# TURBINE AND PADDLEWHEEL FLOWMETERS
## Flow Reference Section

## INTRODUCTION

Turbine flowmeters continue to be the most popular way to measure flow electronically in a wide range of industries. A review of the advantages turbine flowmeters have to offer provides insight into the growing popularity of this versatile flow transducer.

Turbine flowmeters provide:

- Wide flow rangeability
- Outstanding accuracy at low cost
- Construction materials that permit use with many process fluids
- Simple, durable, field repairable construction
- Flexibility in connecting to associated electronic readout devices for flow control and computer interface
- Wide variety of process connections
- Operation over a wide range of temperatures and pressures

## FLOWMETER SELECTION TO OPTIMIZE THE TURBINE ADVANTAGE

The turbine advantage can be defined as that unique blend of desirable attributes particular to the turbine-type flowmeter, that produces a transducer with the ability to measure wide flow ranges with outstanding accuracy, at low cost, and provide a convenient pulse output.

Flowmeter selection requires more than just sizing of flowrates and selection of process fittings. The flowmeter must be compatible with the flow media to be measured, and must operate over the desired temperature and pressure ranges. In addition, maintenance requirements must be evaluated consistent with the installation, service and use expected. The following tutorial provides the background information required for the selection of a turbine flowmeter. Additional information may be found on the individual product pages within this section.

### Operation

Inside a turbine flowmeter, the flowing medium engages a vaned rotor, causing it to rotate at an angular velocity that is directly proportional to the flowrate. As the turbine rotates, an AC voltage is induced in a magnetic pickup coil mounted outside the fluid process. As each turbine blade passes the base of the pickup coil, the magnetic flux density is affected, inducing a voltage pulse. Each pulse represents a distinct volume of fluid that has been displaced through two adjacent rotor blades. The pulse rate generated is thus a very accurate measure of flowrate, and the total number of pulses an equally accurate measure of displaced volume.

The turbine flowmeter is an intrusive flow measurement device, and, therefore, the pressure-drop characteristic is an important consideration. Pressure drops at the maximum rated flow are shown with each individual product. These values are based on water at 16°C (60°F).

The most precise equation for calculating pressure drops in liquids with specific gravities and viscosities different from those of the fluid in which the flowmeter is calibrated (usually water at S.G. = 1.0; viscosity = 1.0 centipoise) is as follows:

$$(\Delta)P_2 =$$

$$(\Delta)P_1\ (\rho_2/\rho_1)^{.81}(\mu_2/\mu_1)^{.27}(Q_2/Q_1)^{1.82}$$

where:
P = Specific gravity
$\mu$ = Viscosity in centipoise
Q = Flow rate, in gallons per minute

Note: The pressure drop produced in a turbine can cause the flowing fluid to flash or produce vapor bubbles which can damage the meter. To prevent this, a minimum downstream pressure = (1.25 x vapor pressure) + (2 x $\Delta P_2$) is required.

### Installation

Allow an inlet straight pipe run of at least 10 pipe diameters and outlet pipe run of at least 5 diameters of the same size as the flowmeter.

For certain upstream piping obstructions, longer upstream straight pipe runs may be required.

| Obstruction | Upstream Straight Pipe Run |
|---|---|
| Concentric reducer | 15 pipe diameters |
| Sweeping elbow or tee | 20 pipe diameters |
| Two sweeping elbows diameters | 25 pipe |
| Partially opened valve or two sweeping elbows at 90° | 50 pipe diameters |
| Ball, gate or butterfly valve (wide open) | 14 pipe diameters |

### Performance Characteristics

The K-factor is the number of output pulses the flowmeter produces per engineering unit of volume throughput. The factor is represented by the expression:

$K = 60f/Q$
where:
f= pulses per second
Q= flow rate, in gallons per minute
K= pulses per gallon

For purposes of ordering the proper readout devices, this equation can be rearranged to determine the minimum and maximum frequency outputs of the turbine meter:

$f = KQ/60$
where:
Q = minimum and maximum linear flow rates

The linear range is that flow range over which the K-factor is constant, within the specified limits of linearity. Linearity is a measure of the accuracy of a device, and is the maximum percentage deviation from the average K-factor (K). The linearity of turbine flowmeters is usually expressed as a percentage of the reading. Most other flow metering devices usually state linearity as a percentage of full scale, which gives a lesser accuracy. Each OMEGA® FTB-100, 200 turbine meter is individually calibrated, and the resulting performance characteristics are presented in a tabular format.

