Manual of Petroleum Measurement Standards Chapter 5.3

Measurement of Liquid Hydrocarbons by Turbine Meters

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Revision of API *MPMS* Chapter 5 Metering, when finished will be in five parts beginning with

API *MPMS* Chapter 5.1, *General Considerations for Measurement by Meters*

Following will be the combination of

API *MPMS* Chapter 5.2 *Measurement of Liquid Hydrocarbons by Displacement Meters* and Section 5.4 *Accessory Equipment for Liquid Meters*

API *MPMS* Chapter 5.3 *Measurement of Liquid Hydrocarbons by Turbine Meters* and Section 5.5 *Fidelity and Security of Flow Measurement Pulsed-Data Transmission Systems*

API *MPMS* Chapter 5.6 *Measurement of Liquid Hydrocarbons by Coriolis Meters*

API *MPMS* Chapter 5.8 *Measurement of Liquid Hydrocarbons by Ultrasonic Meters* (ballot resolution pending)

NOTE API *MPMS* Chapter 5.4 and API *MPMS* Chapter 5.5 will have all relevant parts inserted into Chapters 5.1, 5.2, or 5.3 with the next edition of each of these documents, or they will be placed into Chapter 6. Therefore, Chapter 5.4 and 5.5 will be withdrawn when all of the next editions of API *MPMS* Chapter 5 are published.

The verbal forms used to express the provisions in this document are as follows.

Shall: As used in a standard, “shall” denotes a minimum requirement in order to conform to the standard.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 200 Massachusetts Avenue, NW, Suite 1100, Washington, DC 20001, standards@api.org.

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Introduction

API *MPMS* Chapter 5 covers the general characteristics, requirements, and operation of displacement and inference meters without respect to the arrangements necessary to meet specific applications. The guidelines are common to all metering systems, but appropriate precautions should be taken when they are used for specialized metering systems, as discussed in API *MPMS* Chapter 6, “Metering Assemblies”.

Some of the advantages of metering are as follows:

a) Metering can increase the availability of tanks, because no tank needs to be isolated for the sole purpose of measurement.

b) Metering allows for the calculation, indication, and display of flow rate and quantity.

c) Metering is suitable for applications in which a quantity is transferred from one or more sources into one or more receivers.

d) Metering accuracy can be checked by the use of standard references such as static or dynamic provers.

e) Metering allows dynamic quantity weighted averaging in conjunction with the use of process variables such as temperature, pressure, and sample data.

This publication, including its various sections, does not endorse or advocate the preferential use of any specific type of equipment or systems, nor is it intended to restrict future development of such equipment.

The field of application of API *MPMS* Chapter 5.3 is the measurement of liquid hydrocarbons and chemicals by turbine meter, at the temperature and pressure conditions that prevail inside a meter during flowing conditions.

Turbine meters have been shown to operate best with Newtonian liquids. The chapter does not apply to the metering of two-phase fluids.

API *MPMS* Chapter 5.3, together with API *MPMS* Chapter 5.1, is intended to describe methods of obtaining accurate quantity measurements with turbine meters in single phase liquid hydrocarbon service.

1 Scope

API MPMS Chapter 5.3 is part of a set of documents that detail the minimum requirements for meters in single phase liquid applications. This section of API MPMS Chapter 5 covers the unique performance characteristics of turbine meters.

NOTE Metering assemblies, including the installation of turbine meters in a measurement system, are covered in API MPMS Chapter 6.

2 Normative References

The current editions of the following API *MPMS* standards contain information applicable to this chapter:

API *MPMS* Chapter 4.2, *Proving Systems, Displacement Provers*

API *MPMS* Chapter 4.8, *Operation of Proving Systems*

API *MPMS* Chapter 5.1, *General Considerations for Measurement by Meters*

API *MPMS* Chapter 6 (all sections), *Metering Systems*

3 Terms, Definitions, Abbreviations, and Acronyms

3.1 Terms and Definitions

3.1.1 Accessory equipment

Any additional electronic or mechanical computing, display, or totalization equipment used as part of the primary element.

3.1.2 Back pressure

The operating pressure level measured downstream from a measuring device.

3.1.3 Calibration

The process of using a reference standard to determine a coefficient which adjusts the output of the meter to bring it to a value which is within the specified accuracy tolerance of the meter over a specified flow range.

3.1.4 Cavitation

The formation and collapse of vapor cavities (bubbles) in a liquid that result from a sudden decrease and increase of pressure. Collapse of the cavities causes large impulsive pressures in the vicinity of the cavity. Cavitation can occur and cause mechanical damage to adjacent surfaces in meters, valves, pumps, and pipes at locations where flowing liquid encounters a restriction or change in direction.

3.1.5 K-factor

The number of pulses generated by a meter per gross unit of volume or mass.

3.1.6 Two phase

A fluid state consisting of a mixture of liquid with gas or solids. Also a mixture of a gas with solids or with liquid droplets.

3.1.7 Reynolds number (Re)

A dimensionless number representing the ratio of the inertial forces (fluid velocity) to the viscous forces (fluid viscosity) for a flowing fluid.

NOTE: See Annex C of this document for details on Reynolds number calculation in turbine meter applications.

3.1.8 Preamplifier

An electronic accessory designed to increase the amplitude of a low level (mV) voltage signal (such as from a turbine meter pickup coil) to a transmissible square wave type output.

3.1.9 Helical rotor

A turbine meter rotor with a blade design in the shape of a helix (a curve that goes around a central tube or cone shape in the form of a spiral, similar to a screw)

3.2 Abbreviations and Acronyms

DRA – Drag Reducing Agent

CTSm – Correction for Temperature on Steel (meter)

NGLs – Natural Gas Liquids

4 Turbine Meters - General Considerations

A turbine meter is a flow-measuring device with a rotor that senses the velocity of flowing liquid in a closed conduit (see Figure 1). Rotor speed is proportional to the volumetric flow rate through the meter. The movement of the rotor can be detected mechanically, optically, or electrically and is registered. The volume that passes through the meter is determined by proving against a known volume, as discussed in API *MPMS* Chapter 4.8.

