the specific meter you are considering. Performance and capabilities vary by model and type. (U-tube, straight tube etc.)

1. Pipe Diameter Range (flanged): 1/8 inch to 12 inch. Max.
2.a Max.Flow rate (liquid): 3.0 million Kg/Hr Max.
2.b Max.Flow rate (gas): 110,000 Kg/Hr
3.a Percent Accuracy Liquids% AR: 0.05% to 0.5% varies by model.
3.b Percent Accuracy Gases % AR: 0.05% to 0.5%.
4. Repeatability AR: 0.025% to 0.25% varies by model.
5. Turndown Ratio: 20:1 minimum. Some models 100:1
6. Length of straight pipe required: None
7.a Operating temperature range: minus 400 ^{O}F to plus 400 ^{O}F, varies by model
7.b. High temperature versions: up to 700 ^{O}F
8. Operating Pressure Range: up to 5000 PSIG
9. Discharge Coefficient Cd: not applicable. A tube coefficient K is applied for each model and is temperature dependent.
10. Permanent pressure Loss: Moderate, varies with tube and flow design.
11. Minimum Reynolds Number**:** No Minimum
12. Fluid Density correction required : No
13. Cost of Meter: $ 9,000 for 2 inch meter to $ 15,000 for 6 inch c/w multivariable transmitter
14. Cost of Installation: $ 1,500 to $ 5,000

Advantages and Disadvantages – Coriolis Mass Flow Meter

Advantages

- Direct mass flow reading, no correction for pressure or temperature.
- High Turndown Ratio: 20:1 is standard, 100:1 as required.
- No Need for straight pipe runs upstream and downstream.
- Capable of metering multiple liquids, gases, slurries and mixed phase flow.
- Stainless Flow Tubes are standard.
- Capable of metering cryogenic gases – some models.
- Very high accuracy and repeatability.
- Low Maintenance.
- Custody Transfer approvals.

Disadvantages

- High Cost compared to most other meters.
- Moderate permanent pressure loss. (except straight through coriolis)

1.3.6 Coriolis Mass Flow Meter

Fig. 1.48, Yokogawa RotaMASS TI, Coriolis Meter

The Yokogawa RotaMASS TI Coriolis meter features an advanced design in which the dual tubes are decoupled from process vibration and pipe stress. This guarantees reliability and output stability. The progressive development of this Coriolis line incorporates advanced diagnostic functions and ease of use to overcome the challenges of difficult applications. The metered fluid temperature range is **200 ^{O}C to + 350 ^{O}C.** This meter can handle cryogenic and hot gases and liquids and is also capable of metering corrosive fluids.

Image Courtesy of Yokogawa, www.Yokogawa.com/us/products/field-instruments

1.3.6 Coriolis Mass Flow Meter

Metering Natural Gas

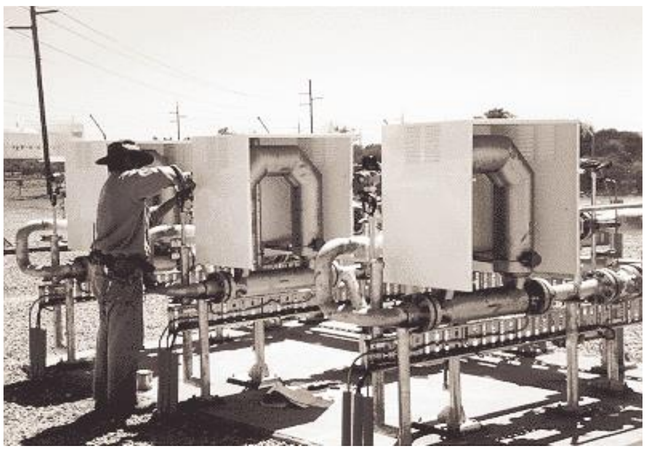
Coriolis meters have been used for several specific applications:

1.) Custody transfer in the natural gas industry at high pressure stations. The mass flow reading from the Coriolis meter is converted to standard volumetric units by dividing the reading by the standard gas density. The standard gas density can be determined by the "Ultimate Gas Analysis" which is routinely conducted by gas pipeline companies.

2.) Accurate combustion control for large boilers. Optimizing efficiency and controlling emissions through accurate fuel/air mixing.

3.) Direct metering of Energy flow by configuring the meter transmitter/flow computer to convert mass flow to energy units (BTU/Hr or GJ/Hr).

Figure 1.49

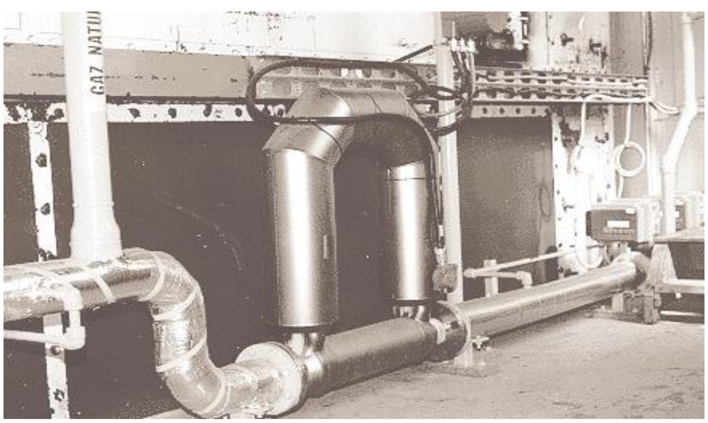


Custody transfer of natural gas to a co-generation plant in Australia. Two,3 inch meters in parallel, one as a "hot" back-up.
Advantage of Coriolis:
Lower maintenance cost compared to turbine meters.
No straight pipe lengths required.

Courtesy of Emerson Automation Solutions, www.emerson.com

Figure 1.50

Metering natural gas supplied to a boiler at a paper mill in Quebec. This control system was implemented to optimize boiler efficiency and to meet emission requirements.



From a paper by Karl Stappert, Emerson Micro Motion Inc. Tulsa, Oklahoma.

"Coriolis Mass Flow Meters for Natural Gas Measurement".

Courtesy of Emerson Automation Solutions, www.emerson.com

SECTION 2, FLOW TRANSMITTERS AND COMMUNICATIONS

2.1 Flow Transmitters
2.1.1 Flow Transmitter Basics and Specifications

The **"Primary Element"** of the flow meter produces an output which may be mechanical, Volumetric **(Vm),** Pressure Differential (**ΔP)** or, electronic pulses. This output is proportional to the variable measured . The problem is that the output signal produced by the primary element **(the primary signal)** cannot be used directly to display or transmit a Mass flow reading**(Qm).** The output signal must be converted to an electrical signal commonly used in industrial instrumentation eg. **40 to 20 mA.**

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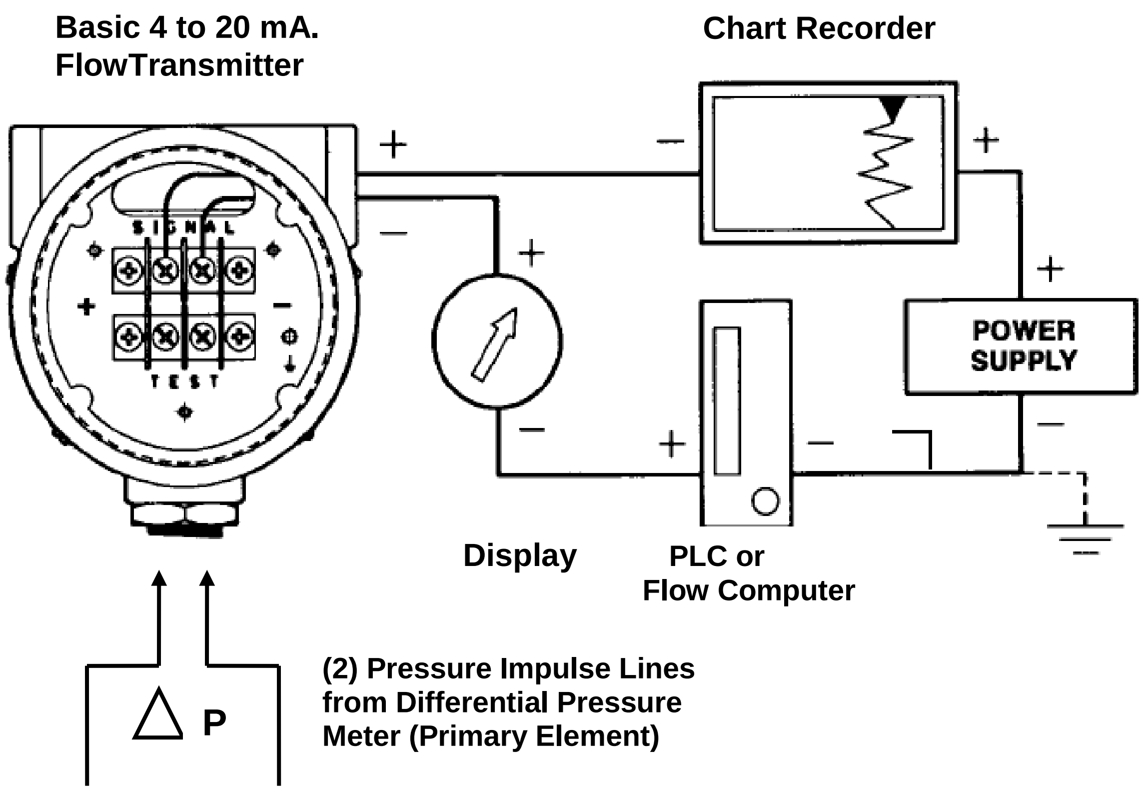
Figure 2.1, Simplified Schematic of a Basic Analog Flow Transmitter for a DP Meter



Inside the transmitter, the main sensor (eg. a diaphragm) is in contact with the fluid. The differential pressure **ΔP** of the fluid provides the force required to move the diaphragm sensor which produces an electrical signal. (Other electronic technologies which are used to convert a force to an electrical value include: **capacitance sensors, differential transformers, strain gauges and piezoelectric elements**). This signal is then further converted by the transmitter to a standard instrument signal such as 4 to 20 m.a. or other communication format to be transmitted to another device.

Transmitters are subject to "drift" due to temperature change and are themselves a source of error in the meter. When specifying flow meter accuracy, a manufacturer should include the transmitter error.

SECTION 2, FLOW TRANSMITTERS AND COMMUNICATIONS

2.1 Flow Transmitters
2.1.1 Flow Transmitter Basics and Specifications

Basic Meter Output Signals
The following gives examples of how a transmitter produces a signal:
1.) For **DP meters**, pressure **P** from the pressure differential **ΔP** is applied to a mechanical device such as a diaphragm which in turn applies force to an electronic device such as a differential transformer, a potentiometer, or a strain guage. Once the mechanical variable (pressure) is converted to an electrical signal, that signal is amplified and altered to produce a commonly used standard signal such as a 4 to 20 mA. output.

2.) For mechanical meters, an **electrical pulse** is usually produced by a magnet passing through an electric field, or by the opening and closing of a physical contact. These pulses can be counted and the resulting count is **proportional to the volumetric flow**.
Note: The volume is based on a standardized condition eg. 14.2 PSIA at 60 ^{O}F. If fluid conditions (**P or T**) vary from the standard, the volumetric flow has to be corrected.

3.) For electronic meters, **various electronic primary signals** are produced by the meter. For example, an electromagnetic flow meter produces a weak electrical voltage when a conducting fluid passes through an electromagnetic field supplied by the flowmeter. Another example is

Traditional Instrumentation Signals
None of these primary signals is suitable for direct use and must be converted to a standard electronic signal. This signal may power a display or drive a chart recorder. It may communicate with a Programmable Logic Controller **(PLC)** or a computer**.**

Examples of standard industrial control and instrumentation signals which are the output of flow transmitters include:
- 4 to 20 milliamp (m.a.)
- 120 V A.C.
- Various D.C. voltages including 6 V D.C., 12 V D.C., 24 V D.C. 48 V D.C.

Traditionally, the standard instrument output signal from a flow meter transmitter has been **4 to 20 m.a. The 4 to 20 m.a. analogue signal** conveys the information to the receiving device.
A **4 m.a.**output indicates zero flow. A **20 m.a**. signal indicates a full scale reading. This signal convention is widely used because it can be transmitted long distances, is relatively immune to noise, and requires only 2 wires.

2.1 Flow Transmitters

2.1.1 Flow Transmitter Basics and Specifications

Flow transmitters can be purchased together with a new flow meter, or individually. Either way, a buyer will likely have to purchase not only the **flow transmitter** but ancillary devices such as **fluid temperature sensor** or a static **pressure sensor** . **See fig. 2.2.**
The following table provides a list of key specifications which can guide the purchaser in selecting a flow transmitter.

Flow Transmitters - Typical Features and Specifications

1.) Supply Voltage: 10 to 48 V D.C. or 230 VAC and 115 VAC.
2.) No. of Wires: 2, 3 or 4-wire.
3.) Temperature Compensation: This refers to compensation for expansion of the flow elements due to temperature of the transmitter.
4.) Operating Temperature: **- 40 ^{O}F to + 180 ^{O}F**. **This is the temperature range at which the transmitter can operate. Higher operating temperatures will shorten the life-span of the electronics. If the ambient temperature is too high, the transmitter can be mounted remotely from the primary element.**
5.) Accuracy: +/- 0.01% of reading (AR)
6.) Turndown Range: 10 to 1
7.) Process Fluid Temperature Range: - 40^{O}C to + 200 ^{O}C.
8.) Maximum Operating Pressure: 300 PSIG
9.) Enclosures: Bronze, Plastic, Aluminum, Cast iron, with approval ratings, eg. Nema 4X, FM, Class I Div 1, Class II Div 2, . The meter owner is responsible for selecting the enclosure which meets the safety requirements of the environment.
10.) Other Approvals: CE, UL, CSA
11.) Output Signal for an Analog Transmitter: (A) Pulse Output: 12 to 80 V D.C. with various pulse widths. **(B) 4 to 20 m.a. output. Details of the output signal are critical to selection. The transmitter will likely communicate with a recorder, PLC, PC or to an existing communication system**.
12.) Output Signal for a Digital Multivariable Transmitter: (A) 4 to 20 m.a. output proportional to mass flow. (B) Serial Standard Communication output in various formats. HART®, Foundation Fieldbus ®, MODBUS ® , BACnet ®.

13.) Functions required:
Display on Transmitter
Totalizing Display
Differential Pressure Display
Static Pressure Display
Fluid Temperature Display
Diagnostics and alarms. (eg. Plugged impulse line).
Scalable Units, (Gallons, Litres, FT^3, M^3 etc.)

13.) Mounting: Vertical, Horizontal. Mounting Block - No. of Ports and Valves

2.1 Flow Transmitters
2.1.2 Calculating the Mass Flow Rate

In the case of a differential pressure primary element (eg. an orifice plate) the basic 4 to 20 m.a. transmitter produces an electrical signal which is proportional to the differential pressure, not to the flow. The flow **velocity** is a function of the square root of the differential pressure.

$$V \quad \alpha \quad \sqrt{\frac{2\,\Delta P}{\rho}} \text{ - - - - - } \textbf{(See appendix A1.1)}$$

When the flow velocity has been calculated, additional factors must be taken into account in order to calculate the mass flow. As described in Appendix A, these factors include pipe diameter, discharge coefficient and fluid compressibility (if it's a gas).

If the fluid density, pressure or temperature vary, a further calculation, requiring further inputs will be necessary to correct for these variations continuously.

This will require additional data, namely, absolute pressure **P** and fluid temperature **T**. This means that, as fluid conditions change, a calculation has to be made continuously.

In **figure 1.47** all of the devices shown (chart recorder, display, PLC) which are supplied by the 4 to 20 m.a. signal may be **"smart"** devices having on-board microprocessors. This type of equipment is programmable. Programmable devices permit the user to enter the data required to convert the 4 to 20 m.a. signal which is proportional to differential pressure, using the formulae and data necessary to calculate the mass flow.

If fluid density varies, additional calculations are required. Temperature or pressure or both, must be included in the input to the devices. The calculation to correct for density variation is then made by the programmed software using the appropriate formulae. This is all done in real time, continuously at a rate which provides a timely mass flow reading for the device to display.

