2.19 Positive-Displacement Liquid Meters and Provers


Types of Designs
A. Impeller, propeller, turbine
B. Nutating disc
C. Oval gear, C-1 if toothless
D. Piston
E. Rotating vane
F. Viscous helix
G. High-precision, specialized, low-flow, and so on
H. Prover

Design Pressure
To 3000 PSIG (21 MPa)

Design Temperature
From −450°F (−268°C) to 560°F (293°C)

Strainer Required
Yes

Materials of Construction
Bronze, cast iron, aluminum, steel, stainless steel, Monel®, Hastelloy®, and plastics

Size Range
0.25 to 16 in. (6 to 406 mm)

Flow Range
From 0.01 GPH to 20,000 GPM (0.04 l/h to 75 m³/m)

Rangeability
From 3:1 to >100:1 (for specialized designs), 10:1 about average

Inaccuracy
Ranges from ±0.1 to ±2% of actual flow; typical average error ±1/2% of actual flow, dropping as size increases

Cost
A 1 in. (25 mm) bronze disk-type water meter with 2 to 3% error costs about $750. Plastic-piston meters for laboratory applications in 1- and 2-in. (25- and 50-mm) sizes are $600 and $1200.
A 1-in. (25-mm) toothless oval meter for high-viscosity service in type 316 SS is $2500.
A 1-in. (25-mm) oval flowmeter for LPG service with ductile iron housing complete and valve, vapor eliminator, and register with printer, about $3000.
A 2-in. (50-mm) piston meter, in steel construction, having 0.5% error and provided with register, preset valve, and ticket printer costs about $5000 to $6000.
A 6-in. (150-mm) flanged, bi-rotor meter for fuel oil service with ductile iron preset valve, impulse contactor, large dial register, and ticket printer costs about $12,000 to $15,000.
Prover costs range from $50,000 to $300,000 depending on size, materials of construction, and control accessories.

Partial List of Suppliers*
Badger Meter Inc. (www.badgermeter.com) (B, D)
Brooks Instrument (www.emersonprocess.com) (A, C, D, F, H)

* The most popular are Brooks Instrument, Smith Meter Inc., and Badger Meter Inc.
Positive-displacement meters split the flow of liquids into separate known volumes, the size of which are based on the physical dimensions of the meter. The meters act as counters or totalizers of the number of these volumes as they pass through. These mechanical meters have one or more moving parts in contact with the flow stream and physically separate the fluid into increments. Energy to drive the moving parts is extracted from the flowing stream itself, resulting in a pressure loss through the meter. The error of these meters depends on the clearances between the moving and stationary parts. The smaller the clearance and the longer the length of the leakage path, the better the precision of the meter. For this reason, meter accuracy tends to increase with larger meter sizes.

**OVERVIEW**

Positive-displacement meters for liquids are among the most widely used volumetric flow sensors for batch-size measurement applications and when fluid is bought and sold on a contract basis. A wide variety of meters, covering a broad spectrum of requirements, are available. Their good accuracy, wide rangeability, and ready availability warrant their consideration when selecting a volumetric meter.

These flowmeters are especially useful when the fluid to be measured is free of any entrained solids. A typical example is the measurement of water delivered to homes, factories, office buildings, and so forth. On the other hand, some designs are well suited for viscous liquid applications. Wear on parts, with the resulting change in clearance dimensions, introduces the major source of error over the service life of the meter. Leakage error increases with dropping process fluid viscosity but remains relatively constant with time. In larger meters, temperature variations and the resulting change in fluid density and viscosity must also be taken into consideration.

Positive-displacement meters provide good accuracy (±0.25% of flow) and high rangeability (15:1). They are repeatable to ±0.05% of flow. Some designs are suited for high- or variable-viscosity services (up to or even exceeding 100 cSt). They require no power supplies for their operation (only for remote transmission) and are available with a wide variety of readout devices. Their performance is virtually unaffected by upstream piping configuration. Positive-displacement meters are excellent for batch processes, mixing, and blending applications.

These meters are simple and easy to maintain by regular maintenance personnel using standard tools. No specially trained crews or special calibration instruments are needed. On the other hand, because of the close tolerances of the moving parts, they are subject to wear and maintenance, and recalibration is required at frequent intervals. On corrosive services, this may result in high costs.

Positive-displacement meters require relatively expensive precision-machined parts to achieve the small clearances that guarantee their high accuracy. From this it follows that the liquids metered must be clean, because wear can rapidly destroy precision. Contaminant particle size must be kept below 100 microns, and most of these meters are not adaptable to the metering of slurries. Positive-displacement flowmeters are expensive in larger sizes or in special materials. They can be damaged by overspeeding and can require high pressure drops. In general, they are not suited for dirty, non-lubricating, or abrasive services.

