Manual of Petroleum Measurement Standards Chapter 5—Metering

Section 3—Measurement of Liquid Hydrocarbons by Turbine Meters

FIFTH EDITION, SEPTEMBER 2005

API
American Petroleum Institute

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Measurement Coordination Department

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FOREWORD

Chapter 5 of the API *Manual of Petroleum Measurement Standards* (API *MPMS*) provides recommendations, based on best industry practice, for the custody transfer metering of liquid hydrocarbons. The various sections of this Chapter are intended to be used in conjunction with API *MPMS* Chapter 6 to provide design criteria for custody transfer metering encountered in most aircraft, marine, pipeline, and terminal applications. The information contained in this chapter may also be applied to non-custody transfer metering.

The chapter deals with the principal types of meters currently in use: displacement meters, turbine meters and Coriolis meters. If other types of meters gain wide acceptance for the measurement of liquid hydrocarbon custody transfers, they will be included in subsequent sections of this chapter.

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Section 3—Measurement of Liquid Hydrocarbons by Turbine Meters

5.3.1 Introduction

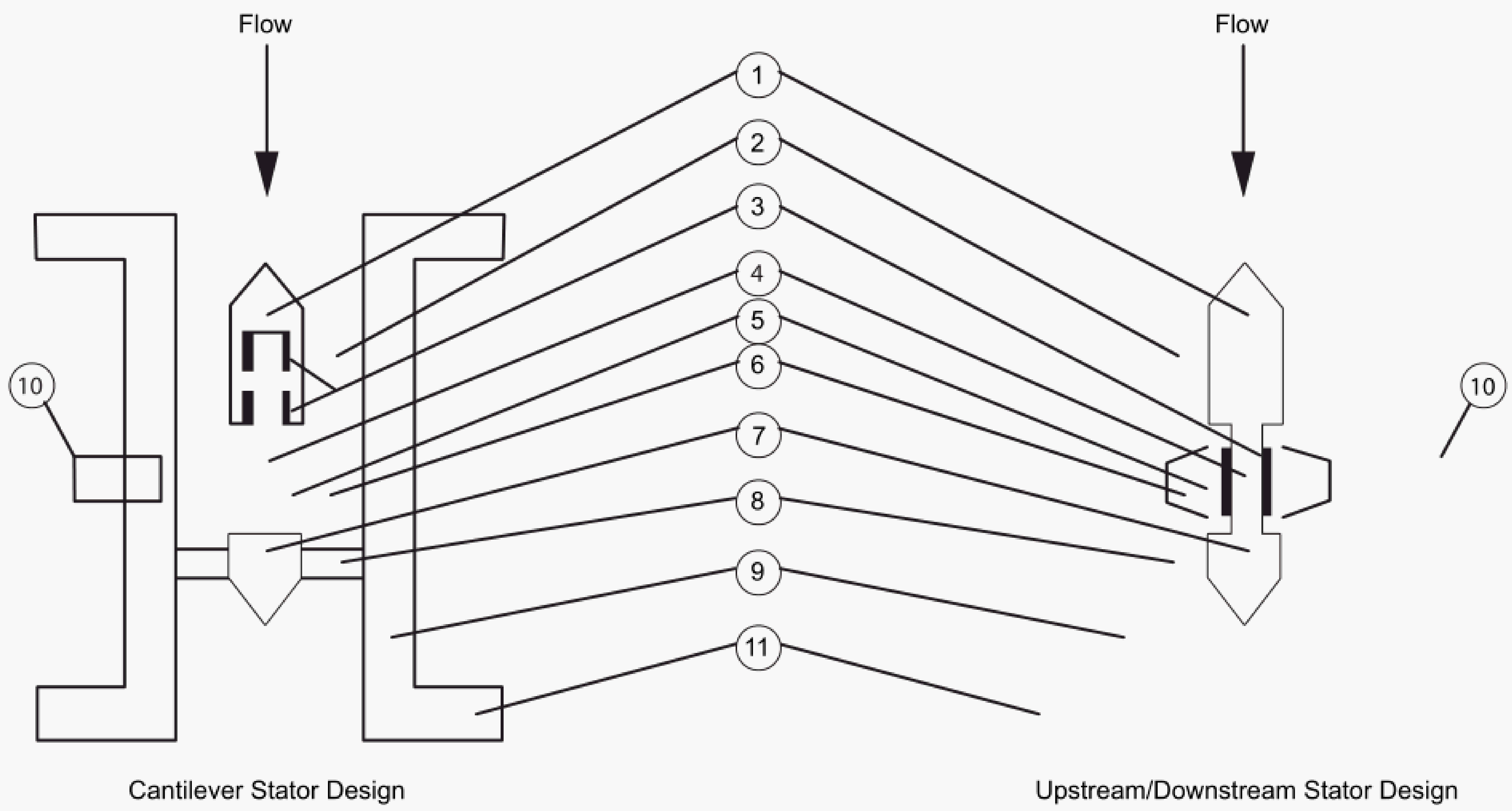
API *MPMS* Chapter 5.3, together with general considerations for measurement by meters in API *MPMS* Chapter 5.1, is intended to describe methods of obtaining accurate quantity measurements with turbine meters in liquid hydrocarbon service.

