

The purpose of this paper is to examine the factors that should be considered when selecting turbine meters for the custody transfer measurement of crude oil. In order to do this, it is necessary to develop a basic understanding of the measurement characteristics of turbine meters in general and to consider the peculiarities of crude oil.

Background

Before turbine meters appeared on the metering horizon, Positive Displacement (PD) meters were the primary devices used for dynamic measurement. However, by the early 1970's, turbine meters were not only being used for the custody transfer measurement of refined petroleum liquids, but also were being used, somewhat experimentally, for high-accuracy crude oil measurement associated with pipelines and ship loading. In many cases, turbine meters were placed in crude oil measurement situations which yielded completely satisfactory results. There were also many cases which resulted in considerable setbacks to the technology of liquid petroleum measurement.

Turbine Meters

Design and Construction

The turbine meter can be broken into three major groups of components: (1) Housing, (2) Internal Assembly, and (3) Pulse Pickup Assembly (see Figure 1).

1. The **Housing** consists of a relatively short tube with flanges on either end. Near the middle of the tube is a pickup boss to which the pickup assembly is attached.

The housing, including the flanges, is normally constructed of carbon steel and can be sized for pressure ratings of Class 900 ANSI or even higher. Corrosive liquids may require a stainless steel tube and, in some cases, stainless steel flanges as well.

2. The **Internal Assembly** is made up of the rotor, which is the only moving part, and the stator assembly. There are two basic stator designs. One design supports the rotor shaft on both upstream and downstream ends and the cantilever design supports on the upstream end only. The rotor can be of the rimmed or rimless type. In the case of the rimmed type, there is also a deflector ring which prevents the flow from impinging on the rotor rim. The rim is commonly made of a nonmagnetic material and fitted with a series of equally-spaced magnetic buttons. With the rimless type, the blades are made of a magnetic material. In each case, as the rotor rotates, the button or blades pass by the pickup boss where the pickup coil is located and generates a signal.

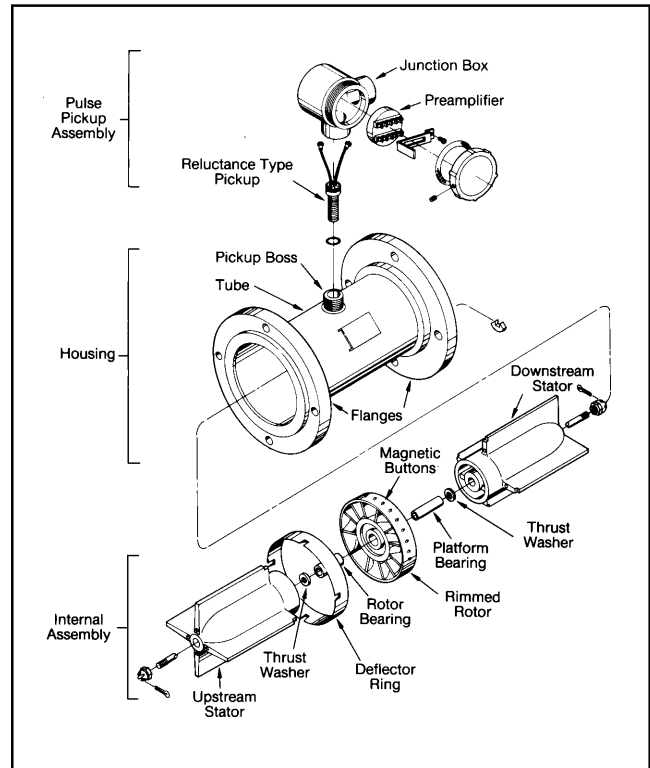


Figure 1 — Turbine Meter Construction - Double Stator

The rotor bearings are commonly made of tungsten carbide and provide excellent service even under low lubricity or abrasive conditions.

3. The most prevalent **Pulse Pickup** is the variable reluctance type. As the magnetic buttons on the rimmed rotor, or the blades on the rimless rotor, pass near the top of the pickup, a voltage signal is generated. The frequency of this signal is dependent upon the frequency at which the buttons or blades pass by the pickup. The strength of the signal is determined by the velocity at which the rotor rotates. If the signal must be transmitted to remote instrumentation, it may be advisable to use a preamplifier to strengthen and square the voltage wave.

