

Flowmeters in Water Supply

Third Edition



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Flowmeters in Water Supply

Third Edition



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Manual of Water Supply Practices — M33, Third Edition

Flowmeters in Water Supply

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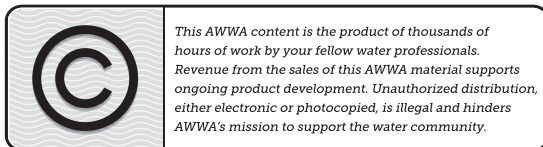
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Foreword



This manual provides information about the most common large flowmeters used in water treatment and in custody-transfer applications. Information on other meters can be obtained from AWWA Manual M6, *Water Meters—Selection, Installation, Testing, and Maintenance*. The flowmeters discussed in this manual include the Venturi, modified Venturi, orifice plate, electromagnetic (mag), turbine and propeller, transit-time ultrasonic, vortex, averaging Pitot, and averaging insertable electromagnetic (mag). The discussion of these meters covers basic theory, installation, maintenance, and advantages and disadvantages. General concepts applicable to flowmeters are also discussed, including flow characteristics, installation and performance issues, communications, information and signal outputs, and flowmeter selection.

The manual can be used as a bridge to other literature on flowmeters, to prepare the reader for further investigations into instrumentation design and applications. The Bibliography lists excellent information sources. For additional information, the reader should acquire the relevant manuals from the meter manufacturers. These manuals contain comprehensive information on meter specifications, theory, sizing, handling, installation, power and wiring, operation, maintenance, troubleshooting, and parts.

While this manual attempts to include recommended practice in the use of flowmeters, it is not intended as an AWWA standard.

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Chapter **1**

Characteristics of Flow

Flow is an important measurement made at treatment and distribution facilities, and flowmeters are used to measure this flow. Flowmeters measure product output of a plant, water distribution into a community, pacing of chemical feeds, and customer charges, to name just a few applications. Day-to-day operational decisions and long-term planning are based on measurements from flowmeters. To achieve proper flow measurement, the fluid must be homogeneous, with evenly dispersed solids or gases, acting as a single-phase fluid with no relative motion among its components. The fluids of main concern in water treatment generally meet these conditions.

FLUID PARAMETERS

The parameters and properties of fluids important to flowmetering are as follows:

- Density (ρ)—mass per unit volume.
 - Density is important when mass transfer measurements are needed.
 - It affects the nature of the flow and fluid behavior and is used to calculate many other fluid parameters.
- Electrical conductivity—ability of the fluid to conduct electricity.
 - This condition is typically met in the water industry.
- Flow area—area of unobstructed flow.
 - Accuracy of cross-sectional area measurement plays a major role in flow measurement accuracy. For example, a $\frac{1}{8}$ -in. deviation in the diameter of a 12-in. pipe will cause a 2 percent change in area. This is important because of the probable change of flow area caused by corrosion and erosion with time.
- Pressure—force per unit area.
 - Flow is driven by the difference in pressure.
 - Some flowmeters use the pressure differential across an obstruction to measure flow.
 - Pressure is a measure of the static component of the fluid's energy.

- Temperature of the fluid
 - Change in temperature affects fluid viscosity, density, and pressure, which may cause measurement errors if not properly compensated for electronically or by recalibration.
- Sonic conductivity—ability of the fluid to conduct sound.
 - This condition is typically met in the water industry.
- Sonic velocity—speed of sound through the fluid.
- Velocity (V)—fluid's speed of flow.
 - V is the average velocity over the flow area.
- Viscosity (μ)—fluid's resistance to flow.
 - Viscosity affects the nature of the flow and fluid behavior and is used to calculate many other fluid parameters.
 - It causes shear forces to be dominant at lower velocities.
 - It causes a point of zero velocity at the pipe's surface.

MEASURING VELOCITY

One of the most common methods to determine rate of flow is to measure the fluid velocity and compute flow by the *continuity equation*, most simply presented as $Q = VA$. In this equation, Q is the rate of flow, V is the average velocity over the flow area, and A is the area occupied by flow. For custody transfer and other uses, flowmeters totalize the flow by integrating the rate of flow versus time. Positive displacement and other volumetric-type custody-transfer meters count and totalize the number of volumes of water that pass.

To date, fluid velocity is measured indirectly by quantifying its effect on an influenced parameter. Most meters are identified according to the physical parameter used to determine the velocity. One or more transducers are needed to detect such effect of liquid movement. The transducer is a device that, by its inherent nature, transforms energy from one form to another. Its output changes when it is influenced by flow. The transducer, in turn, allows detection of a change in flow, therefore indirectly identifying the velocity of a liquid. Examples are turbine, magnetic, and transit-time ultrasonic flowmeters. In turbine meters, the flow impinging on the turbine vanes imparts energy to the turbine and causes it to rotate. The rotation speed is proportional to the flow velocity, enabling the user to arrive at a value of velocity by counting the number of rotations per unit of time.