**ROTATING LOBE AND IMPELLER (TYPE A)**

In this type of meter, two lobed impellers rotate in opposite directions within the housing (Figure 2.19a). They are geared together to maintain a fixed relative position, so a fixed volume of liquid is displaced by each revolution. A register is geared to one of the impellers. These meters are normally built for 2- to 24-in. (50- to 610-mm) pipe sizes, and their capacities (upper limits of their ranges) range from 8 to 17,500 GPM (30.4 to 66,500 l/min).

The advantages of this design include good repeatability (0.015%) at high flows, the availability of a range of materials of construction, and high operating pressures (1200 PSIG or 8300 kPa) and temperatures (400°F or 205°C).
The disadvantages include loss of accuracy at low flows because of the large size, heavy weight, and high cost.

The rotating impeller design is illustrated in Figure 2.19b. It has only two moving parts: the two impellers, which are made out of wear-, abrasion-, and corrosion-resistant thermoplastics. Operation is based on a proximity switch sensing the passage of magnets that are implanted in the impeller lobes and transmitting the resultant pulses to a counter. Units are available from 0.125- to 4-in. (3- to 100-mm) sizes with up to 3000 PSIG (21 MPa) pressure and 0 to 400°F (205°C) temperature ratings. The design is suited for high-viscosity operation, and the claimed precision and rangeabilities are also high.

NUTATING DISK (TYPE B)

The nutating disk meter is used extensively for residential water service. The moving assembly, which separates the fluid into volume increments, consists of an assembly of a radially slotted disk with an integral ball bearing and an axial pin (see Figure 2.19c). This part fits into and divides the metering chamber into four volumes—two above the disk on the inlet side and two below the disk on the outlet side. As the liquid flows through the meter, the pressure drop from inlet to outlet causes the disk to wobble, or nutate. For each cycle, the meter displaces a volume of liquid equal to the volume of the metering chamber minus the volume of the disk assembly. The end of an axial pin, which moves in a circular motion, drives a cam that is connected to a gear train and to a totaling register. This flowmeter measures the liquids with an error range of about ±1 to 2% of actual flow. It is built only for smaller pipe sizes. Its temperature range is from −300 to 250°F (−150 to 120°C), and its maximum working pressure rating is 150 PSIG (1034 kPa). On cold water service, the capacity ranges are approximately as follows:

<table>
<thead>
<tr>
<th>Size</th>
<th>Capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.5 in. (13 mm)</td>
<td>2 to 20 GPM (7.5 to 75 l/min)</td>
</tr>
<tr>
<td>1 in. (25 mm)</td>
<td>5 to 50 GPM (19 to 190 l/min)</td>
</tr>
<tr>
<td>1.5 in. (38 mm)</td>
<td>10 to 100 GPM (38 to 380 l/min)</td>
</tr>
<tr>
<td>2 in. (51 mm)</td>
<td>16 to 160 GPM (61 to 610 l/min)</td>
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</tbody>
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OVAL-GEAR FLOWMETERS (TYPE C)

A special variety of the rotating-lobe flowmeter is made using oval-gear metering elements. In this design, shown in Figure 2.19d, a precise volume of liquid is captured by a crescent-shaped gap, which is formed between the housing and the gear. This volume is then carried to the outlet, and this movement causes the gears to rotate an output shaft through which the register operates.

In new condition, when the slippage between the oval gears and the housing is small, and when both the flow rate and viscosity are high (>1 GPM and >10 cP, respectively), these flowmeters can operate at errors as low as 0.1% of actual flow. At lower flow rates, the relative proportion of the “slip” leakage increases, and so accuracy drops to about 0.5% of actual flow. Viscosity variations will also affect the slip flow. If a meter was
calibrated using water, a fluid with a viscosity of 1 cps, it will have a 1.2% high error if the viscosity rises to 100 cps.

These flowmeters are available in sizes from 0.25 to 16 in. (6 to 406 mm). When the viscosity of the process fluid is between 1.5 and 10 cps, they can handle flow ranges from 0.05 to 0.5 up to 250 to 5000 GPM (from 0.2 to 2 up to 950 to 19,000 l/min). They are available in a wide range of construction materials, including brass, carbon steel, type 316 stainless steel, and Alloy 20®. Operating pressure ratings are available up to 1450 PSIG (10 MPa) and operating temperatures up to 560°F (293°C).

The servo version of this meter has been introduced to completely eliminate slip leakage in smaller sizes (0.2 to 40 GPH or 0.8 to 150 l/h). In this design, the servomotor drives the oval-gear elements at a speed that eliminates the pressure drop across the meter and keeps the outlet pressure the same as the inlet. This eliminates the motivating force, which causes the slip flow and therefore increases accuracy at low flows or under variable viscosity conditions.