The repeatability of a turbine meter is a measure of the stability of the output under a given set of flow conditions. Repeatability is defined as the allowable percentage deviation from the stated K-factor at that flowrate. The repeatability error is usually much smaller than implying the linearity error, inferring a much greater accuracy if the known flowrate dependency of the K-factor is eliminated by the use of an external linearizing device.

## MATERIAL SELECTION AND CONSTRUCTION

Turbine flowmeters are available in a range of standard materials, which permits selection of the optimal combination of useful range, corrosion resistance and operating life for a particular application. A low mass rotor design allows for rapid dynamic response, which permits the turbine meter to be used in pulsating flow applications. Deflector cones eliminate downstream thrust on the rotor and allow hydrodynamic positioning of the rotor between deflector cones. This positioning of the low mass rotor provides wider rangeability and longer bearing life than that of conventional turbine flowmeters. Integral flow straightening tubes or vanes minimize the effects of upstream flow turbulence.

The housing is made of nonmagnetic materials, and the rotor is made of magnetic or magnetized materials. Bearings are chosen based on media service, cost and accuracy considerations.

Selection of the materials of flowmeter construction is usually dictated by the requirements of media compatibility, availability and by cost considerations.

## BEARING SELECTION

Many bearing types are available, including ball bearings and sleeve-type constructions of tungsten carbide and ceramic.

When selecting from among several chemically compatible bearings, the ball-bearing design offers the highest accuracy at the lowest cost, and will generally have the widest usable range. It remains the bearing of choice in many fluids. Tungsten carbide and ceramic bearings offer the greatest durability for use with those service fluids with which they are compatible. These are the standard for many industrial service environments.

In turbine flowmeters, the flowing fluid provides the bearing lubrication in most applications. It is often observed that fluids which have a high natural lubricity tend to prolong the life of flowmeter bearings. OMEGA turbine meters are specifically designed for low bearing wear, even with low lubricity fluids such as water. Ball-bearing units feature non-metallic bearing retainers to minimize wear, while