Flow is simply the volume of a moving fluid passing through a cross-sectional area per unit of time. To achieve a time rate of change of volume Q in most meters, which is also known as *volumetric rate of flow*, the average fluid velocity V and the cross-sectional area A must be known. Accurate rate of flow determination is directly related to the accuracy of cross-sectional area and velocity measurement.

The flowmeters considered in this manual are for closed-conduit, full flowing pipes, in which the flow cross-sectional area is that of the internal diameter of the pipe or the meter chamber. The basic continuity equation of flow is used to yield dimensions as gallons per minute, cubic meters per second, and million gallons per day. It is called the continuity equation because what goes in one end of a full length of pipe must go out the other end. Therefore, a reduction in the area somewhere along the length of the pipe results in a proportional increase in the velocity and vice versa, because the rate of flow remains constant. Various methods of flow measurement are described in Table 1-1.

Table 1-1 Methods of flow measurement

Type	Measurement	Method
Coriolis	Vibration phase shift	Flow momentum distorts two specially shaped, resonating flow tubes, inducing Coriolis forces. This force causes a vibration phase shift, which is related to mass flow rate.
Differential pressure producers	Pressure	Differential pressure caused by flow-area reduction is measured and related to velocity through calibration.
Magnetic	Voltage	Induced voltage from changes in magnetic field flux is related to velocity through calibration.
Open channel	Level	The flow level is measured at the flume or weir, and flow rate is calculated based on the geometry of the channel cross section.
Optical	Light	The time it takes a particle to cross two light/laser beams is used to calculate flow velocity.
Positive displacement	Count	The flow is broken into packets of known volume, which are counted per unit time.
Sonar	Sound	The time it takes the sound emitted by turbulence to travel from one sensor to the other is related to flow.
Thermal	Temperature	Flow across heated elements causes a difference in temperature, which is related to velocity through calibration.
Turbine	Rotation speed	Flow causes the rotor to spin, and the speed of rotation is directly proportional to velocity related to flow through calibration.
Ultrasonic Doppler	Ultrasonic wave frequency shift	Relates the Doppler shift in a reflected ultrasonic wave to the velocity of the reflecting particle in the fluid.
Ultrasonic transit time	Ultrasonic wave pulse time	Relates the travel time of an ultrasonic pulse between two points and relates it to flow velocity through calibration.
Variable area	Level	Drag causes a vertically oriented float to rise with increased velocity. The increase in float height is related to velocity.
Vortex	Vortex shedding frequency	Relates the vortex shedding frequency induced by an obstruction to flow velocity through calibration.

TYPES OF FLOW

Laminar and Turbulent Flow

Regardless of whether there are disturbances in the flow caused by upstream conditions, the velocity across a pipe's cross section is not constant. As briefly discussed, the viscosity of the fluid causes the layer of the fluid at the pipe wall to have zero velocity. Layers of fluid have increasingly larger velocities the farther away they are from the pipe wall. Maximum velocity or free-stream velocity is reached at the pipe centerline. A plot of the velocity at various distances from the wall is what is called the *velocity profile* or *gradient*. An undisturbed velocity profile is symmetric along the pipe axis. As shown in Figure 1-1, pipe flow can assume two profiles, laminar flow and turbulent flow, with a transition phase between the two.

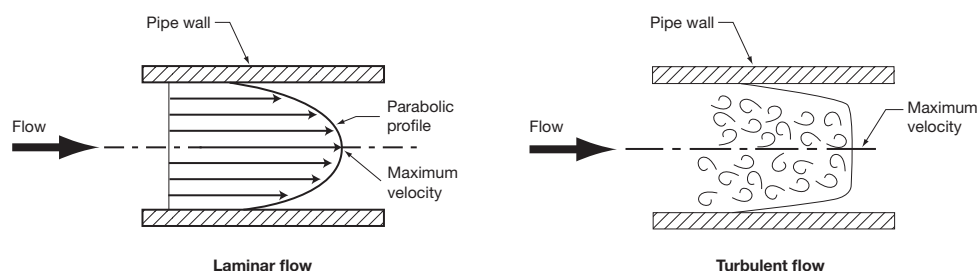


Figure 1-1 Velocity profiles

Laminar flow can result from low, average velocities. The fluid moves in smooth concentric, cylindrical layers or laminae, with the fastest-moving layers toward the central axis and the slowest-moving layers toward the pipe wall. A parabolic profile of flow exists across any diameter of the pipe. In laminar flow, shear stress is caused in the fluid by the sliding of one layer of fluid over another. A small disturbance in the flow is dampened by the viscous forces, which are dominant. Therefore, there are negligible velocity fluctuations normal to the flow directions, and adjacent fluid particles move along in essentially parallel paths.

