

Flowmeters in Water Supply

AWWA MANUAL M33

Second Edition



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Association**

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MANUAL OF WATER SUPPLY PRACTICES—M33, Second Edition

Flowmeters in Water Supply

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Foreword

This manual was prepared as an introduction to the most common large flowmeters currently used in water supply systems. This manual provides information about the most common 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, communication, 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 cited references will provide 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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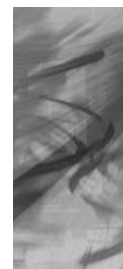
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Chapter 1

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, it is required that the fluid is homogenous with the solids or gases evenly dispersed, acting as a single-phase fluid with no relative motion between 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

- Pressure—force per unit area.
 - Flow is driven by the difference in pressure.
 - Some flowmeters utilize the pressure differential across an obstruction to measure flow.
 - A measure of the static component of the fluid's energy.
- 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.
- Viscosity (μ)—fluid's resistance to flow.
 - It affects the nature of the flow and fluid behavior and is used to calculate many other fluid parameters.
 - Causes shear forces to be dominant at lower velocities.
 - Causes a point of zero velocity at the pipe's surface.
- Velocity (V)—fluid's speed of flow.
 - V is the average velocity over the flow area.
- Flow area—area of unobstructed flow.
 - Accuracy of cross-sectional area measurement plays a major role in flow measurement accuracy. For example, a $1/8$ -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.

- Temperature—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.
- Electrical conductivity—ability of the fluid to conduct electricity. This condition is typically met in the water industry.
- Sonic velocity—speed of sound through the fluid.
- Sonic conductivity—ability of the fluid to conduct sound. This condition is typically met in the water industry.

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, rate of 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. A transducer(s) is needed to detect such an effect of liquid movement. The transducer(s) 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(s), in turn, allows detection of a change in flow, therefore, indirectly 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 rotations per 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, thereby allowing the flow cross-sectional area to be 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 into 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.

TYPES OF FLOW

Laminar and Turbulent Flow

Regardless of whether or not 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 further away they are from the pipe wall. Maximum velocity or free stream velocity is reached at the

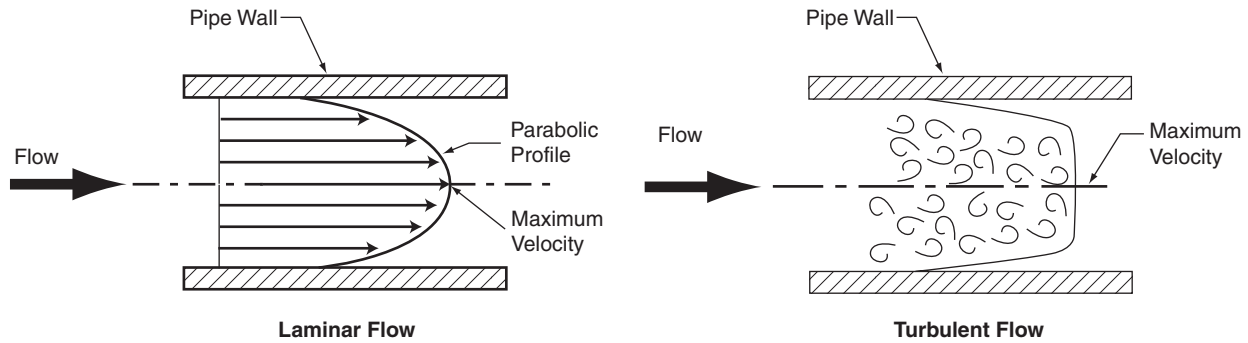


Figure 1-1 Velocity profiles

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.

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. This is 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 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 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 turbulent steady flow. Even though these fluctuations may be small, they have a large effect on flow characteristics. They cause a 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. The Reynolds number 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. Reynolds number (Re) provides an indication of which forces dominate the flowing liquid. Reynolds number can be easily calculated using

$$Re = \rho VD/\mu$$

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 less than 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 above 4,000 (not a strict borderline value), the inertial forces begin to dominate; the flow becomes turbulent, the particles begin moving at the same velocity, except in the laminar sublayer at the walls. Reynolds numbers will be noted in textbooks and vendor literature as having some impact on meter accuracy and the meter coefficient of discharge.