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). 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). 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.

It is recognized that meters other than the types described in Chapter 5.3 are used to meter liquid hydrocarbons. This publication does not endorse or advocate the preferential use of turbine meters, nor does it intend to restrict the development of other types of meters. Those who use other types of meters may find sections of this chapter useful.

5.3.2 Scope

This section of API *MPMS* Chapter 5 covers the unique installation requirements and performance characteristics of turbine meters in liquid-hydrocarbon service.



Notes:
1. Upstream stator.
2. Upstream stator supports.
3. Bearings.
4. Shaft.
5. Rotor hub.
6. Rotor blade.
7. Downstream stator.
8. Downstream stator supports.
9. Meter housing.
10. Pickup.
11. End corrections.

Figure 1—Names of Typical Turbine Meter Parts

5.3.3 Field of Application

The field of application of this section is all segments of the petroleum industry in which dynamic measurement of liquid hydrocarbons is required. This section does not apply to the measurement of two-phase fluids.

5.3.4 Referenced Publications

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

API
Manual of Petroleum Measurement Standards
Chapter 4, "Proving Systems"
Chapter 5.1, "General Considerations for Measurement by Meters"
Chapter 5.4, "Accessory Equipment for Liquid Meters"
Chapter 5.5, "Fidelity and Security of Flow Measurement Pulsed-Data Transmission Systems"
Chapter 7, "Temperature"
Chapter 8, "Sampling"
Chapter 11, "Physical Properties Data"
Chapter 12, "Calculation of Petroleum Quantities"
Chapter 13, "Statistical Aspects of Measuring and Sampling"

5.3.5 Flow Conditioning

5.3.5.1 The performance of turbine meters may be affected by swirl and non-uniform velocity profiles that are induced by upstream and downstream piping configurations, valves, pumps, fittings, joint misalignment, protruding gaskets, welding projections, or other obstructions. Flow conditioning shall be used to overcome the adverse effects of swirl and non-uniform velocity profiles on turbine meter performance.

5.3.5.2 Flow conditioning requires the use of sufficient lengths of straight pipe or a combination of straight pipe and flow conditioning elements that are inserted in the meter run upstream (and downstream, if flow through the meter is bidirectional) of the turbine meter (see Figure 2).

5.3.5.3 When only straight pipe is used, the liquid shear, or internal friction between the liquid and the pipe wall, shall be sufficient to accomplish the required flow conditioning. Appendix A should be referred to for guidance in applying the technique. Experience has shown that in many installations (e.g., downstream of a simple elbow or Tee) a straight pipe length of 20 meter-bore diameters upstream of the meter and 5 meter-bore diameters downstream of the meter often provides effective flow conditioning.

5.3.5.4 For severe swirl, such as generated by two close coupled elbows out-of-plane (i.e., non-symmetrical swirl) or by a header (i.e., dual symmetrical swirl), a straightening element (i.e., swirl breaker) type of flow conditioner is required. These types of swirl are slow to dissipate in straight pipe, often existing after 100+ diameters of straight pipe.

5.3.5.5 A straightening element or swirl-breaker type of flow conditioner usually consists of a cluster of tubes, vanes, or equivalent devices that are inserted longitudinally in a section of straight pipe (see Figure 2). Straightening elements effectively assist flow conditioning by eliminating swirl. Straightening elements may also consist of a series of perforated plates or wire-mesh screens, but these forms normally cause a larger pressure drop than do tubes or vanes.

5.3.5.6 Proper design and construction of the straightening element is important to ensure that swirl is not generated by the straightening element since swirl negates the function of the flow conditioner. The following guidelines are recommended to avoid the generation of swirl:

a. The cross-section should be as uniform and symmetrical as possible.
b. The design and construction should be rugged enough to resist distortion or movement at high flow rates.
c. The general internal construction should be clean and free from welding protrusions and other obstructions.