When the average velocity increases above a certain value, some disturbances begin to appear because the inertial forces are becoming gradually more dominant than viscous shear forces. The flow appears to become more and more irregular. This is what is called *transition flow*. In the transition phase between laminar flow and turbulent flow, the change is gradual, with no distinct transition point.

As the average velocities continue to increase, turbulent flow is reached. Turbulent flow is characterized by velocities normal to the flow direction as individual fluid particles zigzag and gyrate in irregular, random motion. Adjacent particles are in a more or less random motion, not moving in parallel paths in turbulent flow, at which point flow layers practically disappear and the velocity across the stream is more uniform. This happens because the transverse movement of the fluid particles causes the flow in slower-moving layers to increase and the flow in faster-moving layers to decrease. The velocity profile is flattened, and the free-stream velocity is reached in layers closer to the pipe wall. Because turbulent velocity fluctuates, a time-averaged mean velocity is used to represent a turbulent steady flow.

Even though these fluctuations may be small, they have a large effect on flow characteristics as they cause mixing of the fluid. The motion of particles in directions normal to the main flow acts as an equivalent shear stress. This shear stress may be hundreds of times larger than the laminar viscous shear stress caused by the sliding of the layers. This results in a blunt, more uniform velocity profile. However, because of the friction and the lower velocities near the wall, a small laminar sublayer appears between the flattened velocity profile region and the wall. In the water industry, flows are typically turbulent.

Reynolds Number

Closely associated with flow properties is the Reynolds number, which is the ratio of inertial forces (from a pump or gravity) to viscous forces (the internal fluid resistance to flow) in a flowing liquid. As a ratio of force to force, the parameter is dimensionless. The Reynolds number (Re) indicates which forces dominate the flowing liquid. It can be easily calculated using

$$Re = \frac{\rho V D}{\mu} \quad (\text{Eq 1-1})$$

where ρ is density, V is velocity, D is pipe diameter, and μ is viscosity. The type of flow, laminar or turbulent, is related to the Reynolds number. Low values (Reynolds numbers $<2,000$) indicate that the viscous forces are dominating the flow. Therefore, the flow is laminar. Flow with Reynolds numbers between 2,000 and 4,000 are in the transition phase. The velocity profile may fluctuate between laminar and turbulent. At Reynolds number values $>4,000$ (not a strict borderline value), the inertial forces begin to dominate. The flow becomes turbulent and the particles begin moving at the same velocity, except in the laminar sublayer at the walls. Reynolds numbers are noted in textbooks and vendor literature as having some impact on meter accuracy and the meter coefficient of discharge.

Distorted Velocity Profiles

Distorted velocity profiles occur downstream from fittings, valves, or other obstructions. Major disturbances to the velocity profile generally result in a skewed profile, swirl, or flow separation. In a skewed profile, velocities are asymmetrically higher in some sections than in others. Swirl means that the flow has random vortices with rotation along and/or normal to the flow direction. Crossflow may be a part of swirl; however, it involves flow with velocity vectors nonparallel to the pipe axis. When the fluid passes over a sharp edge or corner, the flow separates from the wall, possibly reattaching at a later point downstream.

All the previously mentioned conditions create what can be called *distorted profiles*, which make accurate flow measurement difficult because the average velocity is not uniform and steady throughout the pipe's cross-sectional area. The importance of this topic cannot be overstated. With all inferential flowmeters, the velocity profiles, both upstream and downstream, affect the flowmeter. This points out the importance of upstream and downstream undisturbed lengths of pipe, or the need for additional flow conditioning, or additional testing.

FLOW CONDITIONING

When the required undisturbed pipe length is unavailable, flow conditioners may be used to attempt to straighten the distorted velocity profiles shown in Figure 1-2 and return them to uniformity. This is an option if the fluid being measured, such as finished water, contains no solids or other material that can plug the conditioner and if the additional head loss can be tolerated. Flow conditioners include such devices as tube bundles, vanes, and other proprietary devices that are placed in the flow to create an obstruction. These devices cause a quick return to the normal turbulent profile shown in Figure 1-1 by inducing pressure gradients and redirecting velocities normal to the main flow direction. However, they still require some downstream straight lengths before the flowmeters.