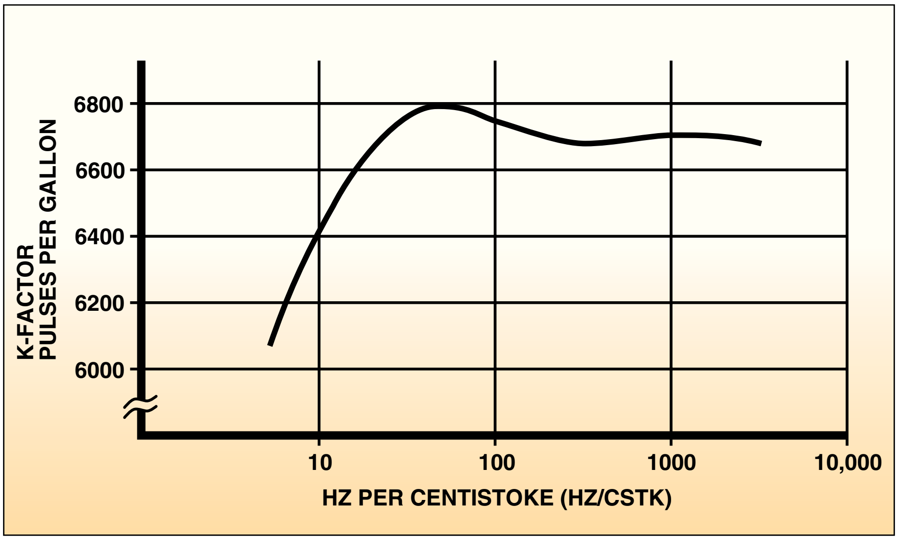


*Figure 1: Universal viscosity curve*

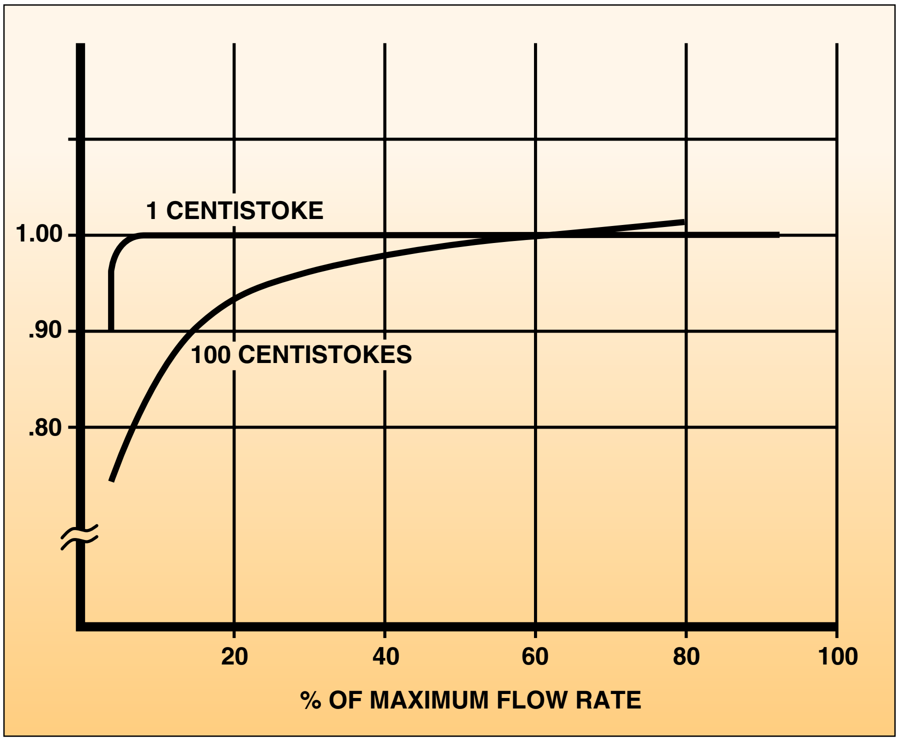


*Figure 2: Viscosity effects on a 1” turbine meter*

sleeve-bearing units use very hard tungsten carbide and ceramic to minimize wear.

Bearing life has been found to be approximately inversely proportional to the square of bearing speed. To prolong the life of a flowmeter, it is therefore advantageous to operate the flowmeter at rates much lower than the maximum permissible flowrate. For example, if the flowmeter is operated at 33% of its maximum flowrate, its life will be extended by a factor of ten. For ball-bearing units, inspection of the bearings is recommended approximately every six months. The rotor should be rotated by blowing air into the unit. If the rotor comes to a sudden halt, the bearings should be replaced (this causes no loss of calibration). For sleeve-bearing units, the tungsten carbide ball can be measured with a micrometer to determine bearing wear.

## FLOWMETER PICKUP SELECTION

The flowmeter pickup senses the motion of the rotor and converts it to a pulsing electrical signal of a discrete, digital nature.

### High Output Magnetic Pickup

The standard high output magnetic pickup for OMEGA turbine meters produces a high-level sinusoidal output. To produce this, the pickup generates a relatively strong magnetic field. The signal may be transmitted up to 200 feet without amplification. A flow range of 10:1 or better is common with this pickup type.

The output signal voltage of a magnetic coil is approximately sinusoidal. The frequency range of the pulsing signal varies according to size. However, standard ranges allow for maximum output frequencies at the nominal maximum linear flow ranging from approximately 400 to 1100 Hz.

The amplitude of the output signal is a function of the flowrate. The voltage at the minimum linear flow is greater than 28 millivolts peak-to-peak when measured into a 10,000 ohm load. As the flowrate increases, particularly on larger flowmeters, the output level may exceed several volts peak-to-peak.

The DC output resistance of magnetic pickup coils for ball-bearing units is nominally 1400 ohms at room temperature. If the resistance of the pickup coil is significantly different from these values (20% or more above or below), the pickup coil should be replaced.

### Signal Conditioners/Converters

All transducers benefit from the use of integral signal conditioning. When a signal conditioner is mounted in close proximity to the sensor, the possibility of signal interference and distortion is significantly reduced. The conditioner takes the low-level sensor output and conditions, amplifies and transmits a high-level signal to the host system. This high-level signal is less likely to be affected by ambient conditions, thereby preserving system accuracy.

Signal conditioners for turbine flowmeters provide amplification, filtering and wave-shaping of the low-level flowmeter pickup output signal. They generate a high-level pulse output signal suitable for transmission to a remote host system through an electrically noisy environment.