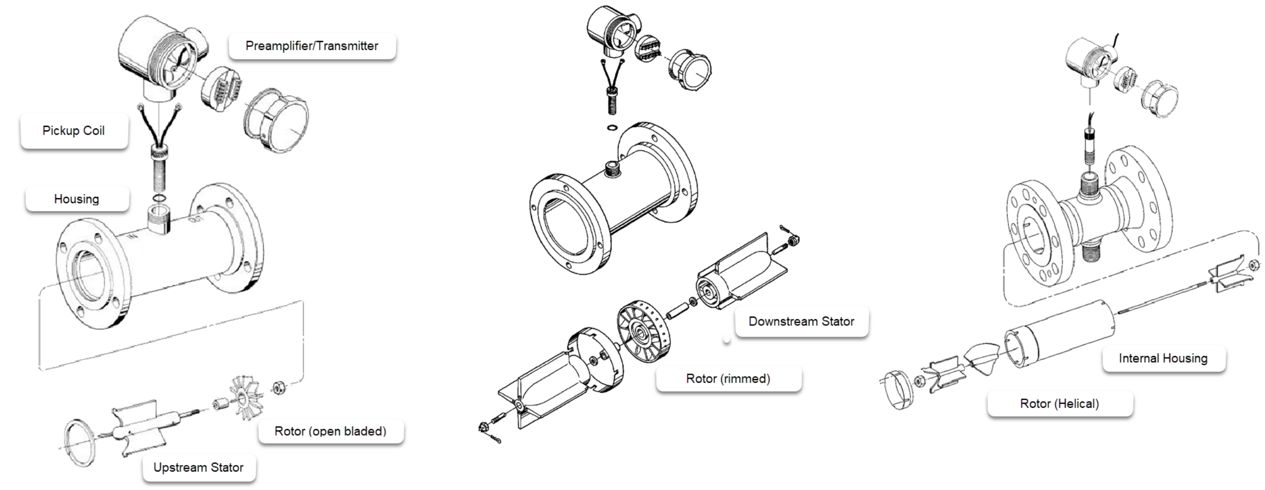


Figure 1—Turbine Meter Types and Typical Components

4.1 Types of Turbine Meters

Rotor designs vary widely across manufacturers. Turbine meter designs generally fall into one of the following categories, based on rotor construction:

- Rimless (open bladed) – Typically used in smaller meters, the blade tip passing the pickup generates a signal that can be used to represent rate and determine volume.

- Rimmed – The rotor has an outer rim that typically had embedded magnets; as the magnets pass the pickup they induce a similar signal.

- Helical – Typically a two bladed, helically curved rimless rotor that typically also incorporate magnets.

Turbine meters have one or more pickup transducers, based on the application requirements.

The majority of designs are based on a full bore geometry (flow path through the meter is same inner diameter as the flanges). There are also designs that feature a reduced bore geometry. By reducing the measuring chamber bore, the liquid velocity (flow rate) is increased relative to the system flow rate which increases the meter rangeability.

Some meters have a double-case design, which eliminates the effect of pressure on the critical dimensions of the measuring element. This type of design also facilitates simpler maintenance, as the internals can be replaced as a unit in the field.

Refer to Annex A for more information on meter construction and signal generation via pickup transducers.

5 Installation

It is important that the line is free of debris on startup as turbine meters can be susceptible to damage or inaccuracy if struck by or contaminated with foreign matter.

As with most mechanical meters, over-speeding a turbine meter can cause damage, particularly to the bearings. For the same reason, systems should be properly purged of air/vapor prior to flowing through the meter.

Refer to the appropriate section of API *MPMS* Chapter 6 for additional recommendations and requirements related to meter installation.

Turbine meters are especially susceptible to damage from cavitation caused by insufficient back pressure. Reference section 7.2.9 of this document for more info on back pressure requirements.

5.1 Pre-Installation considerations

An appropriate strainer should be installed upstream of the meter run per manufacturer recommendation, to protect the meter and other downstream equipment from any debris that might be introduced into the stream.

Lifting – Do not lift by pickup bosses, etc. Use flanges or lugs provided, or if using slings apply slings at each end near the flanges. Avoid dropping, which can cause damage to bearings and affect performance.

Refer to the appropriate sections of API *MPMS* Chapter 6 for additional installation guidance.

5.2 Mounting

Installation shall adhere to manufacturer recommendations. Turbine meters may be mounted in either the horizontal or vertical direction if manufacturer recommendations allow.

Turbine meter performance can be affected by improper mounting, e.g. pipe strain. Pipe strain can cause deformation of the meter body or shaft misalignment through the bearings, potentially increasing drag and affecting performance. Meter installation should conform to API RP 686 regarding pipe strain and flange mounting. Also refer to the appropriate sections of ASME B.31 (B 31.3/B 31.4) for additional recommendations.

Installation shall assure that sufficient flow conditioning exists, including straight sections upstream and downstream of the meter. Reference API *MPMS* Chapter 5.1, Normative Annex A for recommendations.

5.3 Flow Direction

Metering flow in the reverse direction is not recommended. Refer to the appropriate section of API *MPMS* Chapter 6.xA for additional requirements in specific applications. Separate meter factors shall be established for both flow directions if metering in both forward and reverse directions.

Flow in vertical installations should be in the upward direction.

5.4 Flow Conditioning

The performance of turbine meters is affected by swirl and non-uniform (asymmetric) velocity profiles that can be induced by upstream and downstream piping configurations, valves, strainers, pumps, fittings, joint or gasket misalignment, welding projections, etc. Flow conditioning shall be used to mitigate the effects of swirl and non-uniform velocity profiles on turbine meter linearity or repeatability.

Refer to API *MPMS* Chapter 5.1, Normative Annex A, for general information related to flow conditioning for meters.

Research conducted by API from 2005 to 2006 using water revealed that placing a strainer immediately upstream of various flow conditioners and a 4-inch turbine meter with a multi-bladed rimless rotor can lead to shifts in meter factor due to changes in debris amount and location on the strainer screen. These shifts were significantly greater in magnitude when only a 20-diameter straight pipe flow conditioner was used. The optimal distance upstream of the turbine meter for positioning the strainer to minimize or eliminate this issue remains unknown. Therefore, using a flow conditioning element instead of just straight pipe is recommended for more effective turbine meter flow conditioning. Additionally, this research found that without a secure strainer basket positioning and locking mechanism, altering the amount and location of debris on the strainer basket screen significantly affected meter factors when using a tube bundle flow conditioning element. Subsequent tests using hydrocarbon liquids supported these findings, confirming that high-performance flow conditioners resulted in more consistent meter performance (i.e., less meter factor shift) compared to using straight pipe or tube bundles, especially when there were shifts in strainer basket position or changes in debris location.

6 Meter Performance

Meter performance is defined by how well a metering system produces, or can be made to produce, accurate quantity measurement. Refer to API *MPMS* Chapter 5.1 section on meter performance for additional details.

6.1 Meter Factor

Meter factors shall be determined by proving the meter under conditions of rate, viscosity, temperature, density, and pressure similar to those that exist during intended operation. Meter proving shall be performed in accordance with API *MPMS* Chapter 4.8.

Meter performance curves can be developed from a set of proving results. The curve in Figure 2 is called a meter linearity curve. Refer to API *MPMS* Chapter 13.2 for more information.