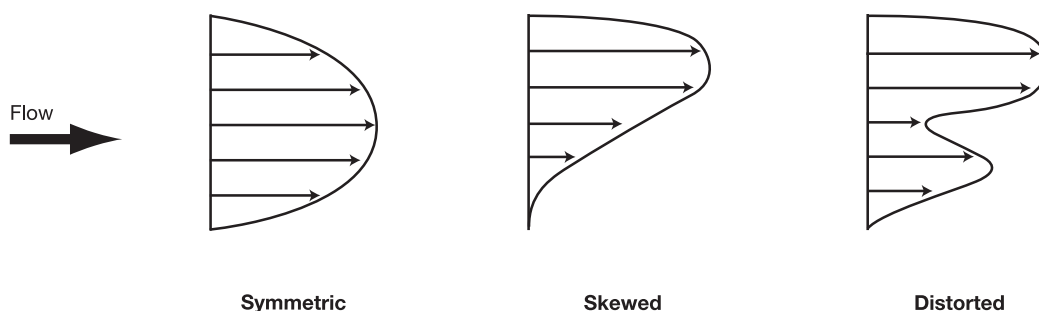


Figure 1-2 Distorted velocity profiles

Consulting with flowmeter and flow conditioner manufacturers regarding applicability and installation data is highly recommended. A detailed discussion of the effect of velocity profiles on flow measurement is provided in chapter 4.

METER COEFFICIENT OF DISCHARGE

The coefficient of discharge C_d is used to account for deviations from the true average velocity and the cross-sectional area of the pipe and is used primarily with differential pressure meters. The ratio of actual rate of flow (determined by high-accuracy measurement) to the theoretical flow (calculated from a mathematical model published by the manufacturer) defines the meter's discharge coefficient.

A flow coefficient K_{CD} (or K_{CD} factor) is sometimes used that effectively combines C_d with the geometric and conversion parameters. The K_{CD} factor = $Q / (\sqrt{\Delta P})$ where Q is in gallons per minute and ΔP is in inches of water.

Chapter 2

Types of Flowmeters

This manual describes the more common types of flowmeters used in water treatment and custody-transfer applications. Information on other meters can be obtained from AWWA Manual of Water Supply Practices, M6, *Water Meters—Selection, Installation, Testing and Maintenance*, and from the respective manufacturers. Table 2-1 lists various types of meters used in the water industry. Meters described in this manual for use in water treatment and custody-transfer applications are highlighted in **bold letters** in Table 2-1. Criteria for the selection of flowmeters for various water treatment and custody-transfer applications are provided in Chapter 3.

Some meters described in this manual, as well as other meters used in applications for revenue billing (such as displacement, multijet, single-jet, compound, and fire service meters), are described in AWWA Manual M6.

Among flowmeter types, several numerical values are presented for accuracy, repeatability, and rangeability. These are provided as representative or typical values, specifically for meters used in water treatment and custody-transfer applications. These values have been reported by one or more manufacturers of the meter type based on their laboratory testing and are illustrated in Table 2-2. Some metering technologies (turbine, propeller, magnetic, and transit-time ultrasonic) are also used in products designed for the retail sales of water to individual customers within a utility service area. For these applications, meter performance requirements are often quite different from those in water treatment and custody-transfer applications. For example, a turbine meter designed for retail water sales may have substantially wider rangeability and wider accuracy limits than one designed for a process control application. The authors of this document cannot make any warranty as to the accuracy of data in Table 2-2. It is included to provide useful background for the reader.

In any application, for any meter type, it is incumbent on the user to determine what their accuracy needs are, whether conditions of installation fall within the range represented by any manufacturer's data, and whether their specific installation requirements may require additional laboratory testing to determine expected performance.

Table 2-1 Types of flowmeters for the water industry

Type	Usual Size Range	
	<i>in.</i>	<i>(mm)</i>
1 Displacement meters		
a. Nutating disc	1/2–2	(13–50)
b. Oscillating piston	1/2–2	(13–50)
c. Oval gear	1/4–3	(6–80)
d. Rotary vane	1/2–2	(13–50)
2 Nondisplacement meters		
a. Velocity		
Impeller/paddle-wheel	1/2–4	(13–100)
Insertable impeller/paddle-wheel	>2 1/2	(>65)
Magnetic pickup turbine	1/4–12	(6–300)
Mechanical register turbine	3/4–20	(20–500)
Multijet	1/2–2	(13–50)
Propeller	2–72	(50–1,800)
Single jet	1/2–6	(13–150)
b. Differential pressure		
Fixed opening, variable differential		
Orifice	>1	(>25)
Venturi, flow nozzle, flow tube, other profile modifiers	1–120	(25–3,000)
Pitot tube	Unlimited	Unlimited
Variable area, fixed differential		
Rotameter	1/16–12	(1 1/2–300)
c. Electronic velocity		
Clamp-on ultrasonic (transit-time)	Unlimited	Unlimited
Coriolis	1/24–16	(1–400)
Electromagnetic (mag)	1/10–120	(2 1/2–3,000)
Insertable electromagnetic (mag) (averaging)	4–120	(100–3,000)
Insertable vortex	>4	(>100)
Fluidic oscillator	1/2–2	(13–50)
Ultrasonic (transit-time)	1/4–360	(6–9,000)
Vortex	1/4–10	(6–250)
d. Level measurement		
Weir, flume	(Suitable for open-channel flow only)	
3 Compound meters		
a. Standard compound	2–8	(50–200)
b. Fire service	3–12	(80–300)