If density correction is needed but not performed, the flow reading will be erroneous. **(See Appendix A6).**

2.1 Flow Transmitters
2.1.2 Calculating the Mass Flow Rate

Figure 2.2, Differential Pressure Flow Meter with Pressure and Temperature Correction

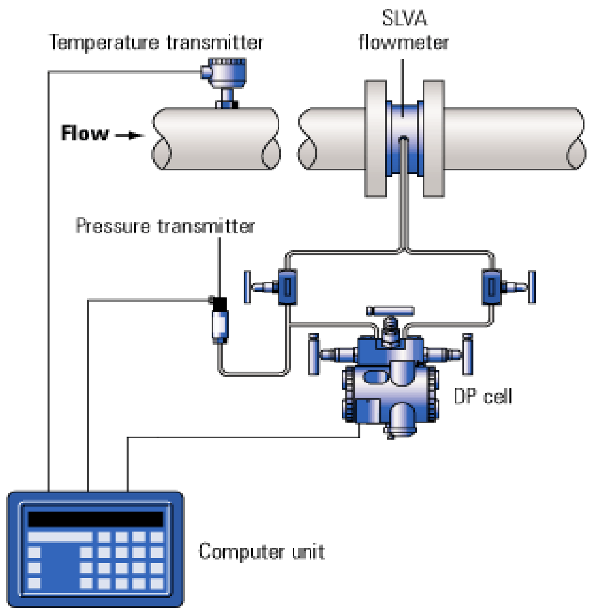


Image Courtesy of Spirax Sarco website" **Steam Engineering Tutorials"**
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

Figure 1.50 above shows a typical configuration for a system which calculates and displays the volumetric or mass flow rates for a differential pressure type steam flow meter. The computer calculates the flow rate using the differential pressure flow reading from the primary element. The calculation includes (discharge coefficient **Cd**, meter flow **area** etc.). The computer also corrects the flow rate for variations in steam pressure and or temperature.
Fixed data pertaining to the flow meter type and design are pre-programmed into the transmitter.
The inputs to the flow computer are:

- Differential pressure from a 4 to 20 m.a. analog transmitter.
- Absolute pressure (static pressure)
- Fluid temperature.
- Pre-entered data such as Cd, Flow Area, fluid compressibility.

The flow computer displays the calculated mass flow rate **Qm** as well as the measured pressure and temperature values. It also shows the instantaneous and totalized flows. The flow computer also communicates to other computers and devices through a HART, MODBUS, Foundation Fieldbus or other communication protocols or through a 4 to 20 m.a. signal to another computer such as a Programmable Logic Controller (PLC). (See **Section 2.2** – Communications)

2.1 Flow Transmitters
2.1.3 Multivariable Transmitters

Figure 2.3 Multivariable Transmitter.

The ABB Multivariable (MV) Transmitter model 266CSH
The MV transmitter is programmed using a PC. Special software is supplied by the manufacturer. The MV transmitter is capable of many functions:
-as a flow computer, converting the flow meter primary element reading to a mass flow.
-displaying readings of all inputs and outputs.
-communicating to a central computer or to a process.
-signaling alarms.

Courtesy of ABB, www.abb.com/flow

The **multivariable transmitter** is growing in popularity as a solution to the problem of converting the measured variable (Differential Pressure) to mass flow when fluid density changes. These are “smart” transmitters with on-board microprocessors, capable of performing a range of tasks. Multivariable transmitters can accept several process variables (eg. temperature, pressure, differential pressure).
Their capabilities include:

- Producing a corrected mass flow **(Qm)** or Volumetric **(Qv)** signal output from the metered flow variable (eg. differential pressure (**DP**)).
- Displaying all process variables, DP, static pressure, Process temperature etc.
- Totalizing readings.
- Communicating all metered data as a 4-20 m.a signal or other data protocol.
- Diagnosing faults within the meter.
- Alarms for pressure, temperature or flow set-points.
- Scaling output variables in units the user requires (LB, Kg. ^{O}C, ^{O}F etc.).
- Security Code Access.

Mutivariable transmitters can be serviced, calibrated and re-programmed in the field. Multivariable transmitters can extend the turndown range of a DP flow element from 4:1 to 8:1 by more sophisticated modeling of the flow element’s performance at low flows. They also offer higher accuracy and repeatability.

Multivariable transmitters are equipped to communicate in a variety of protocols including Modbus, HART® and Foundation Field Bus® etc.. (See **section 2.2** – Communications)

2.1 Flow Transmitters

2.1.3 Multivariable Transmitters

Multivariable transmitters can be programmed to perform mass flow calculations and density or temperature correction for liquids as well as gases. There are available as a remotely mounted transmitter in cases which require it (say high temperature applications).

Multivariable transmitters can be used with any flow meter:

- **Differential Pressure Meters**
- **Mechanical Meters**
- **Electronic Meters**

Figure 2.4, Vortex Shedding Meter with Multivariable Transmitter

ABB Vortex Master FS 430/450
Flange mounted vortex shedding meter integrated with a multivariable transmitter (**MV**).
Typical size range for vortex is ½ inch to 8 inch pipe diameter.
There are three process inputs to the transmitter:

- Flow velocity from the primary element.
- Gas temperature.
- Gas Pressure.

Sensors are integral to the meter for reduced installation cost. The output from the MV transmitter is compensated mass or volume flow.f

Courtesy of ABB, www.abb.com/flow

Some Suppliers of Multivariable Transmitters

ABB, **www.abb.com/flow**
Armstrong, **www.armstronginternational.com/products-systems/flow-measurement**
Rosemount, **www.emerson.com**
Yokogawa, **www.yokogawa.com**
Honeywell, **www.honeywell.com**
Schneider Electric, **www.schneider-electric.com/products**
Foxboro (Invensys), **www.fielddevices.foxboro.com**

2.1 Flow Transmitters

2.1.3 Multivariable Transmitters

Figure 2.5, Wireless Transmitters

Yokogawa Model EJX910A wireless, multivariable transmitter.
These modules conform to an open wireless communication protocol **ISA 100.11a/IEC62734**. They can communicate with any device which also conforms to this protocol including third party instruments of any type.

Because this is an Open Standard, it enables devices from any vendor to be integrated into a common network,.

Courtesy of Yokogowa
www.yokogawa.com/us/products/field-instruments

2.1.4 Flow Transmitter Accuracy

Accuracy: Typical for Analog transmitter: 0.25% AR within 10:1 Turndown. (B)
Typical for multivariable transmitter: 0.1% AR within meter range.
Note: The transmitter accuracy affects the overall accuracy of the meter but is usually a much smaller factor than the accuracy of the primary element. For example, a flow meter has an accuracy of 2% AR and its transmitter has an accuracy of 0.25%. The overall meter accuracy is:

Combined Accuracy of Meter and Analog Transmitter:

$$= \pm\sqrt{(2.0)^2 + (0.25)^2} = \pm\ 2.12\ \%$$

2.1.5 Transmitter Costs.

Transmitters have a wide price range depending on the manufacturer, the quality and the features. Here is rough idea of the cost of transmitters alone, excluding the primary flow element:

Analog Transmitter (4 to 20 m.a. output) : **$ 800 to 2,000**
Digital Transmitter (multivariable input,
Communication output): **$ 3,000 to $ 4000**

When purchasing a meter, the buyer should discuss the transmitter specifications and capabilities with the supplier with the same diligence as he discusses the meter primary element.

2.2 Flow Meter Communication

2.2.1 Communications - Basics

An Energy Management Information System (EMIS) employs one of many available industrial communication protocols. The challenge for the project manager charged with the responsibility of implementing an EMIS is to decide which protocol to use.

You should discuss this with experts, probably “system integrators” or specialized consultants. These are companies whose business is to match a mixture of industrial control components to systems and software.

2.2.2 Communication Buses

At the basic level (the **“Physical Layer”)** there are several **“BUS”** or communication hardware standards which have developed since the early days of personal computers and office networks. The bus standard defines such things as how many wires the data system employs, the operating voltages, baud rate, grounding, the maximum number of receivers per transmitter and the maximum cable length for reliable transmission. The bus standard also determines which **“Protocol”** can be run on that communication standard.

- **RS 232** serial communication. 3-wires, Up to 19.2 K baud per second (slow), point to point connection, daisy chain connections only, 50 feet maximum distance.
- **RS 485** serial communication, 2-wire or 4-wire, Up to 19.2 K baud per second, multi-drop up to 32 connections per bus, 4000 feet maximum distance between hubs.
- **Ethernet** serial communication, up to 10,000 K baud per second, multiple connections, 300 feet max distance with wire, 10 miles with fibre optic cable. Can handle multiple Protocols on one bus**.**

As an analogy, the bus is a human voice box together with ambient air (the transmission medium) which transmits sound. The protocol is the language, English, French or Spanish.

2.2 Flow Meter Communication

2.2.3 Communication Protocols

A protocol is a set of rules and conventions which defines the specific language structured from digital 1's and 0's.

A protocol defines the type of network and the Bus it can be run on:

- It defines how many "drops" or devices which can attach to the same bus.
- It defines the "topology" of the network, that is interconnections (T, Star, Mesh).
- It defines the transmission medium eg, 2- wire copper, fiber optic, wireless etc. which it can run on.

A protocol includes critical items required for communication such as:

- The address of the device on the bus. If the address has 4 bits, it means that only 16 devices on that bus can be addressed. Some protocols have as many as 38 bits allowing addresses for millions of devices.
- Number of data bytes to follow. A number which tells the system how many bytes to expect with this transmission.
- Status field. The slave informs the master that a requested task has been completed.
- Checksum. Checks the number of bytes sent vs. received.

Following is a list of a few of the most common protocols found in Industrial applications.

- **Fieldbus:** This is standard which supports a long list of protocols. An international standard IEC 61158 was agreed to in 1999. **Caution:** Protocols which come under the Fieldbus umbrella are not necessarily compatible and interchangeable.
- **Control Net** (Allen Bradley)
- **Device Net** (Allen Bradley)
- **HART** (Emerson Automation Solutions)
- **Profibus** (Siemens and other European Companies)
- **Modbus** (Modicon/Schneider Electric)
- **Lon Works** (Echelon Corp.)
- Controller Area Network **CanNet** (Robert Bosch Corp.)

2.2.4 Security

Industrial plants having SCADA are susceptible to security breaches from cyber malware. Security breaches can occur from inside the company, or from outside if the SCADA system is internet based.
If you do not have in-house expertise, consider hiring a specialized industrial IT consulting firm or system integrator to advise you on security.

SECTION 3, FLOW METER INSTALLATION AND MAINTENANCE

Introduction

The buyer of a flow meter should already have identified a location for it. This is because the requirement for straight lengths of pipe which is one of the main criteria for choosing a meter. After selecting, the buyer should plan carefully for the installation and commissioning of the meter. This should not be left entirely to the contractor. Poor installation can render the meter inaccurate. Installing a meter or several meters should be managed as a project. Most industrial plants do not have personnel who are specialized in instrumentation and installing a flow meter is not a routine task. Your meter supplier should be able to help you in this case. For a large metering project, a qualified consultant should be engaged.

The meter owner should address the following questions:

Who will install the meter? If the owner plans to have the meter installed by a contractor, the contractor should have a copy of the installation manual before quoting the price of installation. A contractor experienced in this type of project should be engaged. If the meter is installed by plant trades or maintenance personnel, they need to have the benefit of all of the data and assistance available from the supplier.

What support is available from the supplier? Are you purchasing the meter(s) from a distributor? If so does he have in-house service personnel? If the installer has questions, who can he phone for answers?

Who will Program and Commission the Meter? Many meter representatives and distributors have service personnel who are able to do this. This is an important requisite especially in large projects.

Assign responsibility for maintenance and train the maintainer. Flow meters require on-going calibration and maintenance in the event of electronic or mechanical problems.

Does the supplier or manufacturer have quality documentation available to support installation and maintenance? Review the installation manuals. They vary in quality from one manufacturer to another.

3.1 Installation Manual

The installation manual should include the following information:

1. A description of how the meter works.
2. **Operating limits of the meter**, namely, minimum and maximum operating temperature and operating pressure. Note: The limits for the transmitter are different than those for the meter primary element. The transmitter may have to be remotely mounted for high temperature applications.
3. Details of **upstream and downstream straight length of pipe**.
4. **Step by step installation instructions**.
5. **Mechanical drawings** showing the assembly parts, mounting hardware, and location of drill holes, dimensions for flange insertion etc.
6. **Electrical Connection diagrams.**
7. **Standards** which apply to the meter, piping, hardware, flanges etc.
8. **A Spare parts list** for the meter and transmitter.

3.2 Ancillary Equipment

Every meter installation is different. There are a range of mechanical devices which support flow meters. These devices are required under certain circumstances. They include:

- **Figure 3.1, Flow straightener:** A flow straightener is required if there is not enough straight pipe length up stream of the meter.

F-2000 wafer style flow straightener for **vortex meters.** Reduces the upstream straight pipe length required for accurate readings. Flow straighteners are very specific to the type of meter and application. This one is designed specifically for steam or hot water.

- Installed between flanges.
- Stainless steel
- Pipe sizes from 2 inch to 12 inch.
- Steam and High temp. Hot Water applicaions

Image Courtesy of ONICON Incorporated, www.onicon.com

- **Figure 3.2, Strainer:** A strainer to filter pipe debris may be required. Some meters are more susceptible to plugging than others. Steam and hot water lines often have this problem. Vertical installation of the meter may be adequate to solve this problem.

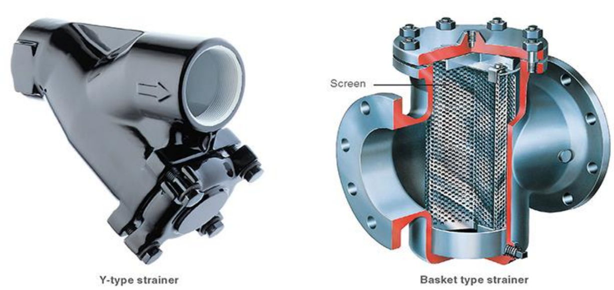


Fig. 12.4.1 Typical strainers

Y- type and Basket Strainers are filters designed to remove larger particles and debris from pipe lines. Strainers protect down-stream equipment and clarify the fluid or gas being metered. They must be maintained (cleaned) or they cause flow blockage or high pressure drop.

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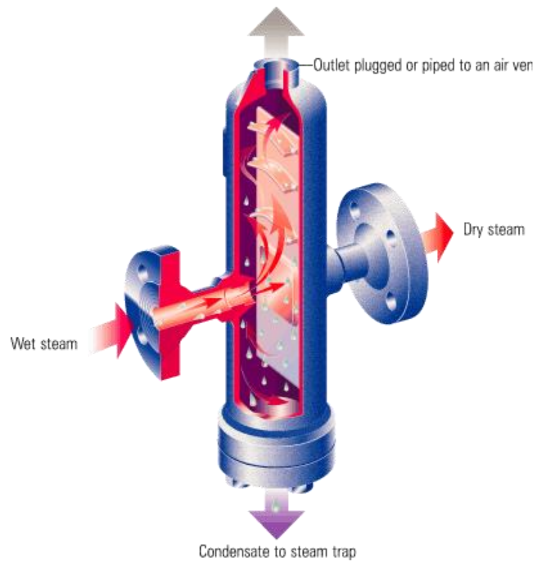
3.2 Ancillary Equipment

- **Figure 3.3, Steam Separator:** A steam separator may be required to remove water from steam in many cases where a meter is used for saturated steam.



Baffle type steam separator. Steam dryness is critical for some applications including sterilization. For many applications, separators are required to remove water from wet steam in order to prevent equipment and piping damage down-stream. Dry steam also improves heat transfer in heat exchangers.

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- **Pressure Guage**: It is very useful to insert a mechanical pressure guage upstream of the meter for most applications. This helps to troubleshoot problems and also to guage variations in pressure at the meter. If the transmitter has a pressure input and display, this is not necessary.

- **Meter By-pass**: A pipe by pass with appropriate valves permits the meter to be isolated for maintenance while maintaining fluid flow. This is especially important for in-line meters which can potentially shut down the process or **the entire plant** if they fail.

3.3 Installation Steps and Cost Estimate for Installation.

An Example: The items on the list below are taken from the **Rosemount** Installation and Operation manual for the Mass Pro Bar Insertion Type Flow Meter. (Hourly estimates by author).

Installation of an Insertion type Flow Meter

Step	Hours Est.	Install Cost Est.
1.) **Plan Meter Installation**. Review of Manual. Verify orientation and location of meter.	1.0 HR	$ 100
2.) **Shut Down process**, islolate piping, purge piping if necessary.	0.5	$ 50
3.) **Pipe-work:** • Drill ¾ inch holes 180 ^{O} apart. • Weld threaded saddle to pipe. • Measure inside pipe diameter.	1.5	$ 150
4.) **Meter Installation.** • Install ball valve and nipples. • Insert meter through valve. • Install compression fitting, check fit. • Tighten fittings to spec. Torque if required.	1.5	$ 150
5.) **Electrical Installation** plus materials.	2.5 Materials	$ 250 $ 200
6.) **Re-Start process**. Check for leaks.	0.5	$ 50
7.) **Commission meter**. May require service rep. from supplier. Programming is required if the meter has a multivariable	2.0	$ 200
Total	**9.5 HR**	**$ 1,150**

Note: Excludes: contractor travel time.
Excludes cost of meter., installation of ancillary equipment
Standard hours, no O.T.
Excludes Contingency cost.
Excludes Process Downtime.

3.3 Installation Steps and Cost Estimate for Installation

The cost estimate above is considered to be a “best case” for the installation of an insertion type flow meter.

Now, estimate a **“high”** figure for installation of an insertion meter by adding several common factors:

- Difficult Access to pipe (add 3 hours, $ 300). Eg. Pipe runs along ceiling at 20 ft. level and that’s the best location.
- Add a strainer. $ 300 Material plus 3 hours labor (add $ 600).
- Add Contractor travel time (1 hour, $ 100).
- Contingency 15%.