6.2 Influence Factors for Turbine Meters

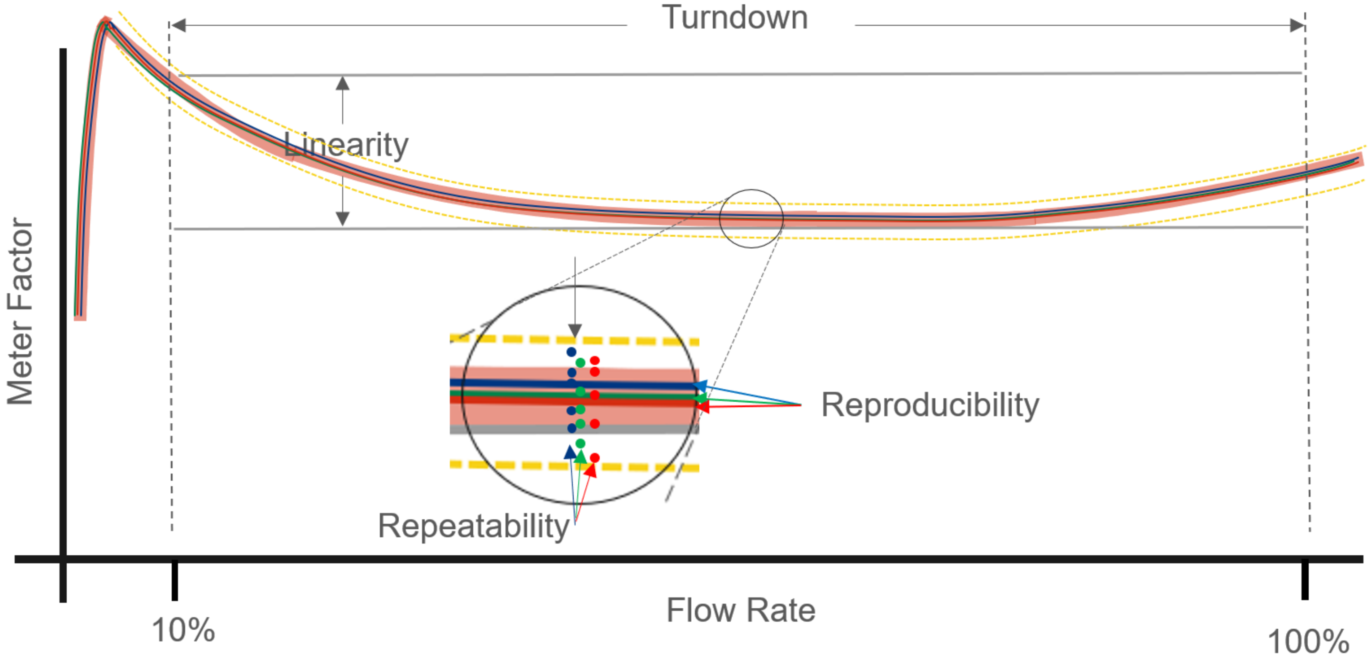
Many factors can change the performance of a turbine meter. Some, such as the entrance of foreign matter into the meter, can be remedied only by eliminating the cause. Others, such as the buildup of deposits in the meter, depend on the characteristics of the liquid being measured; these can be overcome by properly designing and operating the meter system.

Conventional, multi-bladed turbine meters perform in their most linear range when operated at Reynolds numbers (Re) above 30,000. Two-bladed helical turbine meters perform in their most linear range when operated well within the turbulent flow regime (i.e., above 10,000 Re). These meters may be operated below these ranges, assuming the performance is understood. Each turbine meter usually has a "universal performance curve", which is a plot of k-factor or meter factor versus Re. See Figure C.2. Re is basically proportional to flow rate divided by kinematic viscosity for a given size meter. Therefore, if both the flow rate and the viscosity are doubled, the k-factor or meter factor for that particular turbine meter will typically not significantly change since the Re has not changed.

The process and fluid conditions which have the greatest effect on turbine meter performance are flow rate, flow profile (particularly asymmetry and swirl), viscosity, temperature, lubricity, deposits, and foreign matter. If a meter is proved and operated on liquids with inherently identical properties (e.g., viscosity), and operating conditions (e.g., flow rate and profile), the highest level of accuracy can be anticipated. If there are changes in one or more of the liquid properties, in the operating conditions, or in the condition of the meter internals between the proving and operating cycles, a change in meter factor could result and a new meter factor should be determined by proving.

6.2.1 Flow Rate Changes

At the low end of the flow rate range the meter factor curve can become less linear and less repeatable than it is at the medium and higher rates (see Figure 3, Applications A and B). If a plot of meter factor versus flow rate has been developed for a particular liquid, and other variables are constant, a meter factor may be selected from the plot for flow rates within the meter's operating range; however, for greatest accuracy, the meter should be reproved at the new operating flow rate.



Meter factor = ratio of meter indicated volume to actual volume as determined by proving
Repeatability (%) = variation in individual meter factors over multiple prove runs at a given flow rate
Flow range = range from minimum specified flow rate to maximum specified rate
Turndown = flow range expressed as a ratio, e.g., portrayed turndown in chart is 10:1
Linearity (%) = variation in meter factor over the entire specified flow range *(+/-(max-min)/avg)*
Reproducibility = variation in meter factor over extended period of time (stability)

Figure 2—Characteristics of a Meter Performance Curve (Example)

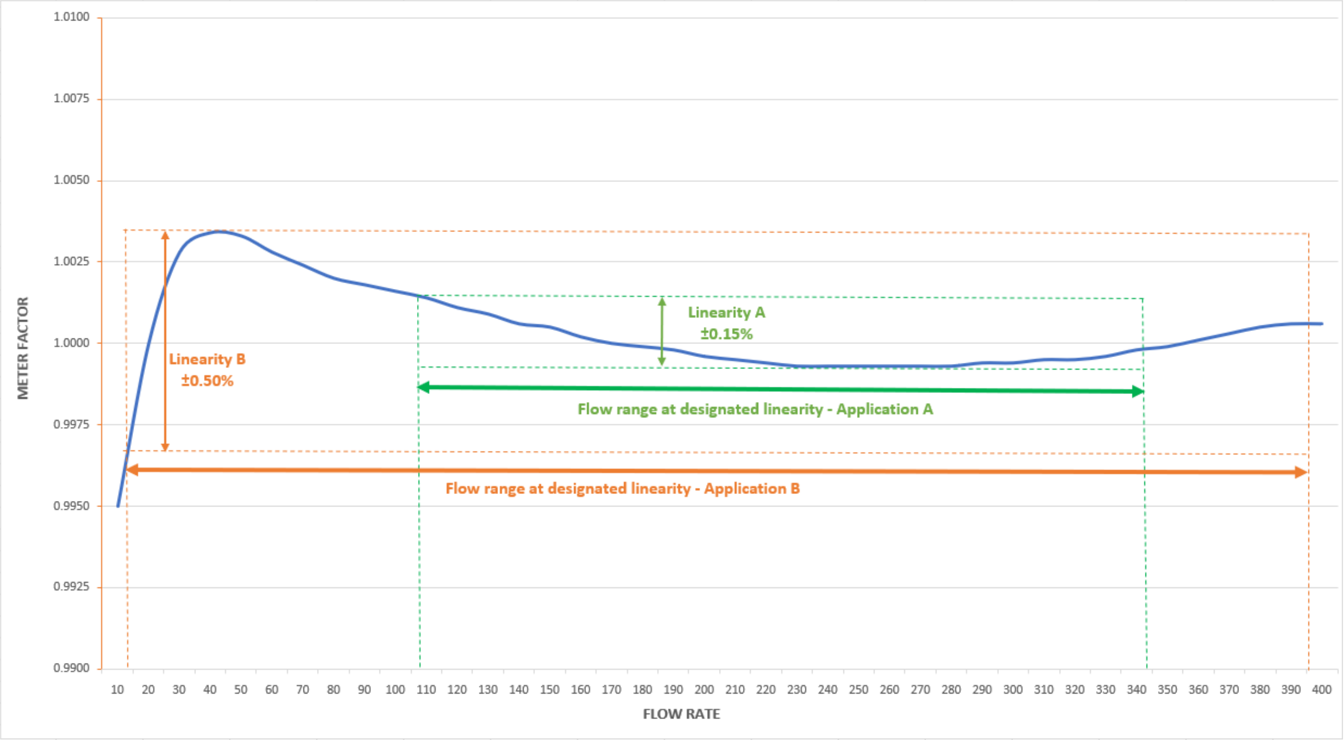


Figure 3—Conventional Turbine Meter Representative Performance Curve

NOTE This figure is illustrative only and should not be construed as representing the likely performance of any given model or size of turbine meter. The curve represents the characteristic performance of turbine meters under stable operating conditions for flow rates within the manufacturer's capacity rating.