Measurement Characteristics

Flow measurement with a turbine meter is fundamentally different than with the PD meter. The PD meter is a direct measurement device, whereas the turbine meter infers the throughput. That is, PD meters divide the flow stream into discrete segments much like buckets and simply count the number passing through. With turbine meters, angular rotation of the rotor is determined and from this information, an inference is made as to how

much liquid has passed through.

First Inference:

The angular rotation of the rotor is directly related to the average velocity of the flow stream.

Is the rotor sensing the true average velocity?

Second Inference:

The average velocity of the flow stream is directly related to the volumetric throughput.

Is the cross-sectional area through the measuring annulus unchanged?

In other words, what is measured is the angular rotation of the rotor and what is desired is the volumetric throughput. Therefore, any factor that causes the relationship of the first inference or the second inference to vary will result in measurement error.

Viscosity

Figure 2 shows an interesting relationship between the

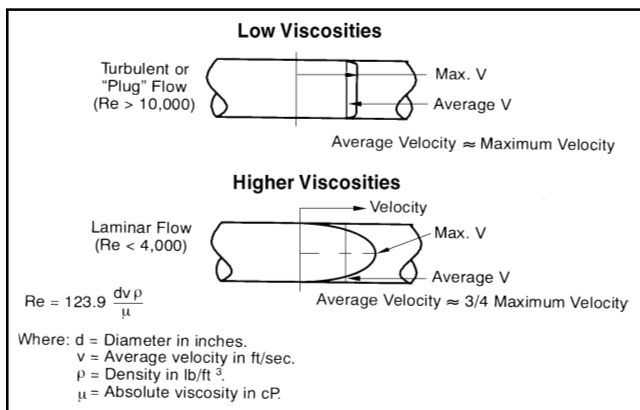


Figure 2 — Velocity Profile - High Reynold's Number and Low Reynold's Number

average velocity and the maximum velocity of a flow stream as the viscosity varies.

Notice that when the Reynold's Number is high (low viscosities), the velocity profile across the stream is even (i.e., the maximum velocity is nearly the same as the average velocity). The turbine meter performs very good in this case.

However, when the Reynold's Number is low (higher viscosities), the velocity profile becomes parabolic shaped (i.e., the maximum velocity is significantly greater than the average velocity). The turbine meter rotor cannot accurately measure the average stream velocity in this case since it tends to follow the maximum velocity more closely. That is, the driving forces resulting from the increase in the maximum velocity portion of the stream overpower the resisting forces resulting from the viscosity increase.

Figure 3 shows how relatively small shifts in temperature produce significant changes in viscosity.

When attempting to meter flow streams with low Reynold's Numbers, the turbine meter cannot differentiate between

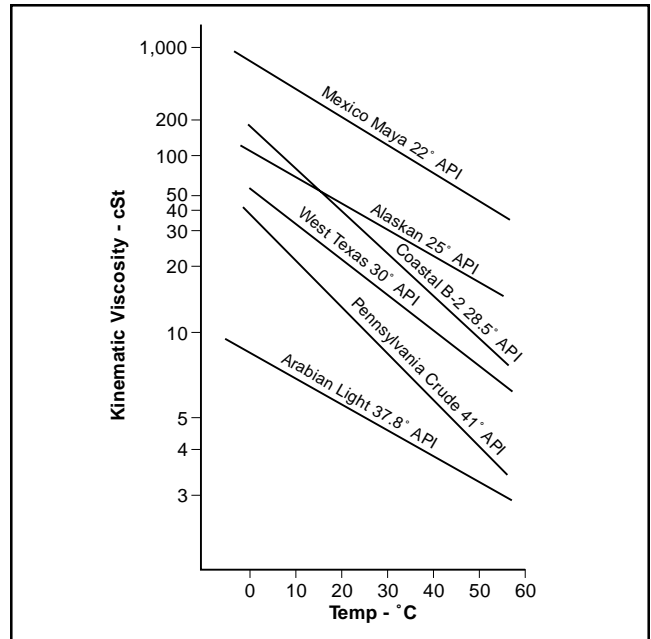


Figure 3 — Viscosity - Temperature Relationships for Various Crude Oils

an increase in flow rate (velocity) and an increase in viscosity.