Table 2-2 Representative characteristics of various types of flowmeters

Type	Accuracy*	Repeatability*	Rangeability	Relative Head Loss
Coriolis	±0.10%	0.05%	20:1	Medium
Electromagnetic (mag)	±0.50%	0.25%	20:1	None to low
Insertable electromagnetic (mag)	±0.50%	0.25%	20:1	Low
Orifice	±1%	0.25%	10:1	Medium to high
Pitot tube	±1%	0.50%	4:1	Low
Propeller	±2%	0.20%	15:1	Low to medium
Rotameter	±0.50%	0.25%	10:1	Low
Turbine	±0.50%	0.20%	10:1	Low to medium
Ultrasonic (transit-time)	±0.50%	0.25%	20:1	None to low
Venturi	±0.75%	0.25%	10:1	Medium
Vortex	±0.75%	0.50%	25:1	Medium

* Accuracy and repeatability values may vary within a specific meter type depending on the accuracy limits and rangeability the meter was designed for. These values are used as examples only and are not indicative of all meter types defined.

TURBINE AND PROPELLER FLOWMETERS

In turbine and propeller flowmeters, flowing water strikes rotor blades that rotate at a rate proportional to the flow velocity. The rotor (turbine wheel) of a turbine meter generally fills the cross section of the pipe and is mounted to spin freely between two central bearings supported in the pipe wall (Figure 2-1, left). The rotor (propeller) of a propeller meter (Figure 2-1, right) is mounted on bearings, or a ceramic sleeve, at the downstream end of the pipe and occupies up to 80 percent of the meter cross-sectional area. The tapered propeller nose faces upstream into the flow and is mounted to spin freely in line with the pipe axis.

Within given limits of flow rate and fluid viscosity, the rotor speed and volumetric flow rate maintain a linear relationship. Most turbine meters and propeller meters used in the water industry have mechanical registers. For turbine meters and propeller meters that use electronic registers, a magnetic proximity sensor in the meter detects the rotor velocity and converts it to a frequency signal. Therefore, the rotation of the rotor blades causes a known number of cycles per unit volume. The meter coefficient is the calibration K-factor, which is a known number of pulses for a given volume measured. The K-factor is typically constant over a 10:1 flow range within a linearity tolerance of ±0.25. For identical turbine meters, the K-factor may vary as a result of manufacturing tolerances. Therefore, each meter with an electronic register may be calibrated for its own specific K-factor value.

Turbine meter accuracy varies from manufacturer to manufacturer. Depending on the application the meter is designed for, ±0.5 percent is a typical representation of accuracy. For specific operating characteristics, refer to ANSI/AWWA C701, *Cold-Water Meters—Turbine Type, for Customer Service*. Manufacturers of propeller meters agree on an accuracy of ±2 percent of the actual flow rate within the normal flow limits of the meter. At low flow rates, accuracy is reduced. For specific operating characteristics, refer to ANSI/AWWA C704, *Propeller Type Meters for Waterworks Applications*.

The orientation and configuration of the meter blade profile are important to the application of the turbine meter. Straight-bladed meters may be less affected by variations in velocity, while helical-bladed meters, as the propeller meter, are generally less affected by variations in viscosity.