As is evident in Figure 3, there is a tradeoff between linearity and turndown. It could be necessary to tolerate (or account and correct for) a wider linearity band in applications that require a broad range of operating flow rates. Alternately, it could be desirable to limit operating flow rates to a narrower region when possible, to assure operating conditions remain within an area of the curve with appropriately high linearity.

6.2.2 Viscosity Changes

Turbine meters are affected by variations in viscosity. Since the viscosity of liquid hydrocarbons change with temperature, the response of a turbine meter depends on both viscosity and temperature. The viscosity of light hydrocarbons such as gasoline essentially remains the same over wide temperature changes, and the meter factor remains relatively stable. In heavier, more viscous hydrocarbons such as crude oils, the change in meter factor can be significant because of the viscosity change associated with a relatively small temperature change. It is advisable to reprove the meter frequently when the viscosity of the fluid is known to vary under normal operating conditions. The performance of two-bladed helical type turbine meters is less affected by viscosity changes than conventional multi-bladed turbine meters. Helical turbine meters have been shown to operate satisfactorily at higher viscosities (i.e., at lower Re), unlike conventional multi-bladed turbine meters.

If the viscosity is being measured or is known, the Reynolds number can be calculated in real time and be used in place of flow rate to determine the meter performance index, i.e. a plot of meter factor vs. Re is used in place of meter factor vs. flow rate. This is called 'Reynolds number indexing'. The viscosity can be directly measured or calculated based on temperature of the liquid, and the viscosity is applied together with the flow rate to determine the appropriate meter factor.

See Annex C for more background information on Reynolds number indexing.

6.2.3 Temperature Changes

In addition to affecting changes in viscosity, significant variations in the temperature of the liquid can also affect meter performance by causing changes in the physical dimensions of the meter. For greatest accuracy, the meter should be proved in the range of normal operating conditions.It is possible to develop and apply a correction factor for the thermal expansion of the meter body and/or internal components (e.g., apply a correction based on a function of CTS_m) in applications where there is a significant change of operating temperatures.

Higher temperatures could partially vaporize the liquid, causing two phase flow, which will severely impair measurement performance. Two phase flow can also potentially damage the meter. See section 7.2.9 on back pressure.

Temperature device(s) and temperature thermowell(s) shall be installed in accordance with the appropriate section(s) of API *MPMS* Chapter 6 for the specific application.

NOTE Proving in situ is preferred, because of the effect of temperature on meter performance.

6.2.4 Pressure Changes

If the pressure of the liquid when it is metered varies from the pressure that existed during proving, the relative volume of the liquid will change as a result of its compressibility. The physical dimensions of the meter can also change as a result of the expansion or contraction of its housing under pressure. The potential for error increases in proportion to the difference between the proving and operating conditions. Some dual case meter designs can negate the effect of pressure on the critical dimensions of the measuring element.

6.2.5 Density Changes

The driving torque of the flowing stream on the rotor is proportional to the liquid density multiplied by the square of the liquid velocity. Therefore, a change in the observed liquid density can result in significant differences in meter factor, thereby requiring the meter to be proved. This difference is less significant with helical rotor designs. For products with lower relative density (e.g. NGLs), linearity at the the minimum flow rate could be affected negatively. The minimum flow rate to achieve satisfactory linearity will vary depending on meter size and type, and the magnitude of the change in density. Establish an acceptable new minimum flow rate by performing sufficient provings at increasing rates until arriving at a flow rate where a meter factor with acceptable linearity and repeatability can be achieved.

6.2.6 Deposits or Debris

Deposits or debris on internal components of the turbine meter, or on the flow conditioning element, can have a significant effect on meter performance. Deposits or debris on the turbine meter rotor can cause a shift in the meter performance for a given flow rate. The effect is less severe for two-bladed helical turbine meters, but could still be substantial, depending on the coating thickness and the size of the meter.

6.2.7 Impurities and Additives

In some applications, DRA can be injected into hydrocarbon flow to increase production (flow rate) for a given geometry, while significantly reducing energy losses through friction. The chemical structure and non-Newtonian behavior of these long molecular chains can impact turbine meter performance. Depending on injection location point, injected quantity, and dilution rate of the DRA into the flow, a meter factor shift can be observed, as well as a deterioration in repeatability and reproducibility. This impact should be regularly assessed through proving.

Two-bladed helical type turbine meters have shown to be less affected by DRA injection than conventional multi-bladed turbine meters.

6.2.8 Flow Profile

Turbine meters are inference meters and are affected by irregularities in the flow and by undeveloped flow profiles. Line conditions such as swirl, non-turbulent flow or pulsation can have an impact on turbine meter accuracy and repeatability. Flow conditioning shall be considered when using turbine meters. Reference API MPMS Chapter 5.1, Annex *FC* for information on proper methods for flow conditioning. Note that some turbine meters incorporate integral flow conditioning features.

6.2.9 Back Pressure Requirements for Turbine Meters

Refer to API *MPMS* Chapter 5.1 and the minimum back pressure calculation for general considerations related to back pressure requirements for meters.

Insufficient back pressure in turbine meters can cause vapor formation and/or cavitation, resulting in increased uncertainty and meter factor variations (see Figure 4). The dynamics of a turbine rotor are particularly susceptible to cavitation, as the pressure drop is focused onto a small area immediately downstream of the rotor. Cavitation can result in physical damage to the meter. Cavitation should be avoided by assuring sufficient back pressure.