Wax

If deposits such as wax adhere to the inside surfaces of the turbine meter, the cross-sectional area of the rotor annulus is affected. This means that the relationship between the average stream velocity and the volumetric throughput has been changed.

Crude oil streams producing wax coatings are impossible to measure accurately with turbine meters since small changes in the thickness of the coating produce significant changes in the cross-sectional area. For example, a change in the thickness of wax coating of only 0.001 inches on a 4-inch turbine meter will alter the annulus area by about 0.5% and result in an accuracy shift of the same magnitude.

Light Ends

As the liquid passes through the rotor annulus, its velocity is increased. This results in a corresponding increase in the pressure at that point. If this local pressure drops to the vapor pressure of the liquid, vapor pockets or cavities are formed. These cavities occupy flow area and cause the velocity to increase through the annulus. Many crude oils have quite high vapor pressures (Table 1), so it is important to guard against cavitation by providing adequate back pressure. The minimum back pressure can be determined from the following equation:

$$P^B = (2\Delta P) + 1.25 VP$$

Where: P^B = Minimum Pressure at the Meter (PSIG)

ΔP = Pressure Drop Across the Meter (PSI)
 V_P = Vapor Pressure of the Liquid (PSIA)

Table 1 — Vapor Pressure For Various Crude Oils

Crude Oil Name	Gravity ° API	Reid Vapor Pressure (PSIA @ 100°F)
Arabian Medium	30.8	3.2
Alaska North Slope	26.4	3.6
Arabian Light	33.4	3.6
Mexico Maya	22.0	4.7
Alberta Medium	40.7	4.9
Venezuela Leona	24.1	5.5
North Sea Auk	37.2	6.0
Nigerian Brass River	40.9	6.9
Margham Light	50.3	9.8

Filamentary Debris

It has been found that many crude oils support an organic growth which takes the form of short, fine filaments. This is sometimes referred to as “grass” and is particularly troublesome when measurement is attempted with a turbine meter. The filaments tend to adhere to the sharp edges of the rotor and rotor rim. When this occurs, the cross-sectional area of the rotor annulus is reduced and the velocity is increased resulting in significant accuracy shifts.

Filters have been used in an attempt to strain the filaments from the stream prior to metering but are not completely effective. A device was even considered to chop the filaments into very short lengths, but again, this was found to be impractical because of the high pressure drop.

The most successful solution to this problem has been to use parallel meter runs so that the meters can be isolated and flushed periodically to remove filament build-up from all sharp leading edges.

Turbine Meters Versus PD Meters

There has been considerable discussion as to which type of meter, PD or turbine, is best for crude oil measurement. Because these meters utilize fundamentally different principles to determine the volumetric throughput, it is logical that, given a set of conditions, there is indeed a best choice.

The previous discussion has been on the characteristics of the turbine meter. Let’s examine the PD meter briefly.

It gets its flow information by dividing the flow stream into discrete segments and keeping track, with the gear train and counter, of how many segments have been filled.

There are two basic areas where measurement error can occur:

1. The volume of the measuring chamber can change due to:
 - a. Wax deposits or viscous clingage.
 - b. Wear resulting in a change in the swept volume.

2. The percentage of bypass around or through the measuring chamber can change due to:
 - a. Change in viscosity of the liquid.
 - b. Wear resulting in greater (or smaller) clearance areas.

Let’s consider the following comparisons:

Cost

Initial Equipment:

Figure 4 shows an approximate relationship between the initial cost of a turbine meter run compared to a PD meter run. This wide differential (approximately seven times) is the primary force that has led to the rise in turbine meters for metering large streams.