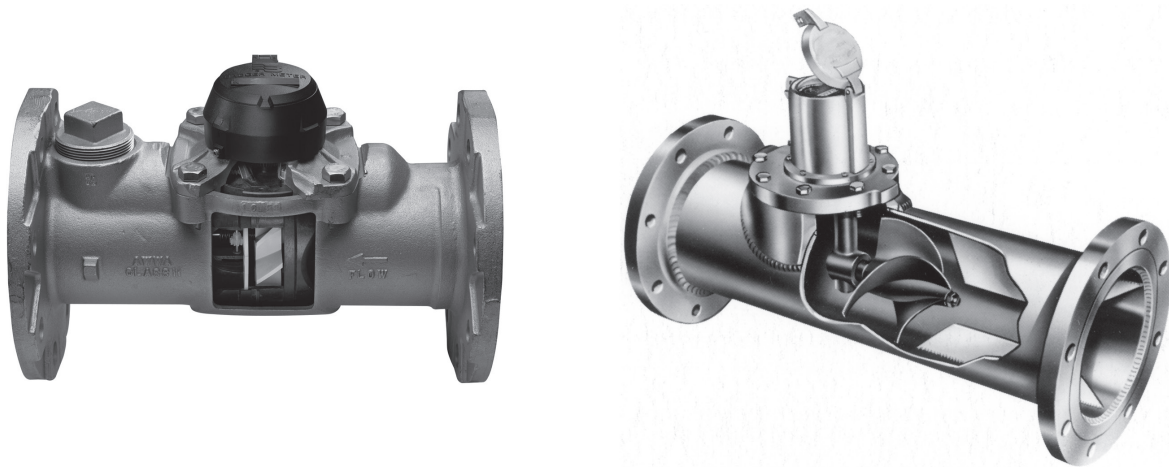


Figure 2-1 Turbine flowmeter (left) and propeller flowmeter (right)

Installation

Turbine flowmeters may be installed with a strainer to prevent solids from interfering with the rotor mechanism, which is not usually the case with propeller meters. Because these meters are affected by upstream configurations that cause swirls or velocity fluctuations, manufacturers frequently provide or recommend built-in straightening vanes upstream in the pipe. These minimize the effect of profile irregularities and smooth flow entering the meter. Straight pipe lengths of at least five pipe diameters upstream and two pipe diameters downstream are a minimum recommendation in applications where the actual types and degrees of flow profile disturbances are assumed to be fairly minor, and the degree to which the specific meter design is able to accommodate these disturbances is unknown. Larger flow-profile disturbances (e.g., those caused by throttling valves, check valves, or paired elbows that are out of plane) could require increased lengths of straight piping or the addition of flow-conditioning elements. On the other hand, some meter designs may be relatively insensitive to various flow-profile disturbances.

When selecting a meter for a specific application, one should take care to ensure that the maximum flow rate will not be exceeded, except for short periods. Running over the maximum flow rate for extended periods increases bearing wear and shifts the meter's calibrated accuracy.

Location downstream from a chemical injection point should be avoided, and the electronic mechanisms that provide digital outputs should be protected from electromagnetic influence.

Maintenance

Periodic mechanical maintenance prolongs the life of a turbine or propeller flowmeter. Factory maintenance programs are available for meter testing, maintenance, and recalibration. Periodic inspection, calibration, and service should be performed at least annually.

Propeller meters are generally manufactured for ease of disassembly and extraction of the metering unit from the pipe body. According to many manufacturers, no special tools are required for maintenance. When the metering unit is removed, a cover plate is commonly available for installation, so line service can continue. During service and disassembly, the complete metering assembly should be examined for wear and corrosion.

Parts should be cleaned, while worn or damaged parts should be replaced. Manufacturers provide troubleshooting procedures covering problems, causes, and recommended corrective actions. An example of a troubleshooting checklist for mechanical meters can be found at the end of this chapter.

Advantages and Disadvantages

Advantages of turbine and propeller flowmeters are as follows:

- The very large sizes have good repeatability and can be very accurate with periodic calibration.
- Output flow signal is directly proportional to a pulse train with high linearity over a broad range of flow rates, at least 10:1 for large meters.
- Head loss is low to moderate, decreasing with larger sizes.
- Meter size is the same as the diameter of pipe in which it is installed.
- Flow is restricted but not blocked if the meter seizes up.
- No external power source is required.

Disadvantages of turbine and propeller flowmeters are as follows:

- Systematic mechanical maintenance and lubrication are required to maintain meter accuracy.
- Gradual deterioration of meter surfaces via wear or fouling makes periodic recalibration necessary to maintain high accuracy. Corrosive liquids, liquids of poor lubricating quality, and liquids with a high proportion of suspended solids cause bearing problems.
- The calibration factor is sensitive to changes in viscosity of the flowing liquid.
- These meters are sensitive to flow disturbances and swirls.
- Bearing friction is detrimental to meter performance; the effect is more pronounced in smaller meters.
- Accuracy decreases significantly at low flows.

ORIFICE PLATE FLOWMETERS

The orifice plate flowmeter uses a differential pressure created through a restriction in the pipe. Measurement of the differential pressure between points upstream and downstream of this restriction is used to calculate flow in the conduit. The orifice plate flowmeter consists of a thin plate with a hole in it (Figure 2-2). The standard plate is a circular disc that fits snugly in the pipe, usually of stainless steel $\frac{1}{8}$ – $\frac{1}{2}$ in. (3–13 mm) thick, that contains an orifice with a sharp leading edge. The hole is usually concentric with the pipe into which the plate is inserted and perpendicular to the axis of flow. The plate is typically installed in a pipeline between two flanges, and the differential pressure across the plate is measured. Because of its simplicity, low cost, ease of installation, and reasonable accuracy, the orifice plate is among the most common primary elements for measuring flow.