Several output forms (*i.e.*, amplified pulse, current and voltage) are available to suit different requirements. Amplified pulse, current and voltage signals can be transmitted several hundred feet through shielded cable, as long as the resistance in the cable is not so great as to degrade the signal. Enclosures are available which allow integral mounting of the signal conditioner to the flowmeter. Models suitable for explosion-proof environments are also available.

### Selection For Viscous Service

Turbine and positive displacement flowmeters are used where very high accuracy, high repeatability flow measurement is required (typically ±1% of rate or better). Paddlewheel flowsensors provide an economical alternative for applications with less demanding accuracy requirements (typically ±1% of full scale). For high accuracy applications, positive displacement flowmeters are employed when variations in the viscosity of the process fluid are anticipated. This is very typical for oil or other viscous fluids when they are measured over a range of temperatures. The accuracy of positive displacement meters is unaffected by variations in viscosity within the allowable viscosity operating range. OMEGA currently offers five styles of PD meters: Visit **omega.com** for the complete selection guide.

The alternative flowmeter for high accuracy applications is the turbine flowmeter. Turbine meters operate over much wider temperature and pressure ranges than do PD meters -268 to 232°C (-450 to 450°F) vs. -26 to 82°C (-14 to 180°F) and up to 7500 psig vs. 150 psig for PD meters). Although special modifications can be made to extend the temperature and pressure ranges of PD meters, they still can't match a standard turbine

**FTB-30, positive displacement flowmeter.**

meter. However, turbine meters are very sensitive to viscosity and viscosity variations, and must be specially calibrated for such applications.

Turbine meters are ordinarily calibrated with water (viscosity = 1 centistoke). This calibration is suitable for fluids with viscosities less than or equal to that of water. For example, when a turbine meter is used to measure liquid Freon (viscosity < 1 centistoke), a standard turbine with water calibration data is used. When a turbine meter is to be used to monitor a fluid with a single viscosity that is higher than that of water, the user has three options:

1) **Narrow the operating range:** For any given flowmeter size, it is observed that, as viscosity increases, the low portion of the flowmeter's range is affected more than is the higher portion of the flowmeter's range. To maintain a required accuracy, the minimum flowrate must increase as viscosity increases. There is also a slight change in the average calibration constant as viscosity increases. Figure 4 shows the calibration trends typical of a ½", 1" and 3" turbine flowmeter. Note that, the smaller the flowmeter, the more sensitive the unit is to higher viscosity.

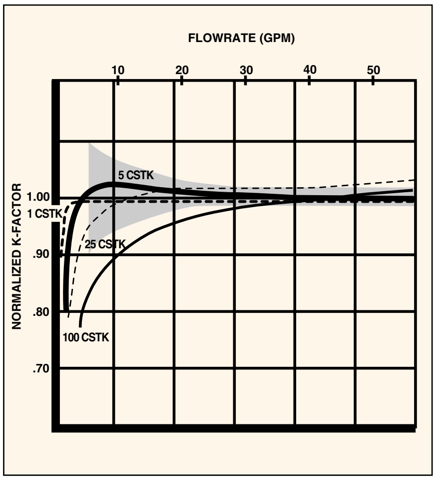


*Figure 3: Viscosity effects on 2-inch turbine. Shading denotes error envelope of ±1% full scale*

Therefore, when selecting a flowmeter for operation in a viscous fluid, it is generally preferable to select a flowmeter sized so it will be operated in the upper portion of its range, to minimize viscosity effects in the measurement.

2) **Accept a lesser accuracy:** Due to the cost advantages of using a turbine flowmeter over other flowmetering types, turbine flowmeters are often used at viscosities that introduce some loss in accuracy and some loss in flow range. A flowmeter may be considered for an application even if its accuracy is only ±1% of full scale instead of the standard ±0.5% of reading which can be achieved on low viscosity fluids. Figure 3 shows the allowable error band of ±1% of F.S. as a frame of reference. It is therefore often possible to provide a standard turbine meter for a viscous fluid application, so long as the user can accept a smaller operating range and/or a decreased accuracy. However, no general guidelines can be laid out, since accuracy, range, and viscosity vary with each application and each turbine meter size. Feel free to call the Flow Department to discuss your application.