The total installation cost for the meter increases from $ 1,150 to $ 2,500.

Using the same method, an installation estimate for a flanged, in-line meter is made. See comparison below.

	Insertion Meter Installation Cost (Range)	**3 inch Flanged Meter Installation Cost (Range)**	**8 inch Flanged Meter Installation Cost (Range)**
Meter	**$ 1,150 to $ 1,900**	**$ 1,350 to $ 2,100**	**$ 1,950 to $ 2,700**
Add Equipment Mtl. and Labor	**$ 600 strainer**	**$ 800 by-pass**	**$ 1,200 by-pass**
Total with Extra equipment.	**$ 1,750 to $ 2,500**	**$ 2,150 to $ 2,900**	**$ 3,150 to $ 3,900**

3.3 Installation Steps and Cost Estimate for Installation.

Figure 3.4, Connections and added devices for Installation of a DP flow meter Showing Impulse Tubing, Remote Transmitter and Additional Temperature and Pressure Sensors.

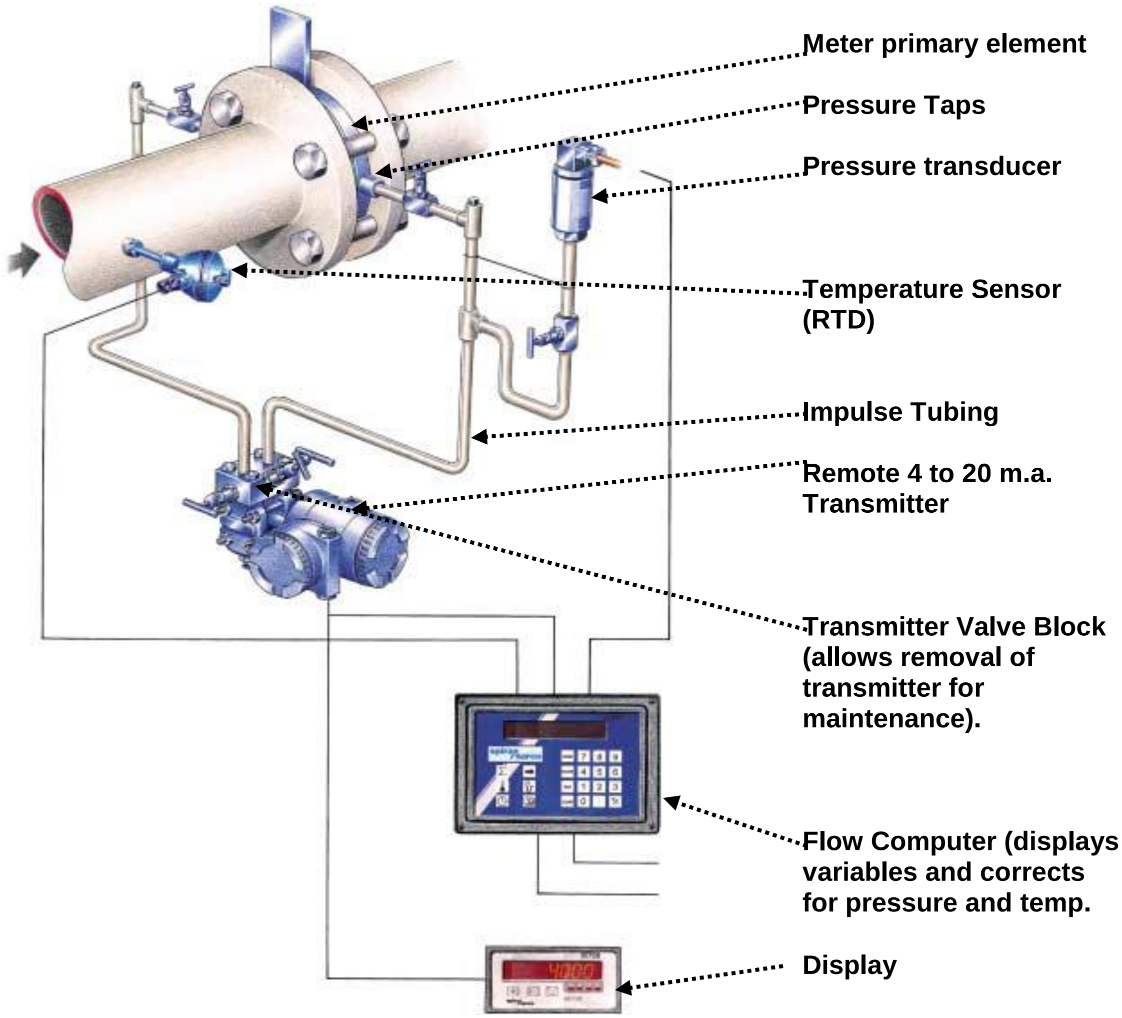


Image Courtesy of Spirax Sarco website"Steam Engineering Tutorials"
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

The cost of installing additional equipment adds labour time and materials to the total cost of a meter system.

3.4 Maintenance and Calibration - Introduction

The maintenance and calibration of flow meters is a neglected activity in many manufacturing plants. Larger sites such as Chemical and Oil Refinery plants have in-house instrumentation departments who perform this task regularly, however most industrial plants do not have the personnel who are qualified to do this.

It is important to maintain and calibrate even the most basic meters regularly, and as the electronic complexity of meters increases, this function is even more important.

Flow meters (and other instrumentation) should be part of a plant's formal PM program.

For flow meters which are applied for custody transfer and batch process measurement, accuracy and reliability is of critical importance. For meters used in Energy Management, and production cycles, their flowmeter operation and accuracy still important.

It is important to estimate the reliability and cost of ownership of a flow meter. When evaluating the business case for acquiring one, the annual calibration and maintenance cost should be included. (**See section 3.6**)

3.5 Regularly Scheduled Field Calibration.

The specific service and frequency of service which is performed on a flow meter depends on the type of flow meter and its transmitter. It also depends on the fluid being metered. For example, steam meters are subject to higher temperatures (including the transmitter), greater wear from wet steam, corrosion and fouling than natural gas meters. They need calibration and repair more often than the same meter used on natural gas service.

Calibration Check, Meter in Situ, Process in Operation

The instrument technician will check the 4 to 20 m.a. output to verify that the scale range is correct. There is a standard called NAMUR NE 43 which applies to this variable.

- Check physical condition of transmitter including ambient temperature.
- The output will be checked under operating conditions. (4 m.a = zero flow, 20 m.a. = full scale).
- Check alarm settings and output (if alarms are present).
- Check D.C. power supply.

3.5 Regularly Scheduled Field Calibration

Calibration Check, Meter in Situ, Process in Operation

Transmitter Verification (Continued):

- For an analog, 4 to 20 m.a. transmitter, there will probably be flow correction system of some type installed. This could be an electronic chart recorder, PLC or a computer. Any of these items could be programmed to apply the pressure and temperature correction factors which generate the final mass or volumetric flow rat**.** These should be included as part of the process.

Microprocessor Based Multivariable Transmitters have a more extensive range of settings and functions to check, including for example:

- Verify programming of correction factors for pressure and temperature.
- Check original programming set points - meter data, fluid data.
- Meter Calibration.
- Check communication format. Modbus, Fielbus etc..
- Check the pressure temperature correction algorithms and performance which are included in the transmitter.

Primary Element Inspection – Meter Removal
For some types of meters, a regular physical check of the primary element is advisable. This depends on the fluid being metered. For example, the edges of orifice plates tend to wear, causing inaccurate readings over time.

Unless the meter has been installed with a piping by-pass, or has a pre-made spool piece, removal of the primary element may require a shut-down of the process. This adds time and cost to the regular maintenance function.

Troubleshooting
For cases when the meter performance is obviously problematic, a service call is required. Failures are predominantly associated with the primary element and parts exposed to the fluid being measured. Another problem is that changes in flow conditions occur, causing the meter to go out of range. Major meter manufacturers maintain statistics on the failure rate of transmitters. This is given in terms of mean time between failure or MTBF. In general, the failure rate of modern electronics is quite low, assuming the operating conditions (temperature and pressure) are met.

Failure of the primary element is much higher, roughly 10 times the rate of failure of the transmitter.

3.6 The Annual Cost of Maintenance

It is difficult to provide the buyer with an expected annual maintenance cost for flow meters. The following is the author's estimate for a DP meter. The source of data is a small survey of instrument professionals. The average cost is approximately **$ 250 per meter per year.**

Definition of a fault:

- Meter grossly exceeds rated error and produces unacceptable readings.
- Meter fails completely. No reading.
- Meter leaks or creates unsafe condition.

The following equipment is included:

- Meter primary element.
- Meter transmitter
- Associated equipment such as pressure transmitter, flow straightener etc.

Reasons for Maintenance/Repair include:

- Regular Calibration Check (Planned maintenance every 2 years per meter).
- Meter and Transmitter Faults (due to equipment defect MTBF 45 years).
- Primary element faults due to wear, plugging etc. (MTBF 10 years).
- Original installation error (one meter in 10).
- Wrong Original Meter Selection (one meter in 10).

Charges include:

- Service Labor at $ 100.00/HR.
- Travel time at $ 100.00/HR.
- Parts. $ 200, per repair.

<u>Average annual cost</u> of maintenance per installed meter assumes that 70% of the meter population requires either planned maintenance or repair each year:

Estimated time including travel, set-up and labor**:**	**1.5 HR/Meter/YR = $ 150 /Meter/Yr**
Estimated cost of parts:	**<u>$100</u> /Meter/Yr**
Total	**$ 250 /Meter/Yr**

Excluded:

- Cost of shut down or loss of production.

The maintenance cost for a single meter can vary widely from the overall average.

FLOW METER GUIDE BOOK FOR INDUSTRY

SECTION 4

APPENDICES

The purpose of **Appendix A** is to provide a review of fluid flow basic principles for the owners of flow-meters who are non-experts. Appendix A is a description of some of the most important flow principles which apply to DP type meters as well as to other types.

In **Appendix B**, a specific example showing calculations for each step in evaluating a flow meter which a buyer might take for a specific application. Suppliers should make these calculations on behalf of the flow meter customer. Most flow meter buyers do not have the specialized expertise to do this analysis. Flow meter manufacturers sometimes use **specialized flow software** when they help customers to select and size meters for their specific fluid conditions.

APPENDIX A **Fluid Flow and Metering Basics**

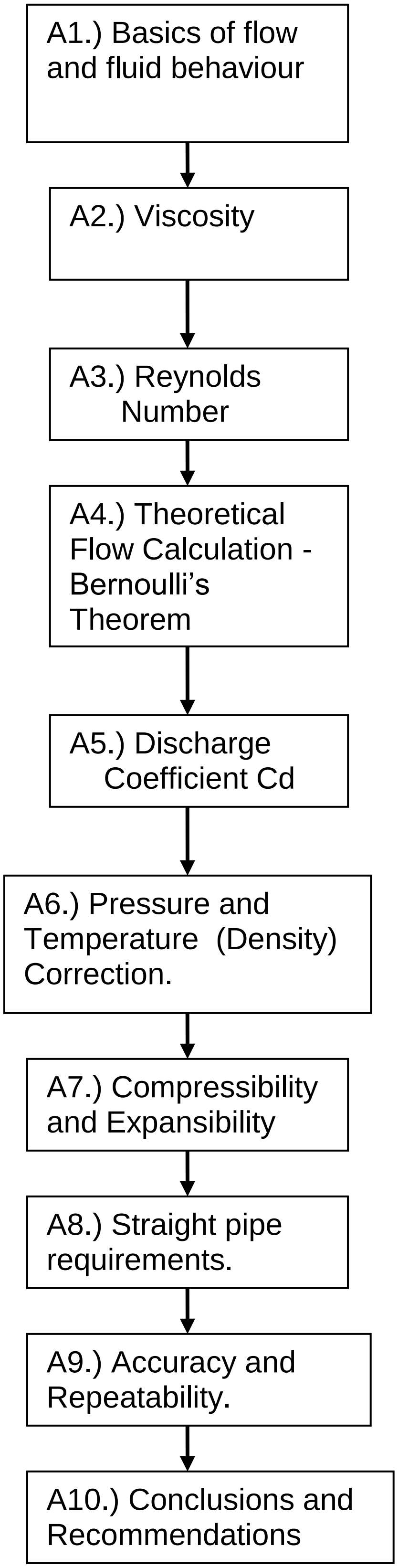
APPENDIX B **Calculations, Graphs and Charts**

APPENDIX C **Definitions and Symbols**

APPENDIX D **Standards for Flow Meters**

APPENDIX E **Flow Meter Manufacturers and Suppliers**

APPENDIX A – FLUID FLOW AND METERING BASICS



1.) Determine the properties and flow range of the fluid to be metered. This can be a Catch 22. You can't size a meter if you don't know the flow range and you can't meter it if you don't have a meter. Do your best. There is a risk of purchasing the wrong meter.

2.) The importance of fluid viscosity is described. Viscosity varies with temperature and pressure. This parameter is used to calculate Reynolds number Re. Guidance to find viscosity from various sources is given.

3.) Reynolds number is important because it determines the shape of the flow velocity profile of the fluid. DP type meters are calibrated for a specific flow profile. Reynolds number varies with flow rate, fluid density and viscosity.

4.) In Appendix B an example of flow calculation using Bernoulli's theorem is shown.

5.) The discharge coefficient (Cd) applies the specific meter design as well as fluid and flow conditions including the Reynolds number. This is why all meters have their own specific range of operation and accuracy specification. Meter manufacturers provide the Cd and calibrate your specific meter for the specified fluid and flow conditions.

6.) Most flow meter applications are subject to changes in fluid pressure and/or temperature. The meter element is calibrated for a specific P and T. For accuracy, most gas flow meter applications require both pressure and temperature to be corrected to the reference condition. Liquid flow meters may require only temperature correction or no correction at all .

7.) The Expansibility Factor is discussed.

8.) Flow meter manufacturers specify the length of straight pipe required upstream and downstream of the flow meter. The upstream requirements can range from zero to 50 D.

9.) These terms are explained. The flow meter purchaser should be sure of the definition provided by the vendor.

Note: Appendix A is describes the topics at each step. Appendix B calculates the values based on a specific example to illustrate the use of some of the formulae.

A1) Basics of Flow and Fluid Behavior

A1.1) Bernoulli's Theorem (www.wikipedia.org/wiki/Bernoulli's_principle)

The basic principle behind Differential Pressure (DP) type flow-meters was first stated by Daniel Bernoulli, a Swiss mathematician, in 1738. The behavior of fluids described by the theorem also applies to flow in pipes and channels, as well as to other types of flow meters.

Why is Bernoulli's theorem important?
Bernoulli's theorem establishes the relationship between the pressure drop across a restriction (eg. an orifice) in a pipe, and the velocity of the flowing fluid. If we can measure the pressure drop, we can calculate the velocity and from that, the volumetric flow and the mass flow. (see section A1.1, eqn. (1.) and eqn.(2.))

Bernoulli's equation is a statement of the fundamental principle of the conservation of energy as applied to the flow of a fluid. It states that in the steady flow of a fluid, the sum of all forms of energy remains constant (if no work is done or heat exchanged). This is true even if the fluid changes flow direction, passes through a change in flow area or an orifice. This principle can be expressed mathematically as follows:

Total Up-stream Energy = Total Down-stream Energy

$$\frac{V_1^2}{2g} + \frac{P_1}{g\rho} + Z_1 = \frac{V_2^2}{2g} + \frac{P_2}{g\rho} + Z_2 \quad \text{- - - - - A1.1-1}$$

Where: V = velocity of fluid
P_1 = static pressure of fluid at the inlet of the orifice or restriction.
P_2 = static pressure of fluid at the outlet of the orifice or restriction.
ρ = Density of fluid
g = acceleration due to gravity (constant = 32.2 ft / sec^2)
Z = potential due to elevation change energy (usually ignored, the same up and down-stream for most meter applications)

$\frac{V^2}{2g}$ = Kinetic Energy

$\frac{P}{g\rho}$ = Potential Energy due to fluid pressure

Z = Potential energy due to change in elevation

Equation (1.) can be rearranged as follows: Z (potential energy) is dropped because it is usually insignificant in practical metering applications.

$$\frac{V_1^2}{2g} + \frac{P_1}{g\rho} = \frac{V_2^2}{2\,g} + \frac{P_2}{g\rho} \quad \text{- - - - - - - - - - - A1.1-2}$$

A1) The Basic Concepts of Flow and Fluid Behavior

A1.1) Bernoulli's Equation (Continued)

Removing the gravitational mass factor from equation (2.) yields

$$\frac{V_1^2}{2} + \frac{P}{\rho} = \frac{V_2^2}{2} + \frac{P_1}{\rho} \quad \text{------ A1.1-3}$$

Rearranging eq. (3.) yields:

$$V_1 - V_2 = \sqrt{\frac{2(p2 - P1)}{\rho}} \quad \text{------ A1.1-4}$$

In general terms, equation **(4.)** can be interpreted as follows: When a flowing fluid encounters a change in the pipe geometry, (eg an orifice, an elbow or a change in pipe diameter) the change in velocity of the fluid is proportional to the square root of the pressure differential between the inlet and outlet of the restriction.