A smooth, toothless oval gear design is also available in 1-in. (25-mm) size with screwed connections. It can handle viscosities up to 100 cSt and is rated for 3000 PSIG (21 MPa) and 450°F (232°C). Its linear range is 2 to 25 GPM (7.5 to 94 l/min). If it is used with a nonlinear Hall-effect pickup, its range is claimed to increase to 0.02 to 25 GPM (0.075 to 94 l/min). The meter is made of type 316 stainless steel, its inaccuracy is within its linear range is 0.25% of actual flow, and it is provided with accessories for remote readouts, both analog and digital.

PISTON DESIGNS (TYPE D)

Reciprocating Piston

The oldest of the positive-displacement meters, this meter is available in many forms, including multi-piston meters, double-acting piston meters, rotary valves, and horizontal slide valves. Figure 2.19e shows the schematic of a reciprocating piston meter. Here, a crank arm is operated by the reciprocating motion of the pistons, and this motion drives the register. These meters are widely used in the petroleum industry and can reach the precision of ±0.2% of actual flow.

Another version of this meter is shown in Figure 2.19f. In this design, the liquid enters the cylinder on the left, forcing the piston down by lever action of the control plate. As a result, the piston on the right is forced up, discharging the liquid first into the inner portion of the valve, then down through the center of the meter and out through the meter discharge outlet.

Oscillating Piston

The moving portion of the oscillating piston meter consists of a slotted cylinder that oscillates about a dividing bridge that separates the inlet port from the outlet port. Spokes connect this cylinder to a pin located on the axis of the cylinder. As the cylinder oscillates about the bridge (Figure 2.19g) the pin makes one rotation per cycle. This rotation is transmitted to the gear train and registers either directly or magnetically through a diaphragm. This meter, in addition to being in common usage for the measurement of domestic water has the capability of handling clean viscous and/or corrosive liquids. This type of flowmeter is normally used in smaller pipe-lines (2 in./50 mm or below) to measure low flow rates.
Measurement errors are in the range of ±1% of actual flow. Metering accuracies are increased by reducing the clearance spaces to 0.002 in. (5 microns). Such small clearances do necessitate pre-filtering the entering fluid in order to remove larger particulars. The cases are usually made of cast iron, bronze, or steel, while the chamber and piston materials are usually made of bronze, aluminum, and Ni-Resist. Iron and bronze meters are good for up to 150 PSIG (1034 kPa) and 200°F (93°C), while steel meters can be used up to 400 PSIG (2760 kPa) and 300°F (149°C).

**ROTATING VANE (TYPE E)**

This flowmeter has spring-loaded vanes that seal increments of liquid between the eccentrically mounted rotor and the casing (Figure 2.19b) and transport it from the inlet to the outlet, where it is discharged as a result of the decreasing volume. This type of meter is widely used in the petroleum industry and is used for such varied services as gasoline and crude oil metering, with ranges from a few gallons per minute of low-viscosity clean liquids to 17,500 GPM (66.1 m³/m, or 25,000 bbl/h) of viscous particle-laden crude oils. Precisions of ±0.1% of actual flow are normal, and ±0.05% has been achieved in the larger meters.

This instrument is built from a variety of materials and can be used at temperatures and pressures up to 350°F (177°C) and 1000 PSIG (6.9 MPa).

Another rotary design is illustrated in Figure 2.19i. Here, an abutment rotor operates in timed relation with two displacement rotors and at half their speed.

**VISCIOUS HELIX (TYPE F)**

The helix flow transducer (Figure 2.19j) is a positive-displacement device utilizing two uniquely nested, radically pitched helical rotors as the measuring elements. Close machining tolerances ensure minimal slippage and thus high accuracy. The design of the sealing surfaces provides a ratio of longitudinal to lateral sealing to minimize pressure drop, especially with high-viscosity liquids.

The large inlet size of the progressive cavity allows for the passage of gels, fines, agglomerates, and even undissolved
or hydraulically conveyed solids. The meter can measure flow rates from 0.5 to >4000 GPM (2 to 15,000 l/min). This flow sensor is available in sizes from 1.5 in. to 10 in. (38 to 250 mm) and can operate at temperatures up to 600°F (315°C) and at pressures up to 3000 PSIG (21 MPa). It is a high-pressure-drop device requiring a minimum of 10 PSID (69 kPa) for its operation at full flow. Its turndown can reach 100:1, and its metering error is claimed to be under 0.5% of actual flow.

Available design variations include versions that are heated to maintain line temperatures for metering melted solids or polymers. Also available are units in sanitary construction. This meter is suited for high-viscosity (over 1000 cps) and for slurry services. The straight-through design with no pockets is also available to simplify cleaning. It is recommended that the process fluids be filtered by mesh size 30 filters before they enter this flowmeter.