3) **Request a special calibration:** A turbine flowmeter can be calibrated on a test fluid that approximates the viscosity it will see in service, rather than on water. However, this typically adds approximately $350 to the cost of the turbine meter, and extends the delivery time as well. Calibrations can be performed on fluids up to 100 centistokes, depending on meter size. However, as we see from Figure 4, depending on meter size, the turbine meter may be very nonlinear (greatly changing the K factor, or number of pulses/gallon) at a particular viscosity and flowrange. This can be linearized in a computer for the entire operating range, so as to maintain the highest measurement accuracy, or it may be necessary to narrow the operating range and accept a lower accuracy to permit the use of a turbine meter. Again, feel free to contact the Flow Application Department to discuss the specifics of your situation.

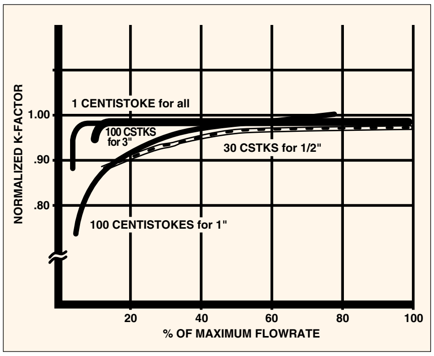


*Figure 4: Viscosity effect on a turbine meter*

**What to do when viscosity varies:** Ideally, a positive displacement meter should be used. However, if the application requires the use of a turbine meter, a special viscosity calibration can be performed, called a Universal Viscosity Calibration (UVC). The turbine meter is calibrated over a range of viscosities (typically three) to generate a curve which characterizes the performance of the meter at different viscosities (see Figure 1 on page F-4).

A UVC can then be represented by a polynomial equation programmed into a computer. The computer receives a temperature sensor input (to calculate viscosity based upon a given equation) and the flowsensor input, and applies the UVC polynomial equation to give a viscosity-corrected flowrate. This is easily done with a personal computer system combined with OMEGA's plug-in interface cards and software. However, a UVC will typically add between $400 and $1000 to the cost of the meter, and will increase the delivery time as well.

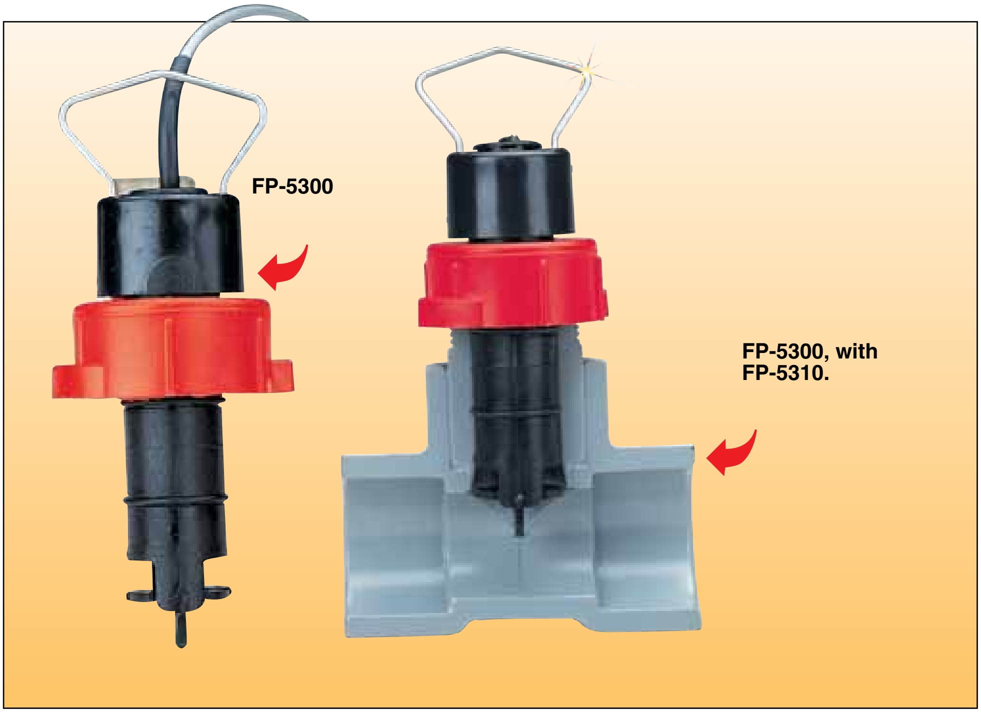


*Figure 5: Paddlewheel flow sensor and installation fitting, which insures proper insertion depth into the pipe system*