In more general terms, equation **(5.)** says that the velocity of a fluid flowing at a particular point and along a specific streamline in a pipe is proportional to the square root of the pressure differential and inversely proportional to the density of fluid at that point.

$$V \; \alpha \; \sqrt{\frac{2 \Delta P}{\rho}} \quad \text{----- A1.1-5}$$

This is the principle behind the design of all types of differential pressure measuring flow-meters.

By measuring the pressure difference at the inlet and outlet of a flow meter, the velocity can be calculated.

From this, the volumetric flow rate and the mass flow rate can be calculated knowing the pipe area and the fluid density respectively.

A1.2) Flow Velocity Profile in a Pipe

The following description applies to both liquids and gases flowing in a pipe.
Fluid flow in a pipe is described as either laminar or turbulent. This is important in measuring flow because the velocity of the fluid across the pipe section (flow profile), from wall to center is **not constant.** The **average** velocity of the fluid determines the average rate of flow. By multiplying the average velocity times the pipe area we can calculate average volume flow. If we measured the velocity only at the center of the pipe, we would have a high estimate of the flow.

Average Velocity X Pipe Area = Volume Flow. **- - - - A1.2-1**

$$\mathbf{V \times A = Qv}$$

Volume Flow X Fluid Density = Mass Flow. **- - - - - -A1.2-2**

$$\mathbf{Qv \times \rho = Qm}$$

Flow-meters must take the velocity profile into account by providing a reading which represents the average velocity. The velocity profile depends on factors such as pipe size and friction, fluid viscosity, fluid density and the fluid's mean velocity. As the flow rate changes, the velocity changes and the velocity profile also changes.

A1.3) Laminar and Turbulent Flow

When flow is laminar the fluid moves smoothly through the pipe in parallel layers (stream lines) having different velocities. The maximum velocity is located in the center of the pipe and the minimum velocity in the wall of the pipe (the boundary). The velocity distribution across a pipe section is parabolic in shape. The fluid at the center of the pipe moves much faster than fluid at the wall of the pipe. In fact, with laminar flow, the average pipeline velocity is ½ of the velocity at the centre of the pipe. Additionally, the velocity profile with laminar flow is unaffected by pipe wall roughness.

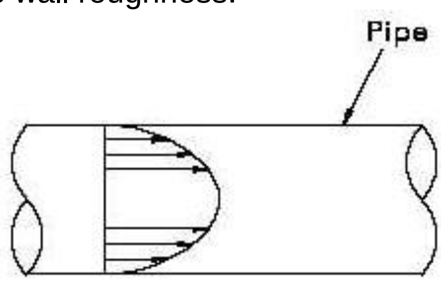


Figure A1. **Laminar** Flow Pattern (Parabolic Profile)

A1) Basic Concepts of Flow and Fluid Behavior

A1.3) Laminar and Turbulent Flow (Continued)

When flow is Turbulent, the velocity profile is much flatter than with Laminar flow. **Almost all industrial applications have turbulent flow.**

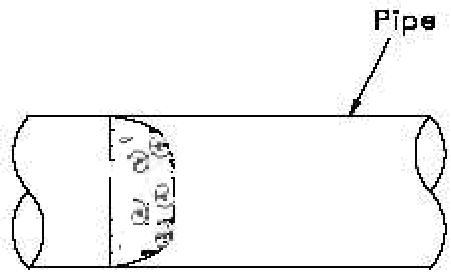


Figure A 2 Turbulent Flow Pattern (Flat profile)

When flow is turbulent, the velocity does not have a fixed profile. **The velocity profile changes with the Reynolds Number**. As the velocity increases, the profile becomes flatter and ultimately, the average velocity is close to the velocity at the centre of the pipe.

A1.4 Identifying the Fluid Properties and Flow Characteristics.

The first step in analyzing a flow meter application is to identify the properties of the flowing fluid. The main fluids measured for factory energy management applications are:

- natural gas
- water
- steam
- fuel oil
- compressed air
- low pressure air (building heating and HVAC)
- exhaust stack gas from boilers and process furnaces.
- purchased industrial gases such as oxygen, nitrogen, argon, CO_2

In order to perform the calculations for your specific application you will require the following data for whichever fluid you are planning to meter.

A1) Basic Concepts of Flow and Fluid Behavior
A1.4, Identify the Fluid Properties and Flow Characteristics.

Table A1, Data required for Typical Flow Meter Application-Example

Fluid: Saturated Steam

Flow Data and Properties	Value	Units	Description – How to Find or Calculate.
Steam Pressure - Nominal	100	PSIG	Plant operating pressure. Boiler pressure
Steam Pressure – Max.	100	PSIG	set-point.
Steam Pressure – Min.	85	PSIG	Experience-Knowing the operation.
Steam Temperature	338	^{O}F	From saturated steam tables.
Specific Volume of Fluid	3.89	fFt^3/Lb	From saturated steam tables.
Density of Fluid	0.2571	Lb/ft^3	Inverse of Specific Volume (calculated)
Steam Viscosity μ_f	**0.31×10^{-6}**	$\frac{\text{Lbf X s}}{\text{Ft}^2}$	From ASME steam tables. Or 0.0148 Centipoise (Cp)
Flowrate–Expected Average	3,000	Lb/Hr	If there is no existing meter. Flows must be estimated from experience and a knowledge of the process or the boiler plant.
Flow Rate-Max.	4,000	Lb/Hr	Initial estimate
Flow Rate-Min	800	Lb/Hr	The minimum is only 20% or the maximum. This turndown ratio 5:1, is outside of the range of some meters. See the selection tables of Section 2 of the Guide book.
Pipe-Size-and-Schedule-Nominal Diameter	3	inch	Schedule 80. Go to API standard pipe tables to find the internal pipe diameter if the nominal is 3 inch.
Inside Pipe Diameter	2.9	inch	This diameter is used to calculate pipe area for the purpose of calculating velocity.
Outside Pipe Diameter	3.5	inch	Difference between OD and ID is wall thickness divided by 2.
Maximum Velocity	94.1	ft/s	See Appendix B1 for calculation of velocities.
Minimum Velocity	18.9	Ft/s	At min. flow rate and nominal. Pressure.

Note: Most flow meter suppliers provide metering application forms and assistance to customers who plan to purchase flow meters. These forms request the above data as well as additional information about the application and features of the flow meter. Additional information requested includes such things as piping material, meter material (eg carbon steel, stainless, plastic), type of flange, pressure tap size and location, transmitter, etc. Many flow meter manufacturers also provide a service whereby they run the application on computerized software to verify the meter selection and flow parameters.

A2.) Viscosity

The viscosity of a fluid is a measure of its resistance to flow. Viscosity is a property of liquids and gases resulting from the attraction of molecules within the fluid to each other. **Viscosity is important** because it is one of the variables used in calculating the Reynolds Number (Re) of a flowing fluid. This in turn, is important in the selection of a flow meter. Most flow meters have a range of Re in which they provide an accurate output.

Figure A 4 on the next page provides some guidance on some of definitions of viscosity and the units associated with each.

The viscosity of liquids increases with increased pressure but only slightly. For example, the viscosity of water at Atmospheric pressure and 60 ^{O}F (15.6^{O}C) is 1.12 Cp. The viscosity of water at 5,000 PSIA is 1.25 Cp, a 12% increase.

Temperature has a much greater effect. The viscosity of water and all liquids **decreases** as temperature **increases**. For example, as temperature increases from 60^{O}F to 100 ^{O}F, viscosity decreases from **1.12 Cp to 0.68 Cp,** a **39% decrease**.

Gases behave in the opposite way to liquids. As temperature increases, viscosity increases. As pressure increases, viscosity decreases. For example, the viscosity of saturated steam at 100 psia and 328 ^{O}F is 0.015 Cp. With an **increase** in temperature, the viscosity of superheated steam at 100 psia and 600 OF is 0.021 Cp., an **increase** of 50%.

Similarly, as pressure increases, holding temperature constant, superheated steam at 100 PSIA and 600 ^{O}F, has a viscosity of 0.21 Cp. With an increase in pressure, steam at 2000 PSIA and temperature 600 ^{O}F has a viscosity of 0.87 Cp. The curve for this is however, flat up to about 1000 PSIA, that is, the effect can be ignored in practice in most cases. Ref: **www.engineeringtoolbox.com/steam-viscosity-d_770.html**

Some viscosities of interest:

The viscosity of water at 20 ^{O}C is:	**1.00 Cp**
The viscosity of Coca Cola syrup at 20 ^{O}C is:	**12.0 Cp**
The viscosity of steam at 100 PSIG is:	**0.01484 Cp**
The viscosity of mayonnaise at 20 ^{O}C is:	**6,500 Cp**

TABLE A2 – VISCOSITY UNITS AND CONVERSION

ENGLISH UNITS

Item	Name	Viscosity Symbol	Unit base Force or Mass	Viscosity Units	Name of Unit	Conversion	Comments
a.	Absolute or Dynamic Viscosity	μ_f	Force pounds	$\frac{Lbf \times s}{ft^2}$	Absolute Viscosity (Force)	(a.) Is the Base case Note: F = m X a F = Force (Lbf) m = Mass (Lbm) a = accereration of gravity = g_c	Where: Lbf = pounds force s = seconds ft = feet Lbm = pounds mass Note: A pound mass Lbm is also called a Slug.
b.	Absolute Viscosity	μ_m	Mass Pounds (Slugs)	$\frac{Lbm}{ft \times s}$	Absolute Viscosity Mass	From (a.) to (b.) $\mu_m = g_c \times \mu_f$	Where: g_c is the gravitational constant: 32.174 ft/sec^2
c.	Kinematic Viscosity	ν_m	Mass Pounds (Slugs)	$\frac{ft^2}{s}$	Kinematic Viscosity	From (b.) to (c.) $\nu_m = \frac{\mu_m}{\rho}$	Where: ρ = fluid density in Lb mass.

SI (Metric) System

Item	Name	Symbol	Unit Base	Units	Name	Conversion	Comments
d.	Absolute Viscosity	μ_p	Mass grams	$\frac{g}{cm \times s}$	Poise or Centipoise	From (b.) to (d.) $\mu_p = \mu_m \times 14.882$ Poise	In the SI system no gravity correction is required. Poise = 100 X Centipoise (Cp)
e.	Kinematic Viscosity	ν_{ST}	Mass grams	$\frac{cm^2}{s}$	Stokes	From (d.) to (e.) $\nu_{ST} = \frac{1000\mu_p}{\rho}$	Where ρ is fluid density in: Kg/M^3

Note:

In **SI units**, the unit of force is a **Newton**. The equation $\mathbf{F_{SI} = m \times a}$ is applied thus: $\mathbf{F_{SI} = 1.0\ Kg \times 9.8066\ m/sec^2 = 9.8066\ Nt.}$

Ref 1: www.onlineconversion.com/viscosity_dynamic.html

Ref 2: Do a search for "Steam Viscosity Calculator" and go to the Spirax Sarco Website listed.

Ref 3: www.engineeringtoolbox.com/steam-viscosity-d_770.html

TABLE A3, VISCOSITY CONVERSION EXAMPLE
Saturated Steam at 100 PSIG

ENGLISH UNITS				METRIC UNITS	
	μ_f Absolute Viscosity Lb Force Units	μ_m Ablsolute Viscosity Lb Mass Units	ν_m Kinematic Viscosity Lb Mass / Density	μ_p Absolute Viscosity LB Mass	ν_{ST} Kinematic Viscosity Mass / Density
UNITS	$\frac{\text{Lbf X s}}{\text{Ft}^2}$	$\frac{\text{Lbm}}{\text{Ft X s}}$	$\frac{\text{Ft}^2}{\text{s}}$	$\frac{\text{Gram}}{\text{cm X s}}$	$\frac{\text{Cm}^2}{\text{s}}$
				Poise	**Stoke**
Example: 100 PSIG sat. Steam. Density = 0.2571 Lb / Ft^3	**0.306 X 10^{-6} From ASME steam tables**	**X 32.174 Ft/s^2 = 9.8639 X 10^{-6} Lbm / Ft X s**	**div. by density 0.2571 Lb/Ft^3 = 38.795 X 10^{-6} Ft^3/s**		
Convert English to Metric Units to find Viscosity in Poise and Centipoise		**Conversion Factor to Poise = 14.882 Note 1.**		**X 14.882 = 146.79 X 10^{-6} Poise =0.0148 Centipoise**	

Note 1: See Spirax Sarco Conversion Table. Search: “Steam Viscosity Calculator” and go to the Spirax Sarco Website.
Note 2: One Poise – 100 Centipoise (Cp)

Conversions:

μ_f **to** μ_m Multiply by 32.174 Ft/s^2

μ_m **to** μ_p Multiply by 14.8882 to get Poise.

A3) Reynolds Number

Whether flow of a liquid or gas in a pipe is laminar or turbulent depends on a dimensionless number called the **Reynolds number.**

The Reynolds Number is important in flow metering because it changes the velocity profile of the fluid flowing in the pipe. That is, fluid velocity is not constant across a section of pipe. The flow reading, whether in Volume units or Mass units, depends on an accurate estimate of the **average velocity** of the fluid across the pipe section.

The Reynolds Number (Re) is a dimensionless number which combines several variables. A change in any of these variables affects the velocity profile of the fluid flowing in pipes. These variables are velocity, viscosity, density and pipe diameter. The Reynolds number indicates the ratio between dynamic and viscous forces of the fluid. For a fluid of constant viscosity, as velocity increases, the forces which cause the layers of fluid to shear, dominate the viscous force which tends to prevent the liquid from shearing. The result is the transition of laminar (slow) flow to turbulent flow. The general expression to calculate Reynolds Number is:

$$Re = \rho VD / \mu \quad \text{- - - - - - Eq. A3-1}$$

Where:

ρ = Density of the fluid
V = Mean Velocity
D = Internal Pipe Diameter
μ = Viscosity

Rule of Thumb: When the Reynolds number is **less than 2,000, flow is Laminar**. When the Reynolds Number is **above 4,000, flow is turbulent.** When the Reynolds number is **between 2,000 and 4,000 flow is said to be transitional**, that is, somewhere between laminar and turbulent.

Why is Reynolds Number Important for Flow-Metering?

The Reynolds Number is not a constant. It affects the velocity profile of the flowing fluid. Differential Pressure type meters and other types such as vortex shedding meters use the velocity of the fluid stream in order estimate the volumetric flow or the mass flow. This velocity is an estimate of the average velocity across the pipe section. These types of meters are calibrated to operate within a specific flow range assuming a constant viscosity and density. Outside the intended range, the meter has reduced accuracy. Even within the intended range, the reading is a compromise because there are small changes in the velocity profile. Meters are supplied with specified operating ranges. For example, the maximum turn-down ratio, accuracy and repeatability are conditions which are defined by the meter’s operating range as established when it is selected by the customer and manufacturer.

A4.) Theoretical Flow Calculation Using Bernoulli's Theorem

Up to this point, in the process of selecting and analyzing a flow meter, the user has defined the fluid properties, flow conditions and pipe dimensions (A-1). In A-2, the viscosity has been discussed and in A-3, the Reynolds Number Re, has been explained. (Calculations for these steps are shown in **Appendix B**).

In practice, the customer and his flow meter supplier would make a preliminary meter selection and test the application using the real flow parameters and making these calculations. In this example, the pipe size is nominal 3 inch, schedule 80, so the meter size will have 3 inch 150 Lb rated flanges. The primary element will have a beta ratio of 0.65. Since the ID of the pipe is actually 2.9 inch, the orifice diameter will be 0.6 X 2.9 inch = 1.88 inch.

The next equation below (used in **Appendix B)**, provides an estimate of the flow and pressure drop through the proposed meter using the example chosen, that is, 100 PSIG saturated steam flowing at 4,000 Lb/Hr.

The equation which will be used is:

$$\mathbf{Qv(cfs) = .09970190 \ X \ \frac{d^2}{\sqrt{1 - \left\{\frac{d}{D}\right\}^4}} \ X \ \sqrt{\frac{Hw}{\rho}}} \quad \text{-------} \quad \textbf{Eq. A4-1}$$

Where:
Qv = the volumetric flow (ft^3/s)
d= Orifice Plate Diameter (inches)
D = Pipe ID (inches)
Hw = pressure drop across the orifice. (In. w.c)
ρ = fluid density. (Lb/ft^3)

This equation is from R.W. Miller, "Flow Measurement Engineering Handbook", McGraw Hill, 1983 pp. 9-5

Note: The equation which is derived from Bernoulli's theorem excludes a number of important factors which apply in practice. Bernoulli's theorem does not account for energy losses which occur in the process of restricting the flow of a fluid, or for variations in the Reynolds number or viscosity. The location of the pressure monitoring taps is also an important factor. The additional factors are described in the following sections.
The result of Bernoulli's theoretical equation applied to the example meter application is: (See Appendix B4 Calculations)

Qv(cfs) = **7.465 ft^3/sec**
Qm = **6,909 Lb/Hr** excluding the discharge coefficient Cd
Qm = **4,207.8 Lb/Hr** including Cd but excluding pressure and temperature corrections.
Theoretical Pressure Drop = **95 Inch. w.c.**

A5) Discharge Coefficient (C_D) of a Differential Pressure (DP) Flow-meter

The theoretical equation of **A4-1** alone, does not allow us to calculate the flow of a fluid through a restriction such as a (DP) type flow-meter. The specific design of the flow-meter and its **primary element** must be included in the equation.