Distorted Velocity Profiles

These 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. A skewed profile means asymmetric higher velocities in some sections than other sections of the profile. 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. Flow separation occurs when the fluid passes over a sharp edge or corner, which causes the flow to separate from the wall, possibly reattaching at a later point downstream. All the previously mentioned conditions create what can be called distorted profiles that make accurate flow measurement difficult. This is because the average velocity is not uniform and steady throughout the pipe's cross-sectional area. The importance of this topic cannot be overstated, but it should be noted that with all inferential flowmetering devices, the velocity profiles, both upstream and downstream, can and do effect 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 not available, flow conditioners may be used to attempt to straighten the velocity profile and return it to uniformity. This is an option provided the fluid being measured, such as finished water, does not contain any solids or other material that can plug the conditioner and that the additional head loss can be tolerated. Such devices include tube bundles, vanes, and other proprietary devices that are placed in the flow creating an obstruction. These flow conditioners 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, it is cautioned that these devices still do require some downstream straight lengths before the flowmeters. Consulting with flowmeter and flow conditioner manufacturers regarding applicability and installation data is highly recommended.

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.

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Chapter 2

Types of Flowmeters

The most common flowmeters currently used in the water industry are described in this chapter. Table 2-1 lists several categories of flowmeters. This table also shows the typical service sizes for each application. 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 shown in bold letters are commonly used in water treatment and custody-transfer applications. (Custody transfer is a situation in which water is sold to a wholesale service customer at one or more major points of delivery for resale to individual retail customers within the wholesale customer's service area.) Criteria for the selection of flowmeters for various applications are provided in chapter 3.

Meters described in this manual are highlighted in **bold letters** in Table 2-1. Displacement, multijet, singlejet, compound, and fire service meters are described in AWWA Manual M6. Several terms are used to describe flowmeter characteristics and are defined as follows:

Accuracy. Accuracy is the degree to which a measured value matches the actual value. The term is typically expressed as a percentage variation of the measured value from the actual value. A flowmeter that generates a measured value between 99 percent and 101 percent of the actual value has an accuracy of ± 1 percent. This method of stating accuracy is commonly referred to as *percent of reading*.*

Repeatability. Repeatability is a measure of the flowmeter's ability to determine identical rates of flow by moving back to a previously indicated rate after deviating from it. Repeatability is the maximum expected variation, expressed as a percentage, for the rate of flow. It is also represented as a percentage such as ± 0.25 percent.

*An alternate way of stating accuracy is *percent of full scale*. Only when the measured variable is at the full-scale value will this method of stating accuracy be equivalent to the *percent of reading* method. When accuracy is stated as *percent of full scale*, the error percentage is predicted to increase as the measured value decreases. Accuracy stated as a percent of full scale may be converted to accuracy as a percent of reading by the following example: if a flowmeter has an accuracy of *0.5 percent of full scale*, then that accuracy at 50 percent of scale will be $(0.5\%) \times (100/50) = \pm 1\%$ of measured value, and at 10 percent of scale, it will be $(0.5\%) \times (100/10) = \pm 5\%$ of measured value. If accuracy is stated without indicating of reading or of full scale, it is normally assumed to be of full scale until the statement can be verified.

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. Rotary vane	1/2–2	(13–50)
2. Nondisplacement Meters		
a. Velocity		
Multijet	5/8–2	(15–50)
Magnetic pick-up turbine	1/4–12	(6–300)
Mechanical register turbine	3/4–20	(20–400)
Propeller	2–72	(50–1,800)
Proportional	3–12	(80–300)
Singlejet	1 1/2–6	(40–150)
b. Differential pressure		
Fixed opening, variable differential		
Orifice	>1	(>25)
Venturi, flow nozzle, flow tube	1–120	(25–3,000)
Pitot tube	unlimited	
Variable opening, fixed differential	1/16–12	(1 1/2–300)
c. Electronic Velocity		
Electromagnetic (mag)	1/10–120	(2 1/2–3,000)
Ultrasonic (transit-time)	1/4–360	(6–9,000)
Insertable electromagnetic (mag) (averaging)	4–120	(100–3,000)
Vortex	1–10	(25–250)
d. Level measurement		
Weir, parshall flume	(Suitable for open channel flow only)	
3. Compound Meters		
a. Standard compound	2–8	(50–200)
b. Fire service	3–12	(80–300)