### Paddlewheel Flowmeters

Because of their cost-effectiveness, paddlewheel flowsensors are often used in viscous applications that don't have high accuracy requirements. As long as the Reynolds number is above 5000, the unit should not require field recalibration and will send out a frequency that is proportional to velocity (and thus, to flowrate). The Reynolds number = (3160 x Q x SG)/(D x MU), where:

Q = liquid flowrate, (in gpm)

D = inside pipe diameter, (in)

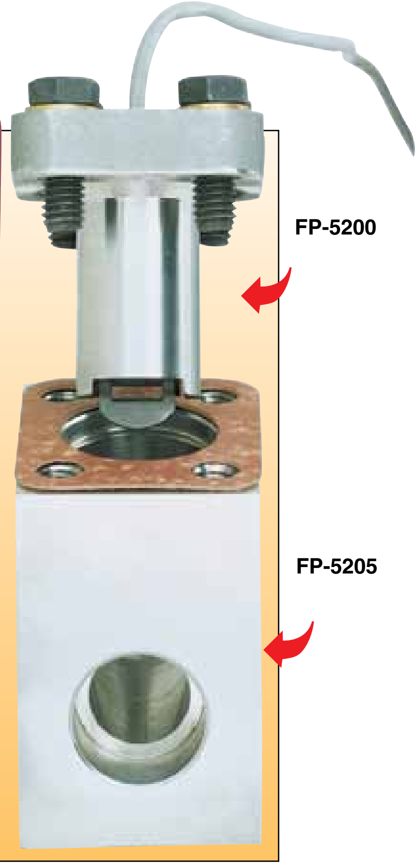
SG = liquid's specific gravity

MU= liquid's viscosity, (centipoise)

To convert centistokes to centipoise, multiply centistokes by the specific gravity.

Thus, when it comes to measuring fluids from low viscosity to high viscosity to varying viscosity, OMEGA® flow systems can handle it.

**FTB-31P, positive displacement flowmeters are ideally suited for viscous fluids.**



**The economical FP-5200 series paddlewheel flow sensor.**

# FLOW STRAIGHTENERS, INSTALLATION KITS AND STRAINERS

## Flow Straightening

Proper application of a turbine flowmeter requires that there be a suitable piping section both downstream and upstream of the meter if it is to achieve optimum accuracy. Whereas an inlet straight pipe run of 10 pipe diameters and an outlet straight pipe run of 5 pipe diameters provide the necessary flow conditioning in general, some applications require an upstream flow straightener. Such applications include custody transfer. A flow straightener consists of a section of piping which contains a suitably dimensioned and positioned thin-walled tube cluster to eliminate fluid swirl (see Figure 6 above).

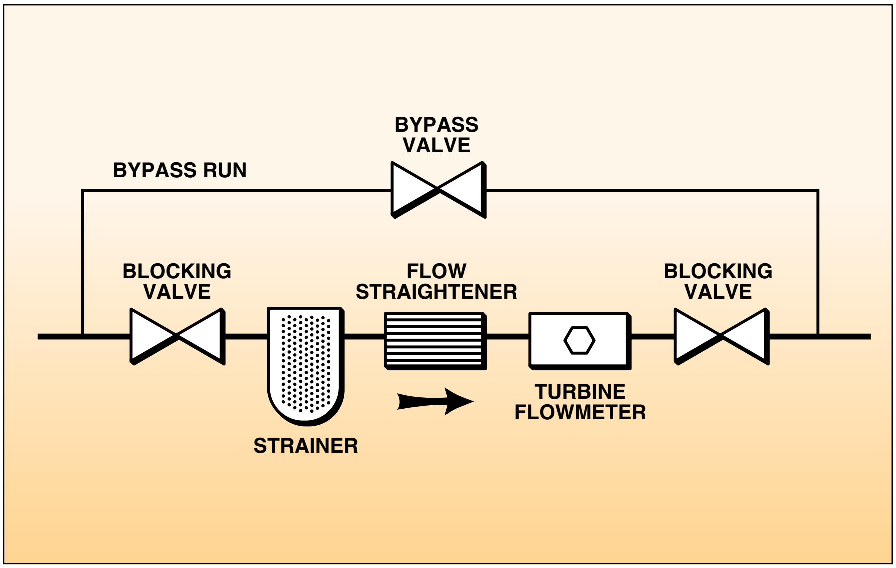
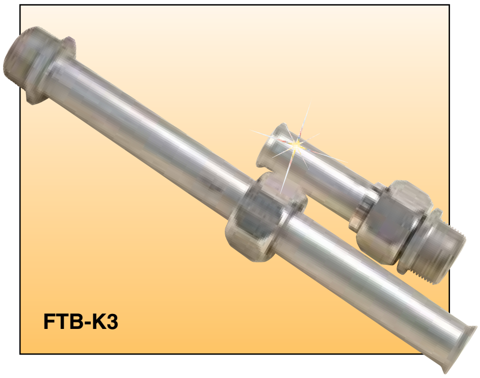