Figure A3 an orifice plate flow-meter showing the flow pattern through the orifice.

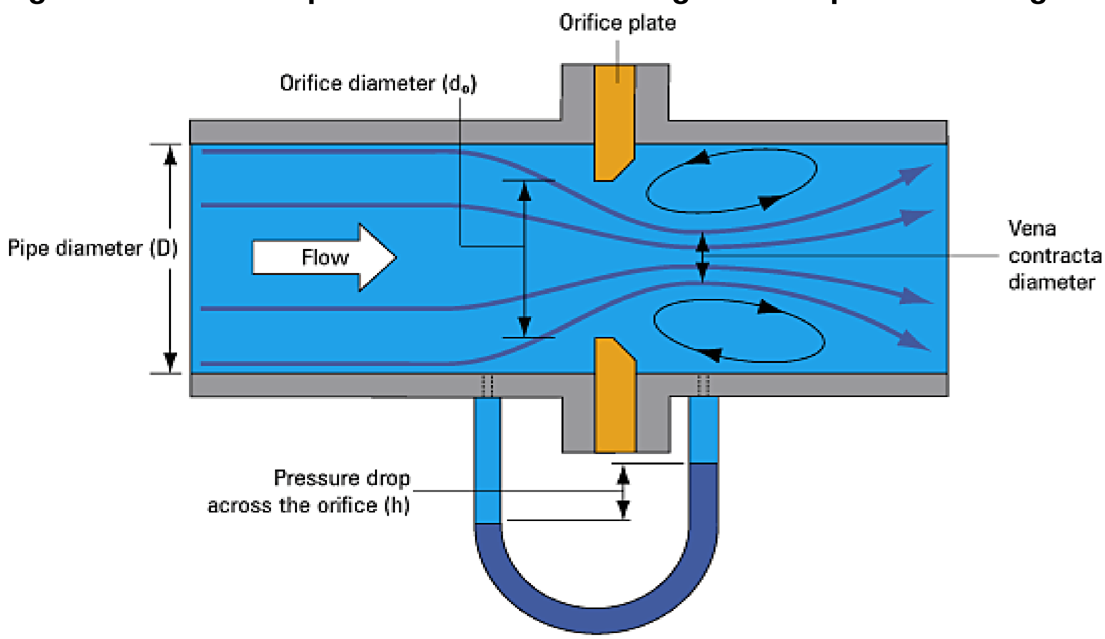


Image Courtesy of Spirax Sarco website, "Steam Engineering Tutorials"
http://www.spiraxsarco.com/resources/pages/steam-engineering-tutorials.aspx

Figure A3 above represents the flow of a fluid through an orifice plate and indicates the key dimensions which affect the pressure drop across the orifice. The proportions of the key dimensions can vary widely and these affect the pressure drop. The key dimensions are:

1. The pipe diameter **Dp**
2. The orifice diameter $\mathbf{d_O}$
3. Vena Contracta diameter **Dv**
4. ***The Beta Ratio*** $\boldsymbol{d_O / D}$
5. The location of the **pressure taps.**

A **factor** which defines the behavior of a specific orifice plate operating on a specific fluid within a specified flow range must be established. This factor is called the discharge coefficient or **Cd** of the meter.

A5) Discharge Coefficient (C_D) of a Differential Pressure (DP) Flow-meter

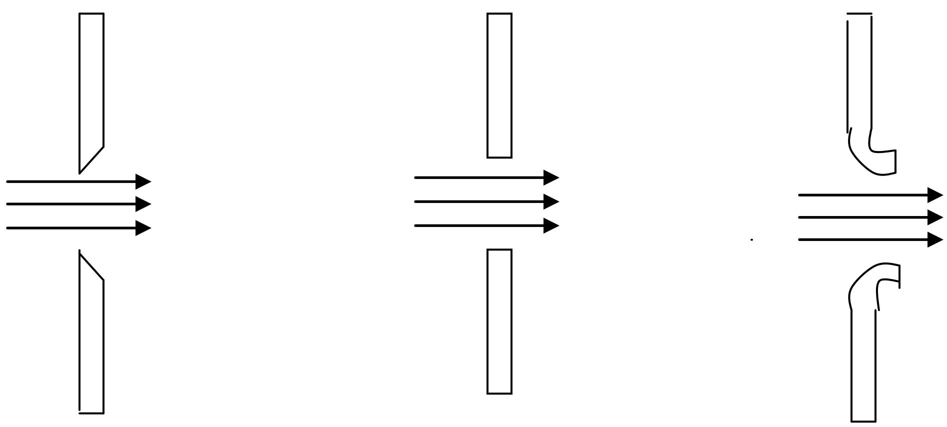
The discharge coefficient corrects the theoretical equation for the effects of velocity profile, (Re), the fact that some energy is lost, and the location of pressure taps.
The location of pressure taps is especially important. Flange taps, or corner taps for example, are used to avoid locating taps on the pipe, upstream and down stream of the meter. This is a good practice because it removes a potential source of error and additional cost in the installation of the meter.
The problem however, is that the flange taps are probably not located at the actual point of maximum pressure drop across the orifice. Therefore, a correction is made to estimate what the pressure drop would be if the taps were located in the ideal location.

The primary element of a flow-meter is the actual orifice plate, pitot tube, flow nozzle or other device. The discharge co-efficient is established **by laboratory testing** which reproduces the geometry of a specific installation.

The discharge coefficient is defined **as the ratio of the true flow rate as measured divided by the theoretical flow rate as determined by Bernoulli's theorem.**

Following is an example of typical discharge coefficients for various shapes.

Figure A4 Discharge Coefficients for several orifice shapes.



Sharp Edge Orifice $C_D = 0.62$ | Straight Edge Orifice $C_D = 0.66$ | Smooth Transition $C_D = 0.97$

The discharge coefficient is influenced by the shape of the orifice. Cd varies with the Reynolds Number and the Beta Ratio.

A5) Discharge Coefficient (C_D) of a Differential Pressure (DP) Flow-meter

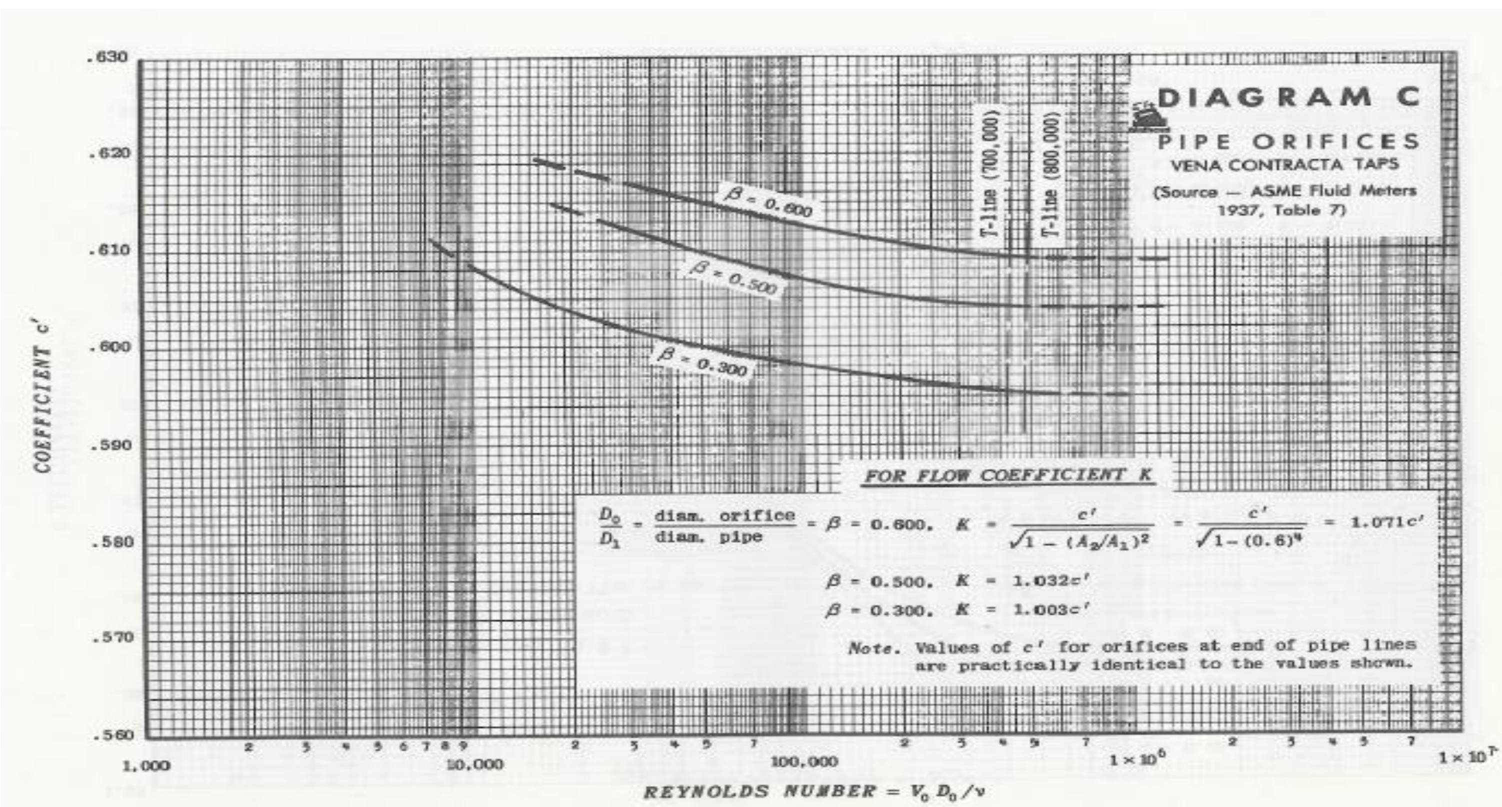
The following table shows how Cd varies with Re and Beta Ratio β

Table A4, Coefficient of Discharge for a Sharp Edge Orifice Plate

	Reynolds Number			
Beta Ratio β = Dp / Do	10^4	10^5	10^6	10^7
0.2	0.60	0.595	0.594	0.594
0.4	0.61	0.603	0.598	0.598
0.5	0.62	0.608	0.603	0.603
0.6	0.63	0.610	0.608	0.608
0.7	0.64	0.614	0.609	0.609

In practice, manufacturers of flow-meter primary elements establish the characteristic of the element by testing it in a lab over a range of Beta Ratios and at extremely high Re. The element is catalogued and buyers who install it have to calibrate it for its specific use with acceptable accuracy.

Graph A1, Discharge Coefficient vs. Beta Ratio and Re



A5 How the Discharge Coefficient is Used.

The discharge coefficient is determined by laboratory testing by the manufacturer for every type of flow meter. The meter is calibrated using the discharge coefficient for the nominal (reference) flow condition including the Reynolds number. The manufacturer can tell you the discharge coefficient for each meter specification.

In calculating the actual flow rate for a differential pressure meter, the result of Appendix A4 is simply multiplied by Cd, resulting in a lower flow rate than predicted by the Bernoulli flow equation.

See Appendix **B5** for calculation.

A5.1) The Flow Coefficient F_K

Not surprisingly, there is often confusion about the definition of Discharge Coefficient $\mathbf{C_D}$ and Flow Coefficient **K**.

The Flow Coefficient has been defined in various ways. One way is that it is a combination of discharge coefficient with the “velocity of approach” factor which is found in the flow equation (See EQ. A-4.1).
The flow coefficient does not change the calculation for volumetric flow rate; it simply combines the following factors into a single value D.

The flow coefficient K is therefore defined as:

$$K = \frac{Cd}{\sqrt{1-(\beta)^4}} \quad \text{--------- Eq. A5-1}$$

Some articles on the subject use **K** to mean discharge coefficient but call it the flow coefficient. This lack of common definition creates uncertainty. It is the responsibility of the buyer of flow metering equipment to be sure about the terminology used by the seller.

A6. Pressure and Temperature (Density) Correction.

A common condition in industrial flow metering is that the base operating pressure varies significantly as conditions in the fluid distribution system change.

An example of this is a steam distribution system with multiple end users. Steam loads change as equipment turns on or off, or the demand for steam modulates. This causes pressure drops through the piping system supplying the loads, and at the boiler plant. The same example applies to a natural gas distribution system.

The sequence of calculations showing flow through an orifice plate, up to Appendix A5, have not accounted for this. The orifice meter has been calibrated using a base (reference) set of conditions including a fixed pressure. In real world industrial plants, pressure varies; the flow reading must be corrected.

The solution is to apply yet another factor to the flow-meter reading (output signal) to correct it to the reference pressure and temperature. The challenge is that this change often occurs continuously as the system operates.

This applies to almost all types of flow-meters, not just Differential Pressure meters.

The relationship between the volume of a gas, the pressure and the temperature is given by the "Gas Density Equation"

$$P\,V = n\,RT \quad \text{or} \quad V = \frac{nRT}{P} \text{ - - - - - - A6-1}$$

Where: V = the volume of gas
P = the base pressure in psia
n = the mass of gas (Number of moles)
T = the temperature in degrees Rankin
R = the universal gas constant which is 10.7315 psia-ft^2 / lb-mole ^{O}R

This equation tells us that the volume of a gas varies directly with its temperature and inversely with pressure. **Therefore, the density ρ of the gas changes with pressure and inversely with temperature.**

In practice, this correction is made in real time by a flow computer associated with the flow meter. Pressure and/or temperature are continuously monitored and a calculation made which adjusts the flow reading from the reference condition to the actual condition of temperature and pressure.

A6) Correction for Pressure and Temperature Variation (Density Variation)

From Eq. A1.1-5, we see that the velocity of flow varies inversely with the square root of density.

$$V \ \alpha \ \sqrt{\frac{2\,\Delta P}{\rho}} \qquad \text{- - - - - see eq. A1.1-5}$$

Therefore, volume flow varies as: $Qv \ \alpha \ A \times \sqrt{\frac{2\,\Delta P}{\rho}}$ - - - - - - - - **A6-1**

When the pressure of the metered gas changes, the flow-meter reading which has been based on the reference density, can be corrected approximately by calculating a correction factor based on the density change.

The new volume flow can be calculated as follows:

$$\frac{Qv\ actual}{Qv\ reference} = \sqrt{\frac{\rho\ reference}{\rho\ actual}} \qquad \text{- - - - - - - - - - A 6-2}$$

That is, the actual reading for the same differential pressure, is a factor defined by equation (A-6.2) times the reference reading. If the reference gas density is greater than the actual gas density, the reading will be high. If the reference gas density is lower than the actual gas density, the reading will be low.