HIGH-PRECISION AND SPECIALIZED (TYPE G)

For the high-precision measurement of fuel and alcohol flows in engine and carburetor test rigs and other applications, specialized positive-displacement flowmeters are often used. Their high precision and high rangeability are achieved by eliminating the pressure drop and thereby eliminating the slip or leakage flows. This is achieved by providing a motor drive for the displacement element and using it to introduce as much pumping energy as is needed to equalize the pressures at the inlet and outlet of the meter (Figure 2.19k). This flowmeter uses a high-sensitivity piston to detect the pressure differential and utilizes photoelectric sensors to detect the position of the piston. The flowmeter is also provided with a variable-speed controller, which adjusts the drive speed whenever the pressure differential is other than zero. Because the response time of the system is less than 0.5 sec, the flowmeter is able to follow most dynamic flow transients or can be used on short-duration tests.

This flowmeter is claimed to provide a reading with only 0.25% error over a 50:1 range and a 0.5% error over a 100:1 range. The meter is designed for ambient operating temperatures and for up to 150 PSIG (10 bars) operating pressures.

The different models of this flowmeter can detect diesel, gasoline, and alcohol flows from 0.04 to 40 GPH (0.15 to 150 l/h). Because vapor lock is a common problem in fuel flow metering, the unit is provided with a vapor separator.

PROVERS (TYPE H)

All flowmeters that consist of moving and stationary parts that rub against each other (such as positive-displacement and turbine type flowmeters) require periodic recalibration. This is necessary because the clearance space and the slip or clearance flow through that space increase with wear. Recalibration can be done by removing the flowmeter from the pipeline and sending it to a calibration laboratory, or it can be done in line. The flow provers that allow for inline recalibration without interruption of the process flow are described below.

As shown in Figure 2.19l, provers consist of a smooth-walled, precalibrated displacement chamber and a barrier piston within it. Usually, a follower rod is attached to the back side of the piston, which is connected to position sensors. The calibrated flow rate is obtained by dividing the volume of the prover with the time it takes to displace its volume. This calibrated flow rate is then compared to the reading of the flowmeter being calibrated.

To minimize the disturbance to the process flow, inline ballistic flow provers have been developed. In these units (Figure 2.19l), the piston is constructed so that it will not disrupt the flow in the line. Therefore, the prover can be permanently installed in an operating pipeline, upstream or downstream of the flowmeter being calibrated. The poppet valve within the piston assembly allows for the piston to be withdrawn to the start position after a calibration run while the process flow continues undisturbed. Both portable (Figure 2.19m) and permanently installed provers are available, and the calibration can be manual or automatic.

The repeatability of provers is around 0.02% of the actual flow if the seals are tight. It is recommended to periodically check the seals by closing a tight shutoff valve downstream of the prover and applying nitrogen pressure to the upstream...
Positive-Displacement Liquid Meters and Provers

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face of the piston. If this results in any movement of the piston, the seals need maintenance. Provers are available for up to 3000 PSIG (21 MPa) operating pressure and 165°F (74°C) operating temperature; they can detect flow rates from 0.001 GPM (0.004 l/min) to 20,000 GPM (75,000 l/min). The calibrated displacement volume of provers can range from a fraction of a gallon to several hundred gallons. Large provers can fit on truck beds or trailers (Figure 2.19m).

ACCESSORIES AND INTELLIGENT ELECTRONICS

Standard accessories for positive-displacement include strainers; air release assemblies, which remove all the vapors from the flow stream before it enters the meter; automatic batch shutoff valves, which provide two-stage closure for full and dribble flow operation; temperature compensators; manual and/or automatic ticket printers; and pulse generators for remote indication, totalization, and other forms of data monitoring and/or control. In addition to the totalizer-type digital readout registers, flow rate indication can also be provided. Impulse contactors are also available to actuate predetermining counters or to serve as electrical interlocks that actuate flow ratio systems, pumps, valves, solenoids, alarms, printers, sampling devices, and so on. Pneumatic pulse generators are still available and sometime used in explosion-proof areas for interfacing with pneumatic batch controllers.

The intelligent positive-displacement meters are usually provided with magnetic or Hall-effect-type pickup and frequency outputs from solid-state pulse transmitters. The frequency outputs can be sent to central computers or DCS/PLC systems over the data highways and can also be converted to 0- to 10-VDC or 4- to 20-mA analog signals.

In household utility applications, there is substantial economic justification for substituting a telemetering system, operated either on the telephone lines or by radio, replacing the current system (human meter readers). It is also feasible to combine the readings of electric, water, and gas meters of a household into a single transmitter and to transmit that information to the appropriate utilities without the need for a meter reader to visit the home or apartment. The economic advantages of this type of metering is not only in labor savings but also in the speed and frequency at which the data can be obtained and used for billing or other purposes.

Bibliography