Rangeability. Rangeability is the ratio of the maximum to minimum flow rates at which a flowmeter maintains its accuracy. It is commonly represented as a ratio, such as 20:1.

Size range. Size range is the flowmeter sizes that are commonly available for a particular type of flowmeter. Other sizes may be available by special request.

Relative head loss. Head loss is the drop of pressure in the piping system caused by the flowmeter. Relative head loss is the head loss of a type of flowmeter compared with other flowmeters.

In the discussion of different flowmeter types, a number of numerical values are presented for accuracy, repeatability, and rangeability. These values have been reported by one or more manufacturers of the meter type, based on their laboratory testing. The authors of this document cannot make any warranty as to the accuracy of this data. It is included in the interest of providing 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, and whether their conditions of installation fall within the range represented by any manufacturer's data, and for determining if their specific installation requirements may require additional laboratory testing to determine the expected performance.

TURBINE AND PROPELLER FLOWMETERS

- Accuracy: ± 0.5 to 2 percent of reading
- Repeatability: ± 0.2 percent
- Rangeability: 40:1 for turbine meters, 15:1 for propeller meters
- Size range: $\frac{3}{4}$ –20 in. (20–500 mm) for turbine meters, 2–72 in. (50–1,800 mm) for propeller meters
- Relative head loss: Medium

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). The rotor (propeller) of a propeller meter (see Figure 2-1) is mounted on bearings at the downstream end of the pipe and does not fill the meter cross-section. The tapered propeller nose faces upstream into the flow and is mounted to spin freely in line with the pipe axis.

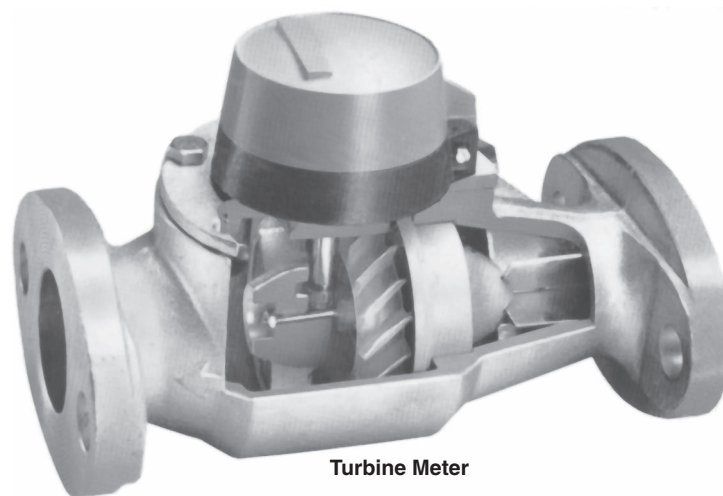
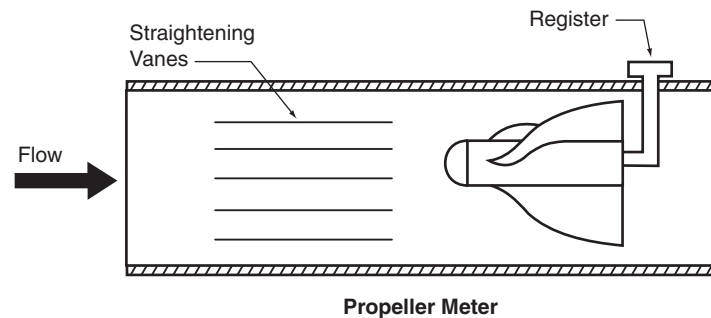


Figure 2-1 Schematic of propeller flowmeter and picture of turbine flowmeter