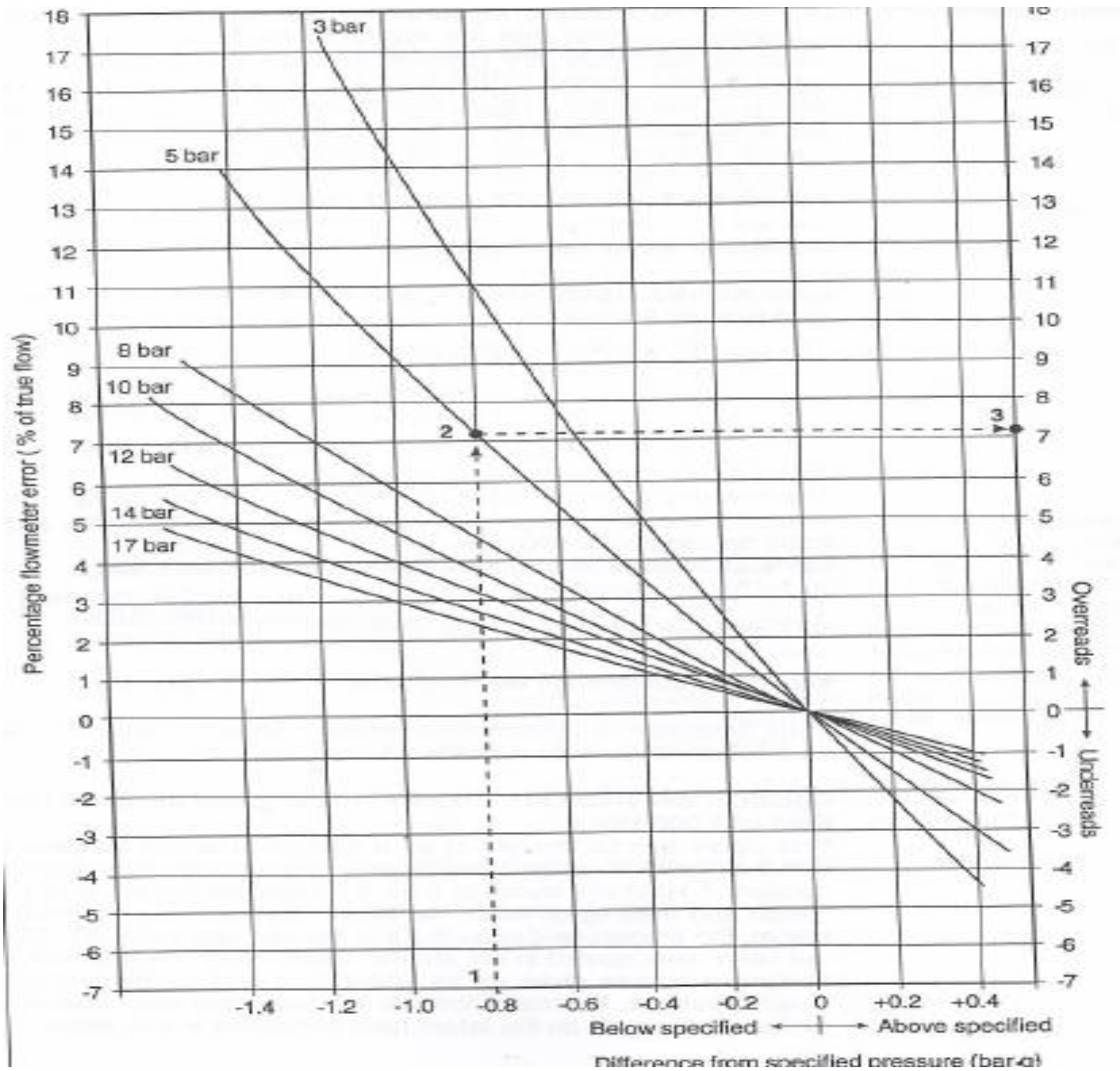
In practice, compensation for temperature and pressure variation in measuring the flow of gases is usually accomplished by means of an algorithm which continuously adjusts the reading from the meter. This calculation may be made in a flow computer or directly in the flow transmitter if it is a multivariable type.

The calculation for base pressure change is shown in **Appendix B 6.1**

A 6) Correction for Pressure and Temperature Variation (Density Variation)

The graph below shows the magnitude of error in the **mass flow** reading of an orifice plate flow meter. In the example, the pressure falls below the pressure for which the meter is calibrated (reference point). (**Note**: 1 bar = 14.5 Lb/Sq. In.)

Graph A2, % Error vs. Pressure Variation for an Orifice Plate



In this example, an orifice plate is calibrated at 5 bar or 72.5 PSI. The actual pressure is 4.2 bar (0.8 Bar below the reference pressure). **The mass flow reading high by 7.1%.**

If the actual pressure is **below** the reference pressure for which the meter was selected and calibrated, the volume and mass flow reading and meter output will be **too high.** If the actual pressure is above the reference pressure, the reading will be **too low.**

A 7 Adiabatic Expansion Factor (Expansibility Factor)

Correction of the flow rate due to adiabatic expansion should not be mistaken for the correction shown in A6 which applies to changes in the base operating pressure.

.

As gas flows through a pressure restriction of an orifice from the inlet to the outlet the pressure decreases. In order to calculate the flow rate accurately, a new factor is introduced to account for the density change due to gas expansion. The adiabatic expansion factor is usually represented by the symbol **Y**. Y can be calculated in a number of ways. See ref. 1 below and Eq. B7-1.

The adiabatic expansion factor **Y**, is related to the **Compressibility Factor Z.** The compressibility factor includes a temperature correction in the gas. This is caused by the fact that the temperature at the up-stream and downstream taps also changes as the gas expands. In practice, the temperature change between the meter's pressure taps is relatively small and the expansion factor Y alone is usually considered to be an adequate correction. For most applications, the error due to Y is in the order of about 1% and the correction is approximately (1.0 – 0.01) or 0.99.

The calculation involving the expansion factor correction compounds the correction made for discharge coefficient. The flow equation derived from Bernoulli's equation is multiplied by the expansion factor thus:

$$\mathbf{Qv(cfs) = .09970190 \times Cd \times \frac{Y \times d^2}{\sqrt{1 - \left\{\frac{d}{D}\right\}^4}} \times \sqrt{\frac{Hw}{\rho}}} \quad \text{-------} \quad \textbf{Eq. A4-1}$$

Where: **Cd** is the discharge coefficient
Y is the expansion factor.

In Appendix B7, the expansion factor is calculated using an equation accepted by the International Standards Organization. (See Appendix B5 for this calculation)

The ISO Equation is: $\mathbf{Z = 1 - (0.351 + 0.256X\beta^4 + 0.93X\beta^8) X \left\{ 1 - \left(\frac{P2}{P1} \right)^{1/k} \right\}}$

- - - - -eq. B7-1

from "Flow Measurement Handbook" pp.99 Roger C. Barker, Cambridge University Press, 2000.

Ref. 1: **"**Flow Measurement Engineering Handbook", R. W. Miller, 1978, pp. 2-79 and 9-6.
Ref. 2: **"**Piping Engineering", Chemetron Corp., 1969 pp.122 Pressure Drop for steam gases – Nomograph.
Ref. 3: "Design of Fluid Systems", Spirax Sarco Inc., 1997, pp 3.

A8 Upstream and Downstream Length of Straight Pipe Required for Accuracy

The accuracy of the meter's output is affected by flow restrictions up-stream of the meter. These restrictions include common piping items such as elbows, valves and changes in pipe size.
Flow-meters are selected and calibrated on the assumption that they are subject to a well developed and symmetrical profile.

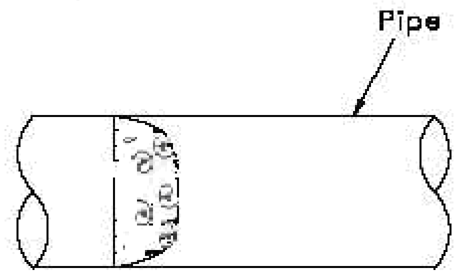


Fig. A5, Turbulent Flow Pattern (Flat symmetrical profile)

Elbows create a swirl in the flow pattern while other restrictions cause a random disruption.
Following these disturbances, the flow pattern eventually returns to normal but this occurs some distance downstream of the disruption. The length of straight pipe required depends not only on the nature of the up-stream disturbance, but on the design of the flow-meter itself. For example, for orifice plates, the required distance increases with increasing β ratio and other geometric factors such as tap location.

The cause of most of these problems is improper installation, that is, the installing contractor does not adhere to guidelines provided by the manufacturer.

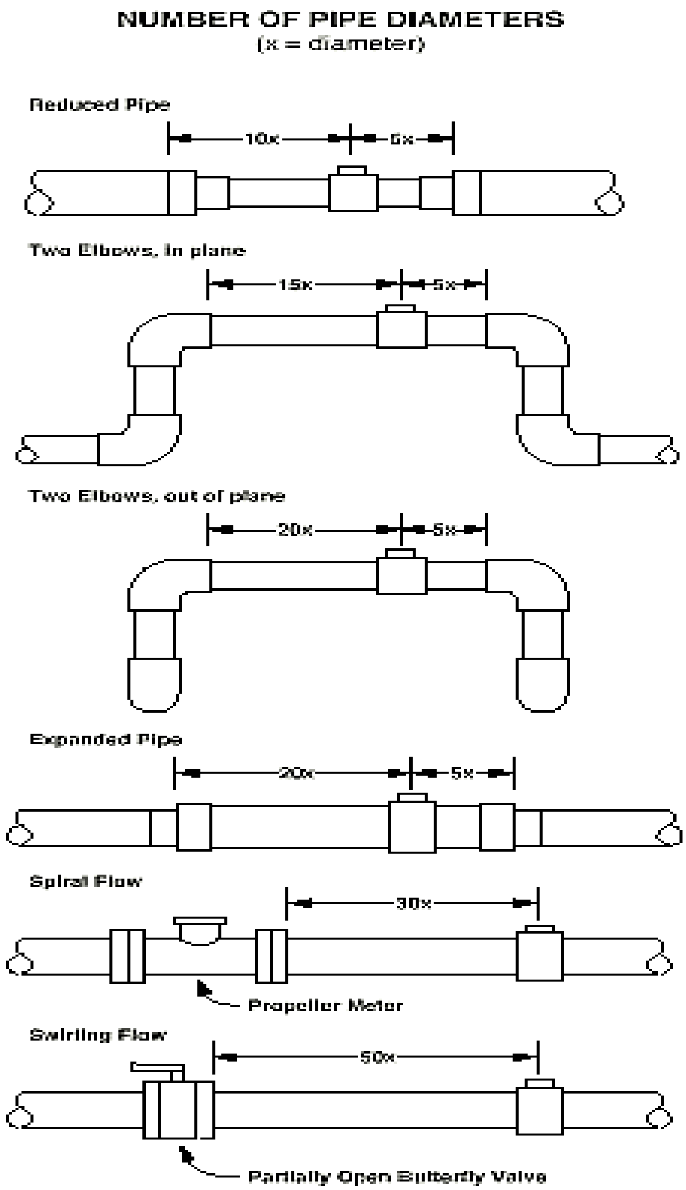
Flow-meter manufacturers recommend the length of straight pipe required to install a meter for various circumstances. (**See figure A.6, next page**). The recommendation is made in terms of the number pipe diameters. For example, for a 3 in. diameter pipe size, the upstream straight requirement may be 20 Diameters or 60 inches. The recommendation is specific to the type and specific model of flow-meter as well as the type of restriction to flow.

The requirement for straight pipe is a very important factor in selection of a meter. In many cases, the physical layout and space available is limited. Meters are available which require relatively few straight pipe diameters for example:

- Electromagnetic flow-meters (for liquids) may require only 3D upstream and 2D downstream.
- Conditioning orifice plates with integral impulse tubes may need only 2D upstream and 2D downstream.
- V-Cone meters require only 4D total straight pipe lengths.
- Positive displacement meters require no upstream or downstream straight pipe.
- Coriolis Meters require no straight pipe lengths.

A8. Upstream and Downstream Length of Straight Pipe Required for Accuracy for DP Meters

Figure A6



The diagram opposite, **Fig. A6** shows the approximate length of straight pipe required when a DP flow meter such as an orifice plate requires when various pipe hardware and obstructions are present.

The distortion in flow pattern caused by elbows, valves and pipe diameter changes, causes significant error.

The worst scenario is a partially open butterfly valve (last drawing) which can cause an error of about **50%** in the reading.

If there is not enough straight pipe run to install a meter, then a flow straightener may be the answer.

Another possibility is to use a Multi-variable transmitter which reduces the number of straight pipe lengths required.

A9 Accuracy (Error) and Precision (Repeatability)

Accuracy is also known as **bias error**. Accuracy is different from **precision** which is the same as **repeatability.** Accuracy is determined by measuring the flow through a specific meter multiple times and by plotting these measurements against the known true flow value. These readings will vary and the average of the readings may be **offset** from the true value by a certain percentage. The deviation of the average of these multiple values from the true value is the accuracy of the meter.

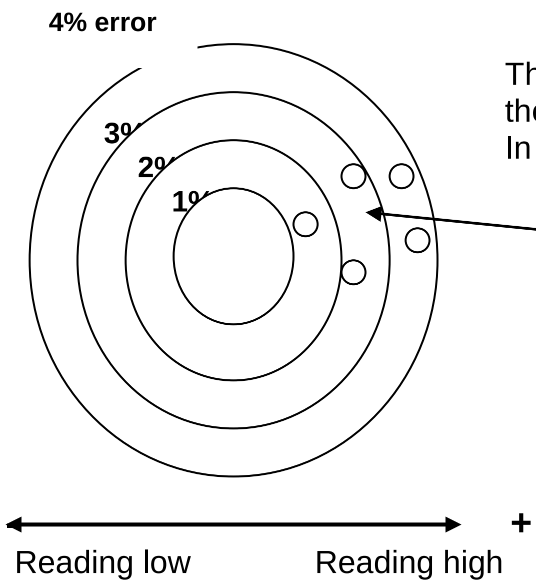


Figure A7, Bias Error or Accuracy
Flow-meter #1

The average error of multiple readings compared to the true reading is the Accuracy or Bias Error.
In this case, the average bias error is 2.8%

Average error = **+2.5%**

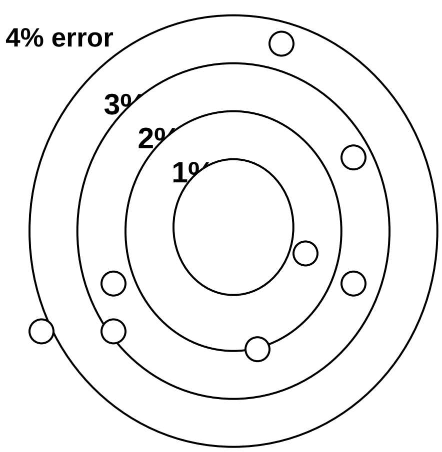


Figure A8, Precision or Repeatability
Flow-meter #2

Precision or Repeatability is determined separately from accuracy.
The average error (accuracy) in this example, Meter#2 is plus 2.5% which is the same as than that of the previous example, however, the readings are scattered widely. Repeatbility is calculated statistically by plotting the normal distribution curve using the deviation from the average for each one, and by calculating the standard deviation.

Repeatability is the ability of an instrument to repeat the same measurement with little variation over multiple readings.

A9 Accuracy, Error and Repeatability

In **energy management applications, repeatability** is more important than accuracy when the main object of the measurement is to compare performance of a specific process over time or for under conditions. It is the change in performance which motivates improvement, not the precise value.

When comparing two separate processes, flow-meter **accuracy** is the most important specification. there should be an understanding of the components which are included in the specified accuracy figure. Typically, the accuracy of the flow-meter primary element (eg. the orifice plate or venturi tube), is specified separately from the accuracy the transmitter. The accuracy of the total metering system including all components can also be specified.

Accuracy is usually specified in terms of percent error. For example, an instrument which gives a reading which is 98% accurate is 2% inaccurate. It is however, said to have 2% accuracy.

The flow-meter buyer should understand that the percent error specified by the seller may be stated in more than one way, for instance:

1.) Error is specified as a percentage of <u>full scale reading</u> over the calibration range.
2.) Error is specified as a percentage of <u>actual reading</u> over the calibration range.

For example, for an orifice plate (**meter #1)**, the accuracy of the <u>flow reading</u> of the primary element is specified as <u>2.5% of full scale reading (FS)</u>, over the range.
If the maximum range of the orifice plate is specified as 4:1, the <u>flow reading</u> error at low flow would be four times that at full scale or 10% of actual reading.
For **Meter #2**, the accuracy is specified as a maximum of <u>2.5% of actual (AR)</u> reading over the entire calibration range. This meter is more accurate than meter #1. At all points in the range, the error is no more than 2.5%.

The total theoretical accuracy of a metering system is equal to the square root of the sum of all of the devices in the system. For example, a metering system having a primary element with an accuracy of 2.5% FS and a transmitter with an accuracy of 0.2% FS has a total theoretical accuracy of:

$$\sqrt{(\text{Primary Element accuracy})^2 + (\text{Transmitter accuracy})^2}$$

Or

$$\sqrt{(2.5\%)^2 + (0.2\%)^2} = \mathbf{2.508\ \%}$$

A9 Accuracy, Error and Repeatability

In applications where accuracy is very important, the buyer of a flow-meter should be aware of various “Error Standards” including ANSI (MFFCC) 1982, ISO TC 30 and the National Institute for Standards and Calibration (NIST).

Some standards which require flow-meters to be highly accurate include:

- custody transfer of natural gas or other fuels.
- batch measurement of ingredients in an industrial process.
- metering natural gas and air to control the fuel to air ratio in a gas burner.

Energy management applications do not usually require such a high degree of accuracy. The buyer should specify the required accuracy of the total meter system including primary element.

The causes of inaccuracy (bias error) include:

- Mechanical wear of primary element eg. Erosion of orifice plate edges, plugging of holes in pitot tube.
- Improper installation of primary element.
- Poor meter setup or verification.
- Operating range outside flow calibration range.
- Lack of correction for pressure or temperature variation.
- Errors in calculating flow rate and correction factors from measured DP.

A10) Conclusions and Recommendations for Flow Meter Buyers

1.) From section A1, Bernoulli's theorem provides the technical basis of operation of all differential pressure flow meters. It describes the relationship between the pressure drop across a restriction in a flow stream and the velocity of flow.

2.) The purchaser of a flow meter should provide detailed information to the vendor on the application. Vendors supply their own forms for this data and will assist the purchaser in filling them out.

3.) From sections A2 and A3, the importance the properties Viscosity and Reynolds Number are shown.

4.) From section A5, The theoretical equation describing the relationship between pressure drop across a flow restriction and velocity has to be corrected for the specific meter design, The factor used for this correction is called the discharge coefficient.

5.) From sections A6 and A7 Further corrections have to be made when the operating conditions of pressure or temperature vary.