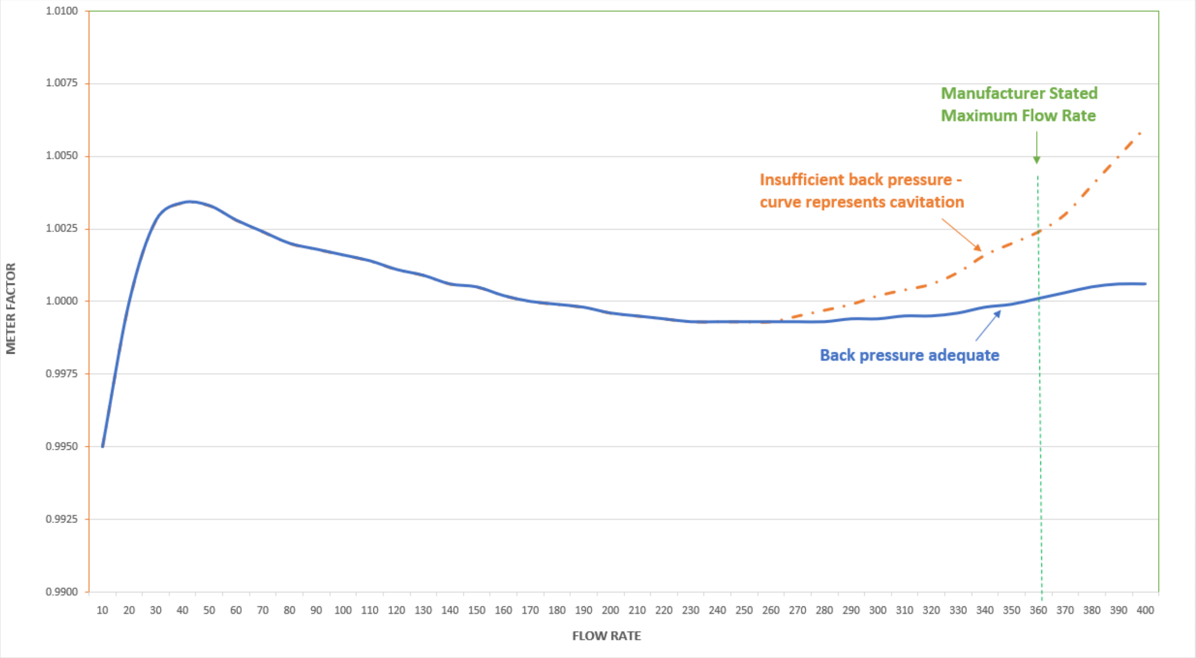


Figure 4—Effects of Cavitation on Rotor Speed

7 Accessories

<u>Preamplifier (Transmitter)</u>

Preamplifiers (or preamps) are used to boost low level magnetic pickup sinusoidal millivolt (20 to 750 mV) signals and to convert them to power supply level square wave signals. Depending on the manufacturer and the type of pickup, the recommended distance between the meter pickup and the signal processor input without a preamplifier varies

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from 20 to a maximum of 2000 feet. Typically the preamplifier is mounted directly on or in close proximity to the meter to assure integrity of the low-level signal. Check with the meter manufacturer for the maximum recommended distance without a preamplifier. Regardless of the distance, preamplifiers are recommended in electrically noisy environments. See Annex A for additional details.

Smart Preamplifier

A so called “smart” preamplifier is microprocessor-based device that in addition to traditional signal boosting and processing, also provides additional functionality such as diagnostics. For example, a smart preamplifier could detect abnormal situations such as a bent blade, bearing wear, a bad pickup coil, and meter overspeed.

Performance compensator

Some preamplifiers or separate electronic accessories provide additional features unique to turbine meters, such as resolution enhancement or viscosity compensation.

Particulary with helical turbines, due to the typical inherent low-resolution output with only two blades to generate pulses, resolution enhancement can be useful for achieving a sufficient number of pulses when proving, and for achieving higher resolution volume determination. Using a high-speed clock, it is possible to ‘manufacture’ a pulse output that represents a multiple of the observed pulses generated by the meter, effectively improving the meter resolution. Refer to API *MPMS* Chapter 4.2 for additional details.

Another type of compensation that is applied to turbine meters provides more linear operation overall when multiple liquids of varying viscosity or wide temperature ranges are encountered. Since turbine meters are affected by viscosity, correcting for this variation allows for a more linear performance curve over the application. See Annex C for details on viscosity compensation.

8 Documentation

Meter manufacturers provide test certificates including performance testing reports. Other documentation for the meter, such as electrical area classification certification, pressure ratings, hydrostatic test reports, material test reports, and welding documentation if applicable, can be provided. Refer to API MPMS Chapter 5.1 for more information on documentation requirements.

9 Commissioning and Operation

9.1 Commissioning

Commissioning requirements are dependent on the application. Refer to API *MPMS* Chapter 5.1 and to the appropriate section of API *MPMS* Chapter 6 for recommendations.

9.2 Operation

Turbine meters are mechanical devices, subject to wear or damage and hence should be proved on a regular basis. Refer to API *MPMS* Chapter 4.8 for recommendations on proving and proving frequency.

10 Field Maintenance

Field maintenance shall be performed only by qualified individuals. Maintenance shall be performed according to meter manufacturer recommendations.

In situ proving should be performed as soon as practicable after retrofit or modification of meter internal components.

Some turbine designs simplify field maintenance by providing a self-contained inner assembly (i.e., a cartridge or inner mechanism), reducing the maintenance time requirement and opportunity for error, and allowing some level of pre-determination of performance of the new replacement.

11 Security for Turbine Meters

Common seal points for turbine meter installations are the pickup mounting fittings and preamplifier and indicator housings. Programmable devices such as smart preamplifiers should be protected against unauthorized changes, via either a sealed switch that prevents changes or via an audit trail. Jurisdictional requirements vary; operators should check with the appropriate regulatory agencies for specific requirements.

Annex A

(informative)

A.1 Turbine Meter Principle of Operation

A turbine meter is essentially composed of a body, normally a section of pipe, integrating a free running rotor mounted on an axial central shaft which positions it in the center of the fluid stream, parallel to the direction of flow. One or more detection sub-assemblies are also associated with the meter body to allow the generation of pulses whose frequency is proportional to the flow through the turbine meter.

A.1.1 Rotor velocity and relationship to rate / volume

The flowing liquid causes the rotor to move with a tangential velocity proportional to the average stream velocity (which is true if the drag on the rotor—mechanical and viscous—is negligible). The average stream velocity is assumed to be proportional to the volumetric flow rate (which is true if the cross-sectional flow area through the rotor remains constant).

A.1.2 Rotor designs

Turbine meter designs can be found with a variety of rotor types. Most fall into one of the categories below.

a) Rimless (open-bladed) rotor
b) Rimmed rotor
c) Helical rotors

Open bladed and rimmed rotors could be constructed with straight or curved individual blades. Helical rotors as the name implies have a helical blade shape, and have the benefit of improved linearity with liquids of higher viscosity (e.g., > 10cSt), or in applications where there is varying viscosity.

The following figures represent typical designs of each common turbine meter rotor type.