Most orifice plate flowmeters for clean water are made with a circular orifice concentric with the pipe. In special applications, notably for flowing solids, the orifice may also be eccentric or segmental. Passage of entrained solids is permitted if the hole is tangent to the inside surface of the bottom of a horizontally laid pipe.

As in a typical differential-pressure flowmeter, the pressure upstream (approximately one pipe diameter from the plate) is compared with the pressure downstream where the flow converges to the point of narrowest stream flow. The narrowest section of flow, the

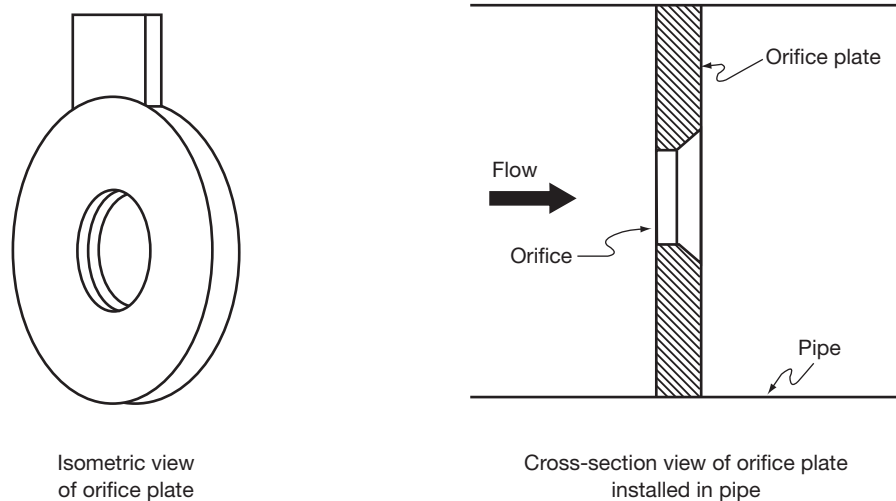


Figure 2-2 Schematic of an orifice plate flowmeter

vena contracta, occurs one-half pipe diameter downstream from the plate. These points define where to locate the pressure taps.

To obtain an electrical flow measurement signal, the pressure at the ports is transferred to a differential-pressure transducer. The transducer is typically a flexible diaphragm with a small chamber where the two pressure lines from the meter tube are connected to the two sides. The pressures exert opposing forces on the diaphragm, causing deflection of the sides. To sense the diaphragm's deflection, a strain gauge or a variable-capacitance or variable-reluctance device is built into the transducer to generate an electrical signal proportional to the pressure difference. Direct reading of differential pressure is possible using a U-tube manometer or double-bellows gauge.

The combination of all the components associated with the measurement of flow in an orifice plate flowmeter is referred to as the *orifice plate flowmeter system*. For an orifice plate flowmeter to operate adequately, all system components associated with the measurement of flow must operate adequately.

Numerous eddies form downstream from the plate between the pipe wall and the *vena contracta*, causing kinetic energy to be dissipated as heat. This dissipation accounts for the medium to high relative head loss associated with the orifice plate flowmeter.

The orifice plate can be fabricated to accommodate any pipe size. Inherent accuracy, independent of pipe diameter errors and the differential-pressure sensor, may be ± 1 percent.

Orifice plates are also available as part of integrated pipe assemblies, which include the plate, pipe length, pressure taps, and, in some cases, the differential pressure sensor and signal transmitter.

Installation

The orifice plate is usually mounted between two flanges. Manufacturers may extend the plate to include a tab above the edge of the pipe flange. The tab, suitable for a nameplate, may contain pertinent data on the specific installation and may identify the upstream side. To prevent errors in flow measurement, the gaskets should not protrude across the plate face beyond the inside pipe wall. Typically, the orifice plate flowmeter also requires a straight run of smooth flow before and after the plate. Pressure taps must be installed

perpendicular to the pipe wall. For horizontal pipe runs, the pressure taps should be in the horizontal plane of the pipe centerline. Burrs and intrusions at the taps must be removed.

Maintenance

As a differential-pressure flowmeter with no moving parts, the orifice plate flowmeter requires maintenance similar to that of the Venturi. The orifice should be visually checked periodically to be sure its dimensions and sharp leading edge are unaffected by the flow. Degeneration of the sharp edge can result in significant measurement errors. Solids may collect behind the plate at the bottom, and gases may be trapped at the top. These may be easily cleared by removal of the plate. Some manufacturers provide special mounting devices to allow the orifice plate to be inserted and removed without interrupting the flow, which simplifies maintenance.

The pressure taps should also be examined for possible obstruction. The pressure-differential measurement assembly should be periodically checked.

Advantages and Disadvantages

Advantages of orifice plate flowmeters are as follows:

- Lowest-cost differential-pressure meter.
- Economically manufactured to very close tolerances.
- Easy to install and replace.
- No moving parts.