6.) From section A8, Every flow meter has a specified length of straight pipe required for its installation. This data is provided by the manufacturer. The owner and installer of the meter must be aware of this.

7.) From section A9, The purchaser of a flow meter should ask the vendor to specify what he means when making claims about accuracy and repeatability.

FLOW METER GUIDE BOOK FOR INDUSTRY

APPENDIX B, CALCULATIONS, GRAPHS, CHARTS AND TABLES

Introduction

In this appendix you will find some basic calculations which we hope will illustrate the engineering principles used in selecting and sizing a meter for a specific application. This section is for the benefit of non-experts in the subject of fluid flow.

Engineering Units

Fluid Dynamics text books written for U.S. readers employ both English and Metric (SI) units when describing the science of fluid flow. Recent books tend to use SI units while older texts use English units only. Many books use both. Other sources such as technical papers found on the internet sometimes employ a mixture of both units in the same article and even in the same formula, using a factor to convert mixed units. This type of problem makes it confusing for the non-expert trying to select a flow meter.

Furthermore, texts and other sources do not use standardized terminology.
For example: **viscosity** can be described as either **Absolute** Viscosity or **Kinematic** Viscosity (a different figure from absolute for the same fluid). Absolute Viscosity is also called Dynamic Viscosity.
Buyer bewares: When doing calculations or reading tables or graphs, the user should pay close attention the terminology and basic units which are employed. If you are doing calculations, or communicating your requirements to a supplier, there is a large potential for misunderstanding when nomenclature or units become confused.

B1. Basics- Identify Fluid and Flow Characteristics.

The following series of calculations is made for the same example. It is aimed at sizing and defining the performance of an orifice plate flow meter in a steam application. Sample calculations follow the 7-step sequence shown in Appendix A, Introduction.

Example: Calculate the average velocity of saturated steam in a 3 inch diameter schedule 80 pipe at 100 psig, having a flow rate of about 4,000 LB/HR.

B1.1 Estimate the Steam Velocity.

From steam tables the specific volume of steam is **3.89 CU FT per LB**.
From pipe data table, the I.D. for schedule 80 pipe is 2.900 in., the flow area of is 6.79 SQ IN. or **0.0471 SQ FT**.
The average flow rate is 4,000 LB/HR X 3.89 CU FT per LB = **15,506 CU FT/HR**.
or 15,506 / 3,600 CU FT/Sec. = **4.31 CU FT/Sec**.
Velocity = 4.31 CU FT/Sec. / 0.0471 SQ FT. = **91.5 FT/Sec**.

B1. Basics-Identify Fluid and Flow Characteristics
B1.2 Fluid and Flow Properties

Table, Data required for Typical Flow Meter Application-Example
Fluid: Saturated Steam at 100 PSIG

Flow Data and Properties	Value	Units	Description – How to Find or Calculate.
Steam Pressure - Nominal	100	PSIG	Plant operating pressure. Boiler pressure
Steam Pressure – Max.	100	PSIG	set-point.
Steam Pressure – Min.	85	PSIG	Experience-Knowing the operation.
Steam Temperature	338	^{O}F	From saturated steam tables.
Specific Volume of Fluid	3.89	fFt^3/Lb	From saturated steam tables.
Density of Fluid	0.2571	Lb/ft^3	Inverse of Specific Volume (calculated)
Steam Viscosity μ_f	**0.31×10^{-6}**	$\frac{Lbf \times s}{Ft^2}$	From ASME steam tables.
Flowrate–Expected Average	3,000	Lb/Hr	If there is no existing meter. Flows must be estimated from experience and a knowledge of the process or the boiler plant.
Flow Rate-Max.	4,000	Lb/Hr	Estimated.
Flow Rate-Min	800	Lb/Hr	The minimum is only 20% or the maximum. This turndown ratio 5:1, is outside of the range of some meters. See the selection tables of Section 2 of the Guide book.
Pipe-Size-and-Schedule-Nominal Diameter	3	inch	Schedule 80. Go to API standard pipe tables to find the internal pipe diameter if the nominal is 3 inch.
Inside Pipe Diameter	2.9	inch	This diameter is used to calculate pipe area for the purpose of calculating velocity.
Outside Pipe Diameter	3.5	inch	Difference between OD and ID is wall thickness divided by 2.
Orifice Bore Diameter	1.88	inch	(to be tested, for this application-not final)
β Ratio	0.65		1.88 / 2.9 to be tested
Maximum Velocity	94.1	Ft/s	See Appendix B1 for calculation of velocities.
Minimum Velocity	18.9	Ft/s	At min. flow rate and nominal. Pressure.

Other Data:
Meter Specifications: Nominal 3 inch pipe, 300 LB rated self-centering flange, flange taps, ½" tap connections, Stainless Steel Orifice primary element, complete with mult-variable transmitter. ANSI / API complian

B2. Viscosity Calculations

Step 1
From the ASME steam Tables, the absolute viscosity (based on Lb force) of saturated steam (force basis) at 100 PSIG (114.7 PSIA) is: $\mu_f = 0.306 \times 10^{-5} \dfrac{Lbf \times s}{ft^2}$

Step 2 Convert μ_f to mass-based unit μ_m in the English System.
(Ref: Table Figure D1)

$$\mu_m = \mu_f \times g = 0.306 \times 10^{-5} \frac{Lbf \times s}{ft^2} \times \frac{32.174}{s^2} ft = 9.845 \times 10^{-6} \frac{Lbm}{ft \times s} \text{ - - -(1.)}$$

Step 3 Convert μ_m (English units) to μ_p (Poise) in the SI system.

$$\mu_p = 9.845 \times 10^{-6} \frac{Lbm}{ft.s} \times \frac{453.6 \frac{gm}{Lb}}{30.48 \frac{cm}{ft}} = 14.882 \times 9.974 \times 10^{-6} \frac{gm}{cm \times s} \text{ - - - (2.)}$$

$$= 146.513 \times 10^{-6} \text{ Poise - - - (3.)}$$

Multiply by 100 to convert to **Centipoise** : $Cp = 1.465 \times 10^{-2}$ Cp

Step 4 Convert μ_p (**Absolute Viscosity**-Poise) to ν_{ST} (**Kinematic Viscosity**-Stokes)

$$\nu_{ST} = \frac{1000 \times \mu_p}{\rho} \text{ - - - - - (4.)}$$

Where: ρ = fluid density in Kg/M^3

From Steam Tables: the specific volume of saturated steam at 100 PSIG is **3.89 ft^3/Lb.**

Convert to metric $S.V. = \dfrac{0.0532\ m^3/ft^3}{0.4536\ Kg/m^3} \times 3.89\ ft^3/Lb = 0.24287\ m^3/Kg$

Calculate the density: $\rho = 1/S.V. = 4.117\ Kg/m^3$

From eqn. (3.) and (4.) $\nu_{ST} = \dfrac{1000 \times 1.465 \times 10^{-4}\ gm/cm \times s}{4.117\ Kg/m^3}$

$$= 3.558 \times 10^{-2} \ \underline{cm^2} \text{ or Stokes}$$

B3. Reynolds Number (Re) Calculation

See Appendix A-3 for the definition of Reynolds Number.

Reynolds number is a parameter which describes the flow profile of a fluid in a pipe. The Reynolds number includes all the variables which affect flow profile in a pipe including viscosity, density and fluid velocity. It can be used to predict variations in the flow coefficient of a flow meter.

$$Re = \frac{\rho V D}{\mu}$$

Where:

ρ = Density of the fluid = 1/3.89 ft^3/lb = **0.2571 Lb/ft^3**
From saturated steam tables @ 100 PSIG.
V = Mean Velocity = **91.5 ft/sec** from calculation Appendix B-1.1
D = Internal Pipe Diameter = **0.242 ft**. From calculation Appendix A-1.4
μ =Viscosity = 1.1484 X 10-4 Poise = **9.845 X 10-6 Lbm / ft x s** from B.3 Eqn. 1

Note: most flow meters have a minimum Reynolds number below which they do not provide an accurate reading.

Calculate the Reynolds Number for the example given in Appendix **A-1.1** namely:
100 PSIG saturated steam having a flow rate of 4000 LB/Hr through a schedule 80 pipe of 3 inch diameter.

$$Re = \frac{0.2571 \frac{lb}{ft^3} \times 94.0 \frac{ft}{s} \times 0.2416 \text{ ft}}{9.845 \times 10^{-6} \frac{Lb}{ft \times s}} \qquad \text{- - - - - - - Eq. B3-1}$$

$$= 5.9307 \times 10^5$$ **Note:** Re is a dimensionless number.

The calculated Re above is acceptable for this metering application. Orifice plate flow meters require minimum Re of 5,000 to 10,000 depending on the manufacturer

B4. Theoretical Flow Calculation (Bernoulli's Theorem)

In this section of appendix B we will use the discharge coefficient for an orifice plate and other variables to calculate the steam flow in the same example, using the orifice plate pressure tap readings. The plant engineer has estimated the steam flow rate already. Here we will test the pressure drop across the orifice plate flow diameter to see if both are a reasonable selection.

The following data pertains to the orifice plate:

Orifice Bore Diameter: **1.88 inch = d (Test Variable)**
Inside Pipe Diameter: **2.9 inch = D**

Area of orifice plate: $\pi \times \left\{\frac{d}{2}\right\}^2 = \mathbf{0.06138\ ft^2}$
Beta Ratio: $= 1.88 / 2.9 = 0.65$
Steam Density: $= \mathbf{0.2571\ Lb/ft^3}$
Estimated Reynolds Number: **$Re = 5.9307 \times 10^5$** (from appendix B.3)
Pressure difference between upstream and downstream taps**: 95 inches (test variable)**

Step 1 Calculate steam volumetric flow rate based on the above readings and variables.

$$Qv(cfs) = .09970190 \times \frac{d^2}{\sqrt{1 - \left\{\frac{d}{D}\right\}^4}} \times \sqrt{\frac{Hw}{\rho}} \qquad \text{--------- Eq. B4-1}$$

$$= 0.997019 \times \frac{(1.88)^2}{\sqrt{1-(0.65)^4}} \times \sqrt{\frac{95.0}{0.2571}} = \mathbf{7.465\ ft^3/s}$$

<u>**Step 2.**</u> **Calculate the Mass Flow in Lb/Hr**

$Qm = Qv \times \rho \times 3{,}600$ s/hr. = 7.465 $ft^3/s \times 0.2571\ Lb/ft^3 \times 3{,}600$ s/Hr = <u>**6,909.3 Lb/hr**</u>

Note: Mass Flow calculated by this equation excludes the Meter Discharge coefficient (Cd) and corrections for pressure and temperature.

B4. Theoretical Flow Calculation (Bernoulli's Theorem)

The Flow equation which is derived from Bernoulli's equation can also be written directly as a mass flow equation rather than a volumetric flow equation as in Eq. B4-1.

From Miller "Flow Measurement Engineering Handbook" pp. 9-5, Eq. 9.17 this is the un-corrected mass flow equation:

$$Q(pps) = \sqrt{2g} \ X \ \frac{\pi}{4} \ X \ d^2 X \sqrt{\frac{1}{1 - \left\{\frac{d}{D}\right\}^4}} \ X \sqrt{\Delta P \ X \ \rho_f} \quad \text{- - - - - Eq. B4-2}$$

Where:

Q(pps) = FLOW in Lb/sec.
d= Orifice Plate Diameter (inches)
D = Pipe ID (inches)
G = the gravitational constant 32.2 ft/s^2
ΔP = differential pressure in inches w.c.
ρ_f = fluid density.

B5. Apply the Discharge Coefficient Cd. to correct the Theoretical Flow Rate

Step 1. Estimate the Discharge coefficient using the graph, **Figure B2**. next page:

At the intersection point of **Re = 5.9307 X 10^5** and $\beta = 0.65$, **Cd = 0.609**

From B4. Qv(cfs) = 7.465 ft^3/s

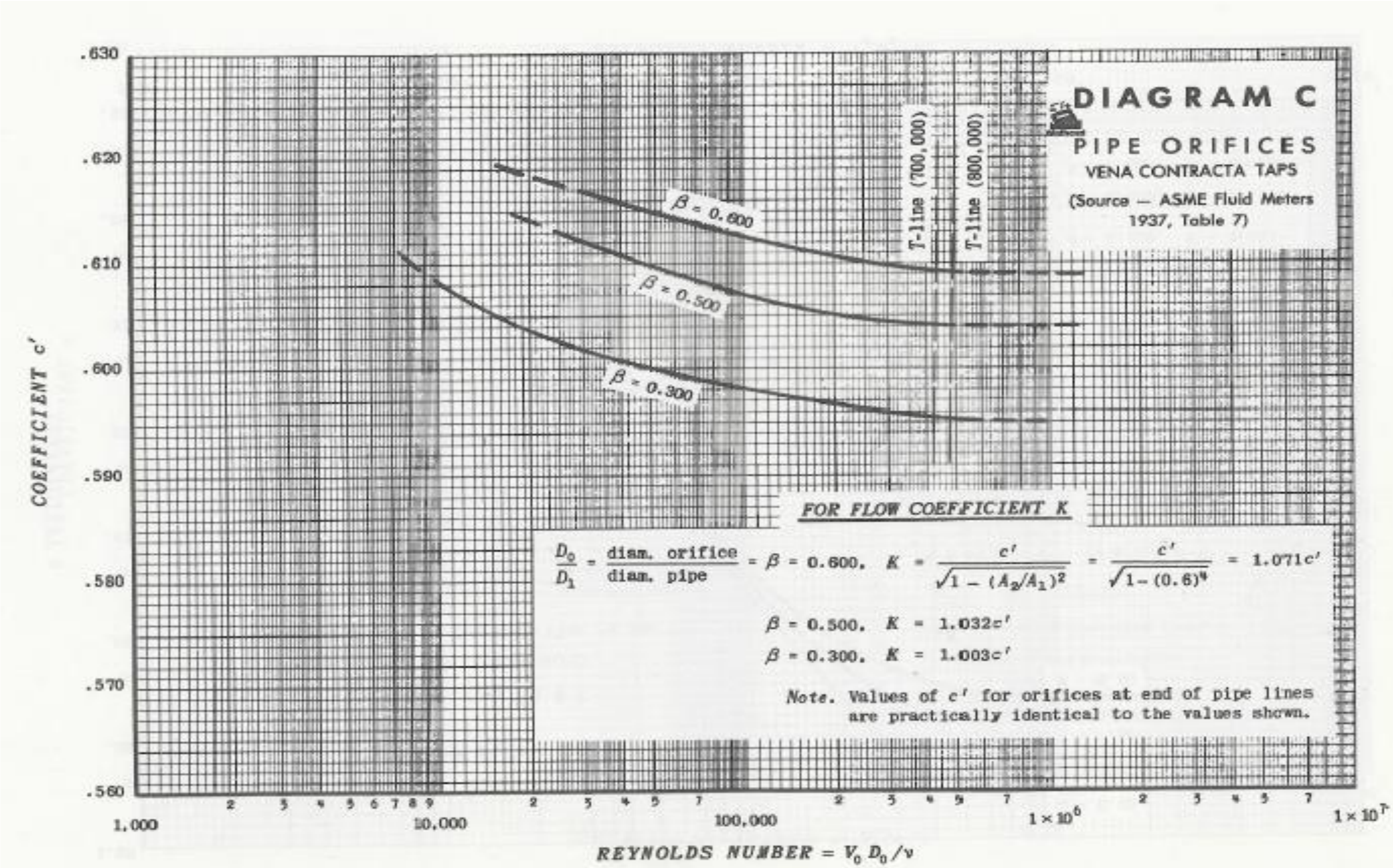
Cd X Qv(cfs) = 0.609 X 7.465 ft/s

From B4. Qm = 6,909.3 LB/hr

Cd X Qm = 0.609 X 6,909.3 = 4,204.8 Lb/Hr

The discharge coefficient corrects for the velocity flow profile, the location of taps in relation to the true location for maximum pressure differential, and the loss of energy in the process

Figure B1, Graph, Discharge Coefficient as a vs. Re and Beta Ratio



B6. Pressure Correction

B6.1 Pressure Correction Only.

A steam flow meter, (DP type) is 100 PSIG saturated steam. The flow-rate calculation is Qv = 7.465 ft3/s and Qm = 4,207.8 LB/HR. (from Appendix B5). At times, the steam pressure falls to a low of 85 PSIG. How much error does the flow-meter produce at the lower pressure?