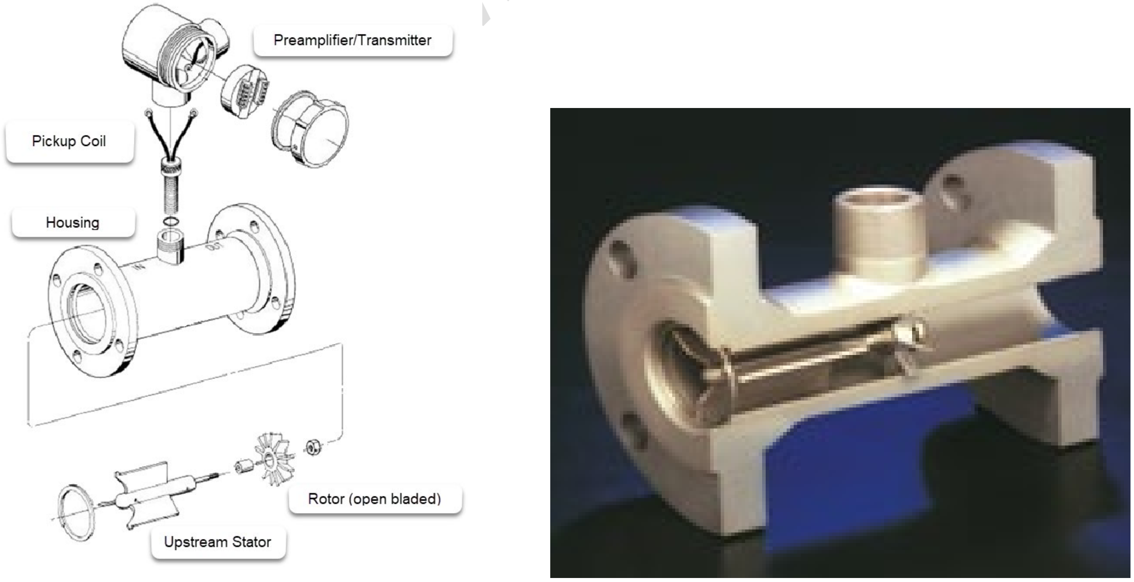

Figure A.1 Rimless (open bladed) Turbine

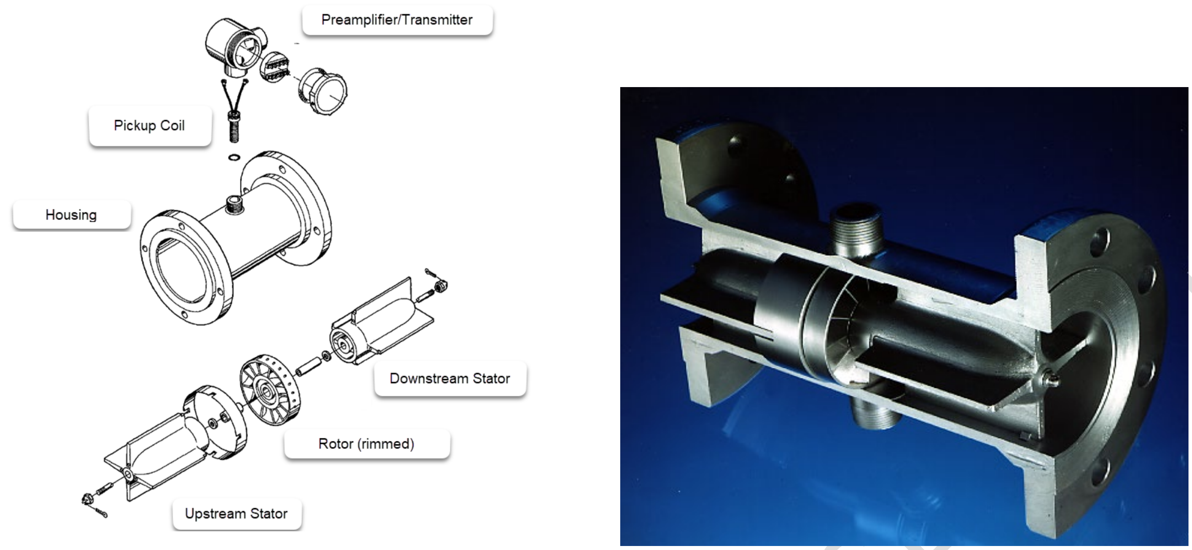

Figure A.2 Rimmed Turbine

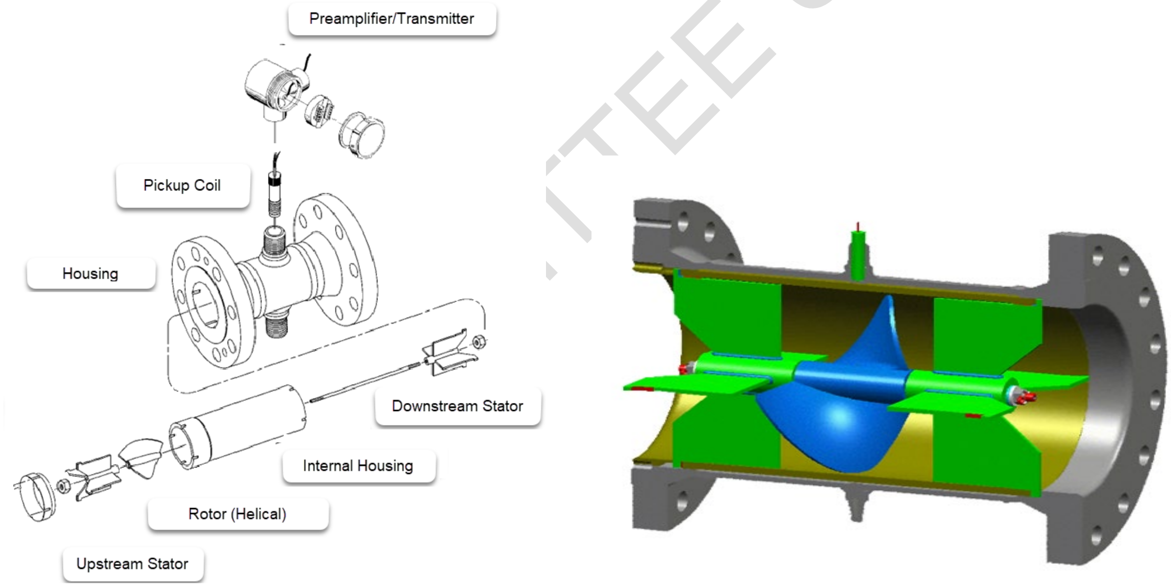

Figure A.3 Helical Turbine

A.1.3 Single case and double case designs

Some meter designs utilize a single meter body and integrated rotor mounting assembly. Others include an internal secondary housing. Benefits of a secondary housing (i.e., a double-case design) include:

a) Suppressing the effect of fluid pressure on performance (e.g. when the meter is calibrated at a different pressure than the operating conditions).
b) Reducing down time during maintenance by replacing the defective internal with a pre-calibrated cartridge.
c) Allowing multiple calibrated cartridges with different flow and/or viscosity ranges to be used within the same meter body.

A.2 Generation of Electrical Signals

The principal types of devices that produce electrical signals and are used with turbine meters are described below. Multiple pickups are commonly installed at specific phase angles to allow for pulse transmission integrity checks and flow direction determination.

A.2.1 Inductance pickup

In an inductance system, the rotating element of the turbine meter employs permanent magnets embedded in the hub or the blade tips, or attached to the rotor shaft or to a ring driven by the rotor. Regardless of the design, magnetic flux from the moving magnets induces a voltage in a pickup that is located near the magnetic field.

A.2.2 Variable reluctance pickup

In a variable reluctance system, a pickup is located on the outside of the turbine meter housing such that the rotor blade tips or rotor rim passes near the tip of the pickup. A permanent magnet, located in the pickup, produces a magnetic flux that extends into the housing. When rotation occurs, the paramagnetic blades cause a variation in the magnetic flux that produces a voltage in the pickup. A rimmed rotor utilizes paramagnetic buttons or slots to induce the variation in the magnetic flux.