Disadvantages of orifice plate flowmeters are as follows:

- High permanent pressure loss through orifice plate can cause significant power costs.
- Volume flow is nonlinear.
- Rangeability is lower than with linear-output flowmeters.
- Longer upstream and downstream straight pipe runs are required than with other types of meters.
- Field calibration is usually required.

VENTURI FLOWMETERS

The Venturi (Figure 2-3) is a type of differential-pressure flowmeter. In the Venturi, a defined constriction (throat) in the meter body causes an increase in flow velocity at the constriction, resulting in a corresponding decrease in pressure in the throat. The ratio of throat diameter to pipe diameter (where the two pressure measurements are taken) is called the *beta ratio*. The difference in pressure between the connections upstream and at the constriction (throat) is proportional to the square of the flow. Flow is calculated from the square root of the measured pressure differential multiplied by a meter factor that accounts for dimensional units and discharge coefficient. The discharge coefficient takes into account contraction characteristics and pressure-tap location for a fully developed velocity profile within a range of Reynolds numbers.

To obtain an electrical flow measurement signal, the pressure at the ports is transferred to a differential-pressure (ΔP) transducer. The transducer is typically a flexible diaphragm with a small chamber; two pressure lines from the meter tube are connected to the two sides of the diaphragm. The pressures exert opposing forces on the diaphragm, causing deflection of the sides. To sense the diaphragm's deflection, a

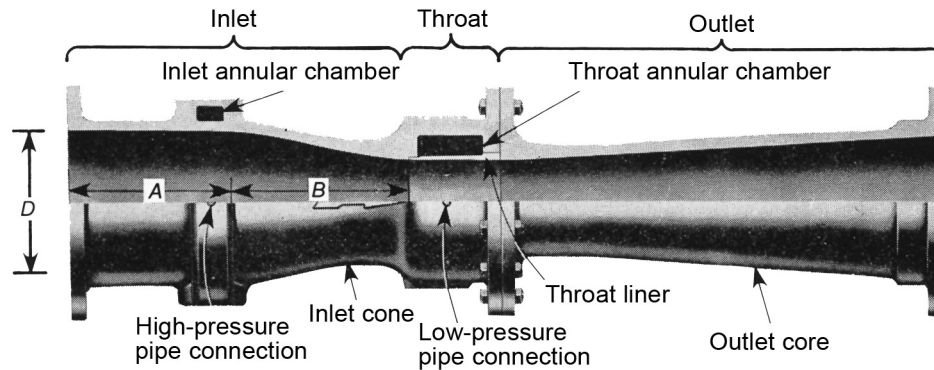


Figure 2-3 Schematic of one type of Venturi meter

strain gauge, or a variable capacitance or a variable reluctance device, is built into the transducer to generate an electrical signal proportional to the pressure difference. Direct reading of differential pressure is possible using a U-tube manometer or double-bellows gauge. The combination of all components associated with the measurement of flow in a Venturi flowmeter is referred to as the *Venturi system*. For a Venturi meter to operate adequately, it is important that all system components associated with the measurement of flow operate adequately.

The theoretical flow equation calculates the actual rate of flow only when all assumptions used to develop the flow equation are met. How closely the actual rate of flow can be calculated depends directly on the geometry of the reduced area. For a Venturi where the reduction is gradual, the agreement is roughly 1–3 percent if the velocity profile is uniform and the Reynolds numbers are high. At lower Reynolds numbers or with increasing viscosity, the velocity profile becomes one dimensional, expansion approaches adiabatic, and unless the effects are well modeled, inaccuracies will exist. The major distinction between the Venturi and many modified forms of this device is that the Venturi discharge coefficient is well known and well documented.

Venturis are normally not used when meters operate at low velocities. The Venturi has no theoretical range limitations up to the speed of sound. However, the flowmetering system, which includes the ΔP device, has definite limits. With the increased use of smart transmitters, the rangeability of the Venturi may be increased. Some Venturi meters provide a rangeability of 10:1 depending on the selection of the ΔP device.

The Venturi meter has a low permanent head loss and does not obstruct the flow of suspended matter. However, caution is urged when the device is used in applications conveying solids, and the manufacturer should be consulted for application assistance.

Commonly constructed from cast iron or plastic, the Venturi requires the greatest laying length of all differential-pressure meters and is, therefore, the heaviest flow tube as well. Fabricated-steel and insert-type Venturi meters are also available.

Installation

Consider the following factors in the selection process before installation:

- Select a meter that generates a high differential pressure (therefore, a small throat size), taking into account how much head loss can be tolerated. A good rule of thumb is to size the tube to provide at least 1 in. (25 mm) of differential pressure at