ρ_{ref} reference at 100 PSIG = 0.257 lb/ft^3

ρ_{act} actual at 85 PSIG = 1/specific vol. = 1 / 4.44 f^3/lb =0. 2252 lb/ft^3

The mass flow correction factor for pressure is approximately:
From Spirax Sarco "Technical Reference Guide" on Steam Metering

$$\frac{\textbf{Qm metered}}{\textbf{Qm reference}} = \sqrt{\frac{\rho \textbf{ reference}}{\rho \textbf{ actual}}} = \sqrt{\frac{\textbf{0.2571}}{\textbf{0.2252}}} = \textbf{1.0686} \quad \textbf{- - - -eq. B6.1-1}$$

The percent error is: (1.068 - 1) X 100% = 6.86%

That is, when the steam pressure and density drop below the reference level, **the mass flow reading is high by 6.8%.**

Therefore, the true mass flow for this meter reading at 85 PSIG at a delta P of 95 in., w.c., is**: 4,207.8 div. by 1.0686 = 3,874.6 Lb/Hr**

See Figure A10 "Graph showing % error vs. Pressure Variation for an Orifice Plate"

B6.2 Pressure and Temperature Correction

In practice, as saturated steam drops in pressure by 15 PSI, there is very little change in temperature. The total enthalpy change is also very small, from 1189.6 to 1187.2 BTU/Lb. The density change is large, from 0.2571 to 0.2252 Lb/ft3 or about 13% as shown in the previous calculation. For the purpose of correction of meter readings, it is enough to correct on density only in most industrial steam applications. Billing and custody transfer situations are an exception.

Temperature correction is more important in metering applications for both gases and liquids which are subject to temperature change in normal usage. For example, natural gas picks up heat as it flows through bare piping from the ground, or compressed air which is subject to a range of temperature influences in factories.

B6.2 Pressure and Temperature Correction (Continued)

For the purpose of illustration, and to continue with the same example, assume that somehow energy is added to the 85 PSIG steam causing it to superheat from 340 ^{O}F to 400 ^{O}F and at the same time the pressure drops from 100 PSIG to 85 PSIG.

In this case we would use the PVT Gas density equation to calculate the new density.

Namely: **PV = nRT - - - - - -eq. 6.2-1** Where: V = the volume of gas in ft^3

P = absolute pressure, PSIA, Lb/ft3

n = the number of moles of gas

R = the universal gas constant

T = Temperature in ^{O}R (Rankin)

Otherwise stated, V varies as $\frac{T}{P}$ or the volume of gas varies directly with temperature and inversely with pressure.

Assume then that V1 = The volume of gas at the reference temperature and pressure.

V2 = The volume of gas at the actual temperature and pressure.

P1 = 100 PSIG or 115 PSIA (reference)

P2 = 85 PSIG or 100 PSIA (actual)

T1 = 340 ^{O}F + 460 = 800 ^{O}R (reference)

T2 = 400 ^{O}F + 460 = 860 ^{O}R (actual)

Equation 6.2-1 can be rearranged to: V2/V1 = (P1 X T2) /(P2 X T1)

V2/V1 = (115 X 860) / (100 X 800) = 1.236

Therefore, the density change factor is 1/1.236 **= 0.8091**

The reference gas density is: ρ_{ref} **=** 0.2571 Lb/ft^3

The actual gas density is: ρ_{act} **=** 0.2571 X 0.8091 = 0.208 Lb/ft^3

From Eq. B6.1 the mass flow correction factor is therefore:

$$\frac{\text{Qm metered}}{\text{Qm reference}} = \sqrt{\frac{0.2571}{0.208}} = 1.111 \text{ - - - - - Eq. B6.2-2}$$

Therefore, the true mass flow rate for this situation is: 4,207.8 Lb/Hr Div. by 1.111
= 3,790.8 Lb/Hr.

B 7. Compressibility Factor

The compressibility factor (also called the Expansibility Factor and the Super-compressibility factor) is another factor which is applied to the flow equation B4-2.

Compressibility is the compression of a gas as it flows from the meter inlet at the base pressure, is compressed as it flows through the restriction and expands as it leaves the restriction.

The compressibility factor is applicable to gases and not to liquids (assuming that liquids are not compressible in the subject operating range).

The International Standards Organization (ISO) has recently developed a standard formula for calculating the compressibility factor **Z**.

The ISO Equation is: $$Z = 1 - (0.351 + 0.256x\beta^4 + 0.93x\beta^8)\ x \left\{ 1 - \left(\frac{P2}{P1} \right)^{1/k} \right\}$$

- - - - - -eq. B7-1 from "Flow Measurement Handbook" pp.99
Roger C. Barker, Cambridge University Press, 2000.

Where:
β = the beta ratio of the orifice plate = d/D=0.65
ΔP = the pressure drop across the orifice = 95 inch w.c. = 3.28 Lbf.
P2 = pressure at the outlet of the meter = 115-3.28 = 111.73 psia.
P1 = pressure at the inlet of the meter = 115psia.
k = the isentropic exponent, which is a function of the ratio of the specific heat of the gas at the operating pressure and temperature. For industrial steam applications, saturated steam less than 700 PSIG) has a **k value** of between **1.25 and 1.40.** From ASME steam tables, the isentropic exponent of 115 PSIA steam is approximately **1.3.**

Substituting the values into the equation B7-1 gives a Y value for compressibility factor
= 0.99042

Application of this factor to equation B4-1 provides a new value for volumetric flow Qv and Mass Flow **Qm** through the flow meter as follows:

Qv = Cd X Z X 7.465 ft^3/s = 0.609 X 0.99042 X 7.465 ft^3/s = 4.5026 ft^3/s
Where: Cd = 0.609 from B5
Qm =
Qv X ρ X 3,600 s/hr = 4.5026 X 0.2571 Lb/ft^3 X 3,600 sec/hr = 4,167.5 Lb/hr

Compare this to the mass flow rate to the base case in section B-5 which is :
4,204.1 Lb/Hr

APPENDIX B, SUMMARY OF CALCULATIONS

B1) Meter Application Data "Base Case"

- **100 PSIG saturated steam**
- **Min. Press. = 85 PSIG**
- **Sat Temp. = 338 ^{O}F**
- **Steam density = 0.251 Lb/Ft^{3}**
- **Orifice Plate diff. Pressure reading = 95 inches w.c.**

B2) Determine the Viscosity of Steam
Absolute Viscosity from ASME steam tables in Lb Force units = $0.306 \times 10^{-5} \frac{\text{Lbf X s}}{\text{Ft}^2}$

Absolute Viscosity in Mass Units = $9.845 \times 10^{-6} \frac{\text{LBm}}{\text{Ft X s}}$
Or 0.0148 Cp

B3) Calculate the Reynolds Number (Re)
You need to know the fluid density, velocity,Viscosity and pipe I.D.

Re = 5.9307×10^{5}

B4) Calculate the Theoretical Flow Volume and Mass using Bernoulli's equation as modified in B4

Volume Flow = 7.465 Ft3/s
Mass Flow = 6,909.3 Lb/Hr

B5) Determine the discharge coefficient for your meter and apply it to the theoretical mass flow to determine the actual mass flow under "base" steam conditions

Cd = 0.609

Actual Mass Flow = 4,207.8 LB/Hr

B6) Correct the mass flow for <u>reduced steam pressure</u> (85 PSIG). Corrected mass flow = 3,874.6 Lb/Hr

B7) Correct actual mass flow for the meter's compressibility factor Corrected Mass Flow = 3,837.5 Lb/Hr

B7) Correct actual mass flow at "base" steam conditions for the meter's compressibility factor.
Corrected mass flow = 4,167.4 Lb/Hr

B8. Upstream and Downstream Length of Straight Pipe Required for Accuracy

Flow meter manufacturers specify the number of straight pipe lengths required. The onus is on the flow meter owner and the installer to follow this specification when installing the meter. See Appendix A8.

B9. Meter Accuracy and Repeatability

The theoretical accuracy of a metering system including all of its components can be calculated using the following the example and formula from Appendix A.

$$\text{Accuracy} = \sqrt{(\text{Primary Element accuracy})^2 + (\text{Transmitter accuracy})^2}$$

$$\text{or} \quad \sqrt{(2.5\%)^2 + (0.2\%)^2} = \mathbf{2.508\ \%}$$

In practice, flow meters, especially DP type meters installed in industrial plants tend to be operating in poor circumstances making them inaccurate to the point where they fall into disuse.

The main cause of disappointment around accuracy and reliability is usually not the original meter or transmitter specification but one or more of the external causes of error, namely:

- Mechanical wear of primary element for example, erosion of orifice plate edges, plugging of holes in pitot tube.
- Improper installation of primary element.
- Poor meter setup or verification.
- Operating range outside flow calibration range.
- No correction for pressure or temperature variation.
- Errors in calculating flow rate and correction factors from measured DP.

Useful Websites

www.efunda.com/formulae/fluids/calc_orifice_flowmeter.cfm Free Flow Calculator
www.daniel-orifice-flow-calculator.software.inform.com Free Flow Calculator
www.lmnoeng.com/Flow/bernoulli.htm Free flow calculator – Java Required.

APPENDIX C, DEFINITIONS and SYMBOLS

Symbols Used in Flow Calculations in this Guidebook

β Beta Ratio of a differential pressure flow meter.
Cd Discharge Coefficient of a flow meter
Cm Centimeter
Cp Absolute Viscosity in Centipoise (Metric system), gm / ((cm x s)/100) = Poise
Centipoise = Cp = Poise/100
d Diameter of the orifice plate opening.
D Internal diameter of the pipe
g The gravitational constant = 32.2 ft/s^2
lbm Pound Mass (lb)
lbf Pound Force (slug)
kgf Kilogram force or Newton
kgm kilogram mass or Kg
m.a. milli-amps
m.v. Milli-volts
p pressure
Δ P Pressure differential across a flow meter element (inches w.c.)
PSIA Absolute pressure usually stated in lb/in^2 in the English system
PSIG Guage pressure = PSIA + 14.7 PSI (lb/in$^{2)}$
Qv Volumetric flow rate in cubic units per unit of time.
Qv Mass flow rate in lbm or kgm per unit of time
Re Reynolds Number
RTD's Resistance temperature detectors
S.V.. Specific Volume, ft3/lb (English), m3 / Kg (SI)
μ_f Absolute Viscosity (force-English Units) lbf x s / ft^2
μ_m Absolute Viscosity (mass-English Units) lbm / ft x s
ν_m Kinematic Viscosity (English units) ft^2 / s
μ_p Absolute Viscosity (mass-SI units), gm / cm x s, (Poise)
ν_{ST} Kinematic Viscosity (SI units) cm^2 / s (Stokes)

Other Terms

ACFM Actual cubic feet per minute
SCFM Standard cubic feet per minute
GPM Gallons per minute (usually U.S.GPM)
Imp.GPM Imperial Gallons per minute.

APPENDIX D, STANDARDS FOR FLOW METERS

There are many standards for flow measurement which have been set by various organizations including:

AGA American Gas Association
CGA Canadian Gas Association, standards are now managed by CSA
API American Petroleum Institute
ISA Instrument Society of America
ISO International Standards Organization
BS British Standards also **BS ISO**
ASME American Society of Mechanical Engineers
AWWA American Water Works Association
ANSI American National Standards Institute
ASHRAE American Society of Heating, Refrigeration and Air Conditioning Engineers
NIST National Institute of Standards and Technology.
The following websites provide a good overview of the Standards which are available from these organizations:

The International Library Service, www.normas.com/
The IHS Standards Store, www.global.ihs.com
The ISO Standards Bookshop

The following is a list of a few standards which are of interest to companies who are planning to invest in flow metering:

ISA 51-1, Process Instrumentation Technology, General
BS 7405, Guide to selection of fluid flow meters
DEF STAN-66-32 P1S1, Code of practice for flow meters, Specifications of flow meters
AGA XQ8805, Gas Measurement Manual Part 8, Flow Computers and Transducers
AGA-ANSI B109.3-92, Rotary Gas Meters
API MPMS 21.1, Flow Measurement using electronic metering systems.
API MPMS 5.5, Security of Data Transmission Systems
ASHRAE STD 41.7, Standard method for measurement of flow of gas
ASHRAE STD 41.8, Orifice flow meters for liquids
ASME 801985, Introductory Guide to Flow Meters
ASME PTC 19.5-2004, Flow Measurement
ASME MFC 18M, Measurement of fluid flow using Variable Area Flow Meters
ASME MFC 16M, Electromagnetic Flow Meters
ASME MFC 12M, Average Pitot Tube Meters
ASME MFC 10M, Installation effects on flow measurement

APPENDIX D, STANDARDS FOR FLOW METERS

The following is a list of a few standards (Continued from previous page)

ASME MFC 7M, Venturi Nozzles (Gas)
ASME MFC 6M, Vortex Meters
ASME MFC 1M, Coriolis Mass Flow Meters
ASME MFC 21.2, Thermal Mass Flow Meters
ASME MFC 5M, Transit Time Ultrasonic Meters
ASME MFC 4M, Turbine Meters
ASME MFC 3M, Orifice, Nozzle and Venturi Meters
ASME MFC 22, Liquid Turbine Meters
AWWA C750, Transit Time (Ultrasonic) flow meters
BS 7834, Specification for Turbine Meters
BS 7965, Guide to Transit Time Flow Meters
BS EN 29104, Electromagnetic Flow Meters forLiquids
BS EN 6817, Electromagnetic Flow Meters
BS ISO 10790, Coriolis Mass Flow Meters
BS ISO 11631, Specifying Flow Meter Performance
BS ISO 13319, Flanged Electromagnetic Flow Meters
BS ISO 14511, Thermal Mass Flow Meters

APPENDIX E, PARTIAL LIST OF MANUFACTURERS OF FLOW METERS

There are approximately 200 manufacturers and suppliers of flow meters in the U.S. and Canada. The following is a list of some of the more prominent ones.

Supplier, Manufacturer	Website	DP	Displac-ement	Elect-ronic	Other, Comments
For listing of hundreds of flowmeter suppliers see: →	***www.globalspec.com***				
1 ABB	www.new.abb.com/products	x	x	x	
2 AAlborg	www.aalborg.com	x		x	
3 American Meter	www.elster-americanmeter.com		x		See Honeywell
4 Armstrong International	www.armstronginternational.com/products-systems	x		x	
5 Badger Meter	www.badgermeter.com	x	x	x	
6 Barton Instruments	www.bartoninstruments.net		x		See Cameron Site
7 Bailey, Fischer and Porter	www.abb.ca			x	
8 Clark Sonic	www.clarksol.com			x	
9 Cox Instruments	www.cox-instruments.com		x		See Badger Meter
10 Cameron	www.c-a-m.com		x		See Barton Instruments
11 Dynasonics	www.dynasonics.com			x	See Badger Meter
12 Daniel Flow Products	www.daniel.com	x			Emerson Automation solutions
13 Dwyer Instruments	www.dwyer-inst.com	x	x	x	
14 Emerson Automation Solutions	www.emersonprocess.com	x		x	
15. Emco Flow Meters	www.spiraxsarco.com		x	x	See Spirax Sarco
16 Endress and Hauser	www.us.endress.com	x		x	
17 Flow-Dyne Engineering	www.flow-dyne.com	x			
18 Flow Metrics Inc.	www.flowmetrics.com	x	x		
19 Fluid Components International	www.fluidcomponents.com	x	x	x	FCI
20 Fox Thermal Instruments	www.foxthermalinstruments.com			x	
21 Foxboro (Invensys)	www.iom.invensys.com			x	See Invensys
22 FTI Flow Technology	www.ftimeters.com		x	x	
23 GE Measurement and Control	www.ge-mcs.com			x	
24 Honeywell	www.honeywellprocess.com			x	
25 Hedland	www.hedland.com	x			See Badger Meter
26 Hoffer Flow Controls	www.hofferflow.com		x	x	

APPENDIX E, PARTIAL LIST OF MANUFACTURERS OF FLOW METERS

Supplier, Manufacturer	Website	D.P.	PD & Turbine	Elect-ronic	Other, Comments
27 ISOIL	www.isoil-usa.com			x	Electromagnetic
28 Krohne	www.krohne.com	x		x	
29 Kurz Instruments	www.kurz-instruments.com			x	Thermal Mass
30 McCrometer	www.mccrometer.com	x		x	V-Cone meters
31 Lambda Square	www.lambdasquare.com	x			Mfg and Testing DP meters
32 Maxon Corp.	www.maxoncorp.com			x	Smartlink combustion control
33 Onicon	www.onicon.com		x	x	
34 Omega Instruments	www.omega.com	x	x	x	Good tech. information
35 Preso	www.preso.com	x			Badger Meter
36 Primary Flow Signal	www.primaryflowsignal.com	x	x		
37 Rosemount	www.rosemount.com			x	Emerson Automation Solutions
38 Romet International	www.rometlimited.com		x		
39 Roxpur Measurement & Control	www.roxpur.com	x			
40 Racine Federated	www.racinefed.com	x	x	x	Badger Meter
41 Sage Metering	www.sagemetering.com			x	
42 Sierra Instruments	www.sierrainstruments.com			x	
43 Siemens	www.automation.siemens.com			x	
44 Spirax Sarco	www.spiraxsarco.com	x		x	
45 Sensus	www.sensus.com		x	x	Ultrasonic, turbine, diaphragm
46 Sponsler Inc.	www.sponsler.com		x		
47 Turbines Inc.	www.turbinesincorporated.com		x		
48 Tri Flow Technologies LLC	www.triflotech.com	x	x		
49 UFM	www.flowmeters.com	x	x	x	
50 Veris	www.veris-inc.com	x			
51 Wyatt Engineering	www.wyattflow.com	x			
52 Yokogawa	www.yokogawa.com/us/products/field-instruments	x		x	