A.2.3 Signal conversion and amplification

The inductance and variable reluctance systems are signal generators. Output frequency and voltage are both proportional to rotor speed. Inductance and variable reluctance systems are low power level devices because they generate only a few milliwatts of electrical power. This output is often locally pre-amplified, and in some instances shaped (e.g., converted to a square wave), at the turbine meter. The preamplifier output would then be a high-level output. Signals that have a higher amplitude are less susceptible to transmission errors because of the increased signal-to-noise ratio.

Annex B

(informative)

B.1 Determining Turbine Meter Linearity at Manufacturer Facilities

The API recommended practice for determining a performance curve for a specific turbine meter at the manufacturer facility is as follows:

a) The meter shall be tested in accordance with current API recommendations for upstream and downstream flow conditioning. If specified by the purchaser, flow conditioning as will be applied in the field should be used.

b) The liquid for proving the meter should be specified by the manufacturer and agreed to by the purchaser. The test liquid should have similar physical properties (e.g., density, viscosity, lubricity) to the liquid that will be metered in the application.

c) The proving method applied should follow one of the methods outlined in API *MPMS* Chapter 4.8.

d) The meter should be proved at a minimum of 6 points over the manufacturers' specified range to include the minimum flow rate, the maximum flow rate and 4 points between the minimum and the maximum flow rates.

e) Repeatability at each point (using either a k factor or meter factor consistently) is calculated as follows:

$$\frac{\text{Maximum factor} - \text{Minimum factor}}{\text{Minimum factor}} \times 100$$

f) Linearity over the specified range is calculated as follows:

$$\frac{\text{Maximum factor} - \text{Minimum factor}}{\text{Mean factor}} \times 100$$

The results obtained from proving a turbine meter at the manufacturer's facility should be interpreted with caution and it should not be assumed that they represent the installed performance of the meter in the field.

Annex C
(informative)

C.1 Helical Turbine Meter Performance vs. Reynolds number

Crude oil pipeline operations frequently deal with multiple liquids representing a wide range of physical properties. Because viscosity in particular influences turbine meter performance, it is useful to have a means of accounting for that influence. One approach to operating helical-bladed turbine meters over a wide viscosity range is to express the meter factor as a function of both flow rate and kinematic viscosity values (i.e., Reynolds number or Re), rather than a simple flow rate. By using Reynolds number rather than flow rate. meter performance can be characterized for changes in both viscosity and flow rate.

This approach is dependent on the knowing the kinematic viscosity at meter conditions, either by live measurement or by viscosity indexing (if the viscosity-temperature curve of the product has been established, we can infer line viscosity based on the temperature measurement e.g., per ASTM D341).

Note that this approach has not been effectively applied to rimmed or rimless conventional turbines.

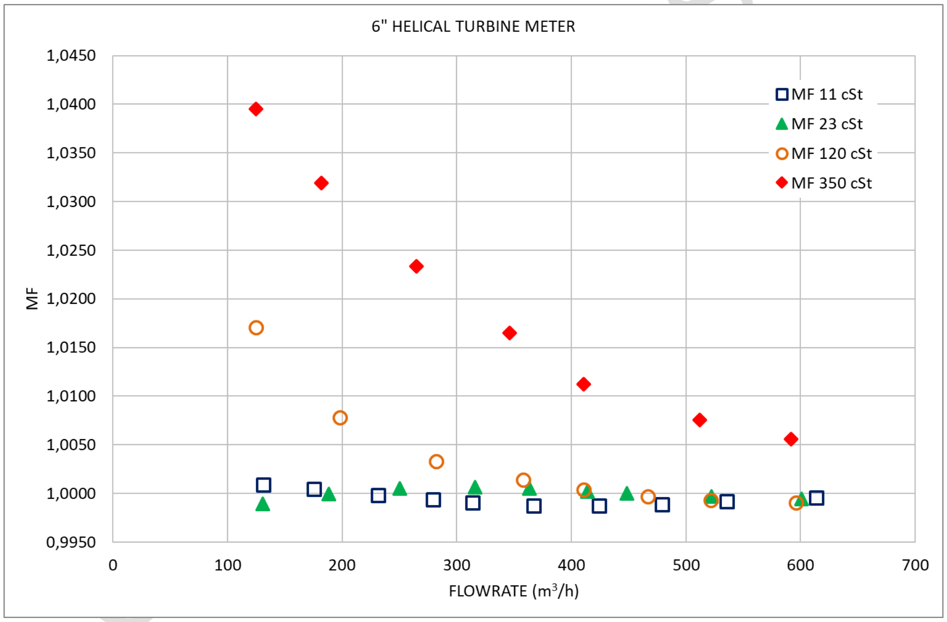

Figure C.1: Initial calibration – meter factor vs. flow rate

Once a turbine meter has been calibrated at different viscosities (i.e., with multiple products) representing the full operating range, and measurement repeatability has been demonstrated for each, the set of resulting curves can be better represented as a function of Reynolds number.

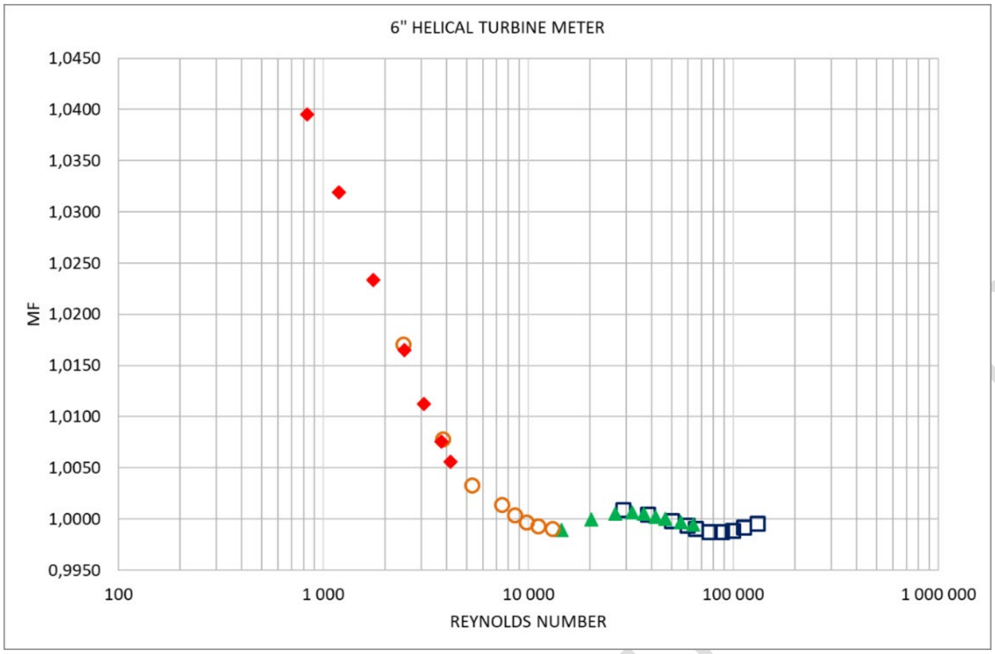

Figure C.2: Meter factor vs Reynolds number

Reynolds number is a dimensionless number that quantifies the relationship between the inertial forces of the flow stream and the viscous forces of fluid flow through the pipe carrying the flow stream. Reynolds number can be mathematically represented as follows:

$$Re = \frac{DV\rho}{\mu} = \frac{DV}{\upsilon}$$

Equation C.1: Reynolds number calculation

where

D is the diameter of the pipe.