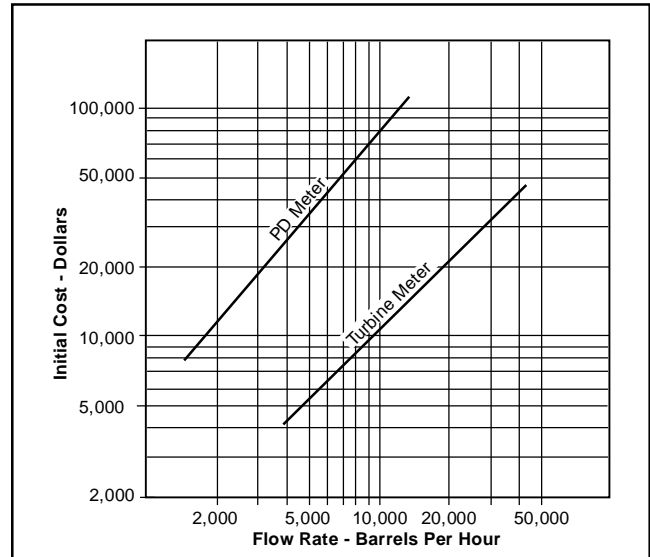


Figure 4 — Approximate Initial Cost Per Flow Rate - Turbine Meter vs. PD Meter

Operating and Maintenance:

There is no doubt that another primary reason why turbine meters have been used on crude oil streams is the relatively low maintenance cost. When compared with the PD meter, which must undergo periodic service to replace worn parts, the turbine meter (with its tungsten carbide bearings) is virtually maintenance-free, barring damage from foreign debris.

When the pressure drop across a turbine meter run is compared to a rotary vane PD meter at the same flow rate, the PD meter is approximately 2.5 psi less. This may seem at first to be insignificant, but if the cost to pump against that extra differential is considered over the life of the metering equipment, the results may be surprisingly in favor of the PD meter.

Size and Weight

Turbine meters, because of their small size and light weight, can be installed where PD meters might not be considered. The need for flow conditioning may lead to some installation problems if length is at a premium.

Places where the turbine meter’s size and weight advantage quite often comes into play include ship deck and jetty installations.

Measurement Accuracy

When consideration is given to the value of the liquid flowing through a custody transfer meter, it becomes apparent that seemingly minuscule improvements in accuracy amount to significant money amounts. For example, a 10-inch turbine meter flowing at 80% of rated capacity is metering about \$18,000 per hour at current crude oil prices. A 0.05% shift in accuracy represents a financial leak of over \$200 a day.

The PD meter has proven to be the superior meter when the viscosity is high since the amount of slippage or bypass is nearly eliminated and the accuracy is unsurpassable.

The turbine meter can be an excellent choice, however, when the viscosity is low and wax is not a problem. Figure 5 can be used as a selection guide in making the correct choice.

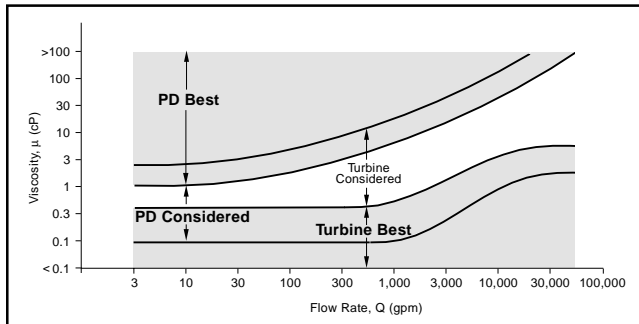


Figure 5 — Selection Guide (API, M.P.M.S., Chapter 5)

Conclusion

Turbine meters can be used effectively for accurate crude oil measurement provided certain precautions are taken in the application and operation. Normally, if wax deposits are a characteristic of the crude oil, accurate measurement is impossible. If the stream size or viscosity are such that the flow is near the transition from turbulent to laminar flow (low Reynold's Number), the turbine meter should not be used. Slight changes in operating temperature will result in viscosity changes that cannot be differentiated from flow rate changes by the turbine meter.

When attempting to minimize measurement error with the turbine meter, it is very important to maintain stable operating conditions (flow rate, pressure, and temperature). The turbine meter should be recalibrated frequently if conditions are changing only slightly. Adequate pressure must be maintained to prevent cavitation and the corresponding measurement error.

The filamentary debris common in crude oils must be periodically removed from the turbine meter's internal sharp edges. Back flushing is the most common method. This may seem like a long list of precautions, but accurate custody transfer measurement of crude oil with a turbine meter does not happen by accident.

Acknowledgment

This paper was originally presented at the International School of Hydrocarbon Measurement (ISHM), University of Oklahoma, May 1989.

The specifications contained herein are subject to change without notice and any user of said specifications should verify from the manufacturer that the specifications are currently in effect. Otherwise, the manufacturer assumes no responsibility for the use of specifications which may have been changed and are no longer in effect.

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