*Figure 6: Typical turbine meter installation*



## 37° Flare Installation Kits

Installation kits for turbine meters with 37° flare end fittings consist of two lengths of stainless steel tubing cut to a length appropriate for the upstream and downstream straight pipe runs and flared at one end. Mating sleeves and nuts are included. The kits can be conveniently butt-welded into the piping system. Flow straightening sections may be provided with the installation kit. These kits are available in tubing sizes from ½ to 2”.

| Model No. | Mating Turbine | Inlet Length | Outlet Length |
|---|---|---|---|
| **FTB-K3** | **FTB-201<br>FTB-202<br>FTB-203** | 10" | 5" |
| **FTB-K4** | **FTB-204** | 10" | 5" |
| **FTB-K5** | **FTB-205** | 10" | 5" |
| **FTB-K6** | **FTB-206** | 10" | 5" |
| **FTB-K7** | **FTB-207** | 14" | 6" |
| **FTB-K8** | **FTB-208** | 17" | 8" |
| **FTB-K9** | **FTB-209** | 21" | 9" |

## Strainers/Filters

A strainer/filter may be required to reduce the potential hazard of fouling or damage that can be caused by foreign matter. Pipe rouge, the extremely fine rust which develops on the inside of some piping, is a serious problem for turbine meters, due to the difficulty in filtering out these particles. Consult the Flow Engineering Department for applications that may entail pipe rouge. Minimum requirements for the FTB-100 and 200 Series turbine meters are:

| Meter Size | Mesh Size | Maximum Particle Size (inch) |
|---|---|---|
| ¼ to ½" | 100 | 0.0055 |
| ⅝ to 1¼" | 70 | 0.008 |
| 1½ to 3" | 40 | 0.015 |

# PADDLEWHEEL FLOWMETERS

Paddlewheel flowmeters are very low cost substitutes for turbine flowmeters, useful where the extremely high accuracy of the turbine is not required. In the case of insertion-style paddlewheel sensors (such as the FP-6000 Series), line sizes up to 36 inches can be accommodated at a much lower cost than that of competing in-line flowmeter systems, visit **omega.com**. In paddlewheel flowmeters, the rotor and blades are perpendicular to the flow, not parallel as with the turbine flowmeters (Figure 7, see below). Owing to the solid rotor design of paddlewheel sensors, which include no ball bearings, this flowmetering system is very tolerant of particulates in the line; no strainers are required, as is sometimes the case with turbine flowmeters. Because the paddles contact only a limited cross-section of the flow, the insertion depth of the rotor and proper flow profile are critical to accurate flowmeter performance. For insertion-style paddlewheels (like the FP-5000 Series), installation fittings which have been specially modified to fix the insertion depth and direction of the rotor are sold separately (see Figure 5, page F-7).

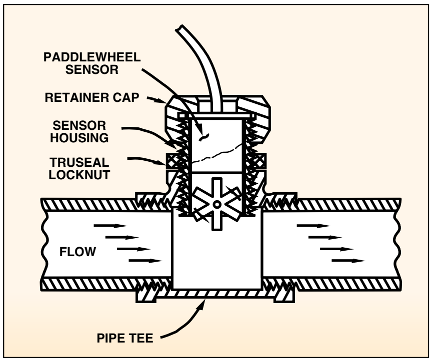


*Figure 7: Paddlewheel flow sensor installation and operation*