V is the average velocity of the flow stream.

ρ is the density of the fluid.

μ is the absolute (or dynamic) viscosity of the fluid.

υ is the kinematic viscosity of the fluid.

For purposes of this discussion, it is assumed that liquid petroleum typically behaves as a Newtonian fluid where the viscosity of the fluid is unaffected by the shear rate and the shear forces that exist when the fluid is in motion through a pipe are proportional to the velocity of the fluid.

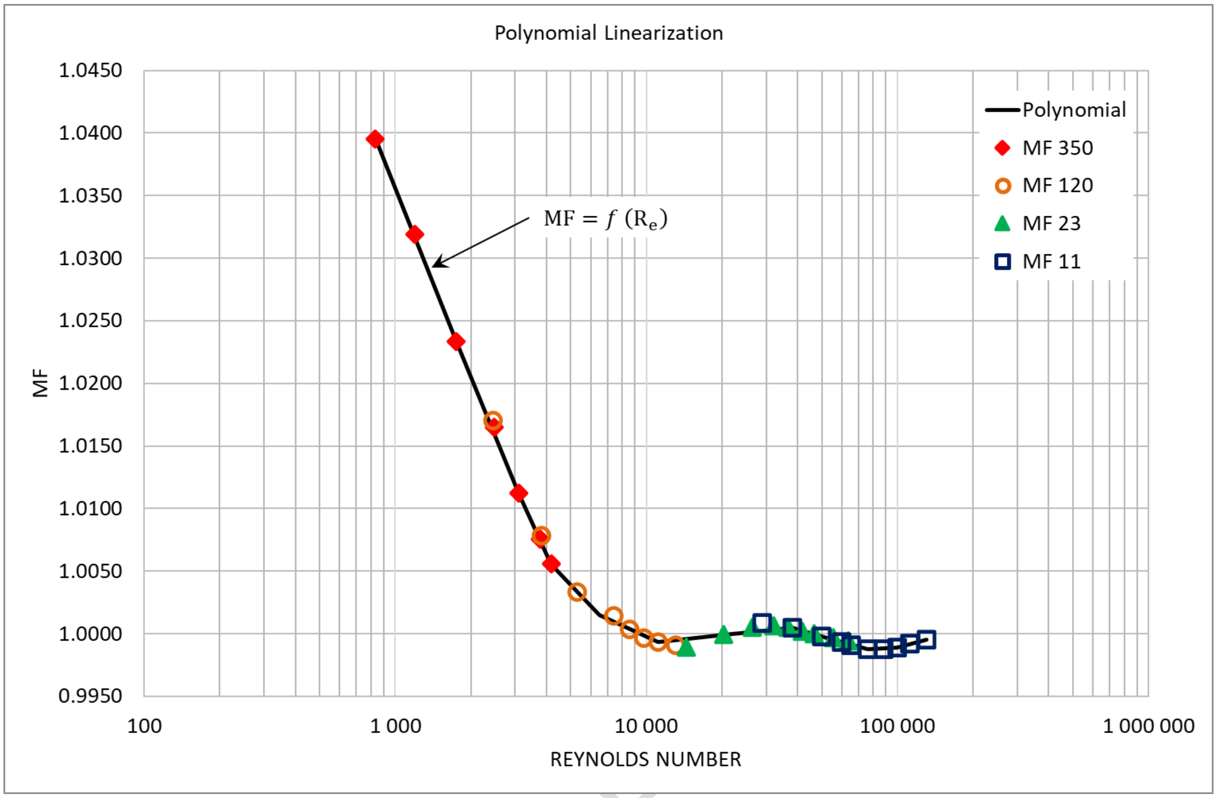

Figure C.3: Polynomial algorithm approximating performance curve

It is visually evident in Figure C.3 that the performance curve is closely related to the Reynolds number, since the individual product curves tend to align where there is overlap.

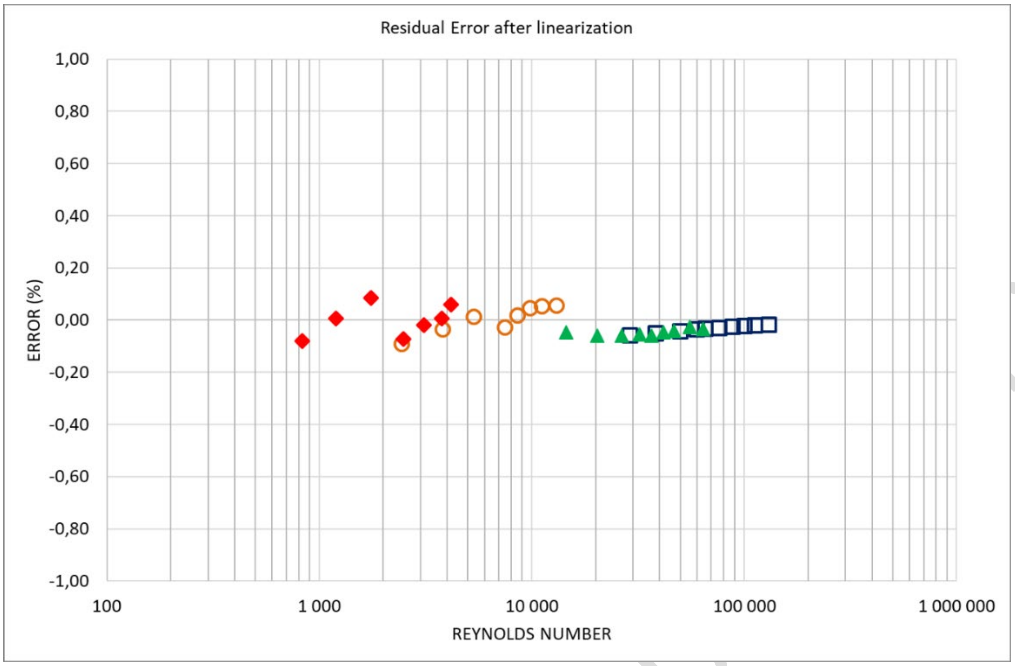

Figure C.4: Residual Error

Reynolds number indexing, compared to flow rate indexing, can provide a more reliable estimate of meter factor in applications where multiple liquids with varying viscosities might be encountered, or when the meter has been calibrated with a different liquid. It could also be useful in single product applications with a wide operating temperature range. Proving at conditions is always the preferred method for determining the appropriate meter factor, when practicable.

Bibliography

API *MPMS* Chapter 6, *Metering Assemblies*

API *MPMS* Chapter 13.2, *Methods of Evaluating Meter Proving Data*

API *RP* 686 - *Machinery Installation Design and Installation*

ASME B.31 *Code for Pressure Piping*