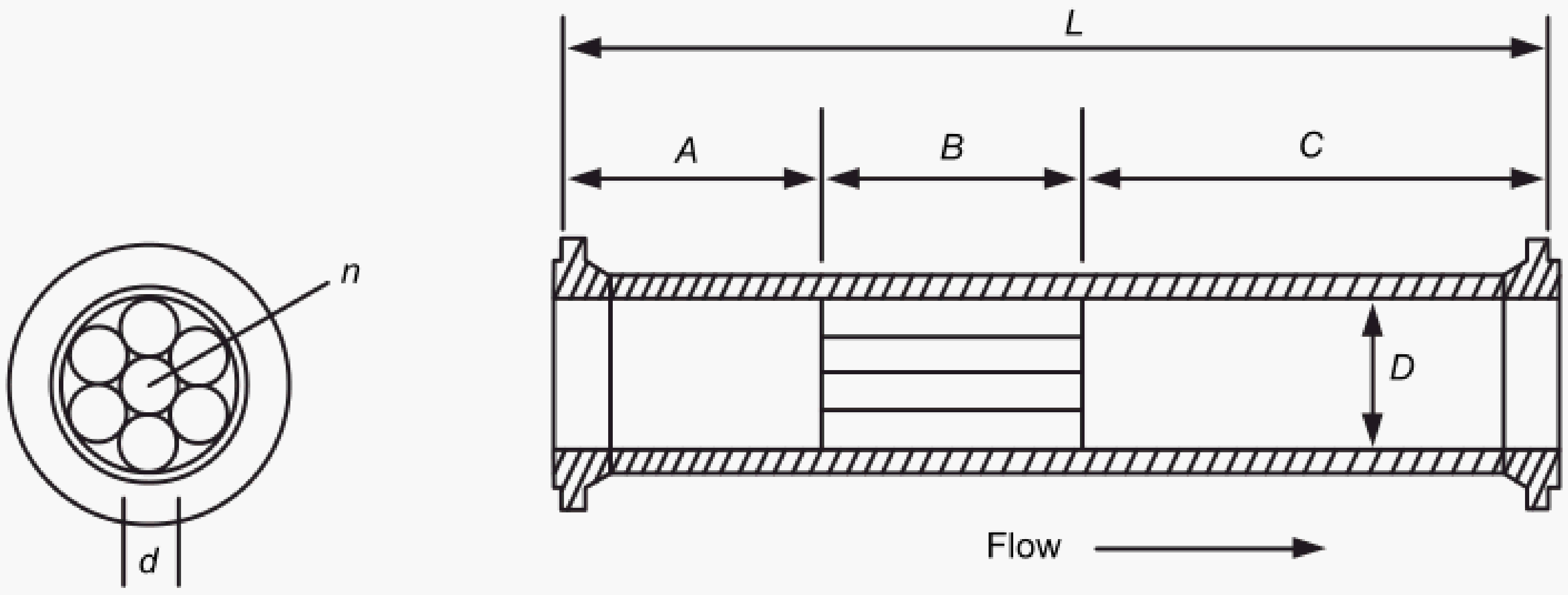
5.3.5.7 Isolating type flow conditioners, which produce a swirl-free, uniform velocity profile, independent of upstream piping configurations, are typically more sophisticated, expensive and higher pressure drop than simple straightening element type flow conditioners. However, in certain installations, they provide a performance advantage and should be considered.

5.3.5.8 Flanges and gaskets shall be internally aligned, and gaskets shall not protrude into the liquid stream. Meters and the adjoining straightening section shall be concentrically aligned.

5.3.6 Minimum Back Pressure to Prevent Cavitation

In the absence of a manufacturer's recommendation, the numerical value of the minimum back pressure at the outlet of the meter may be calculated with the following expression, which has been commonly used. The calculated back pressure has proven to be adequate in most applications, and it may be conservative for some situations.

$$P_b = 2\Delta p + 1.25 p_e$$



Note: This figure shows assemblies installed upstream of the meter. Downstream of the meter, 5*D* minimum of straight pipe should be used.

L = overall length of straightener assembly (≥ 10*D*).
A = length of upstream plenum (2*D*-3*D*).
B = length of tube of vane-type straightening element (2D-3*D*).
C = length of downstream plenum (≥ 5*D*).
D = nominal diameter of meter.
n = number of individual tubes or vanes (≥ 4).
d = nominal diameter of individual tubes (*B/d* ≥ 10).

Figure 2—Example of Flow Conditioning Assembly with Tube Type Straightening Element

where

P_b = minimum back pressure, pounds per square inch gauge (psig),

Δp = pressure drop through the meter at the maximum operating flow rate for the liquid being measured, pounds per square inch (psi),

p_e = equilibrium vapor pressure of the liquid at the operating temperature, pounds per square inch absolute (psia), (gauge pressure plus atmospheric pressure).

For higher vapor pressure liquids, it may be possible to reduce the coefficient of 1.25 to some other practical and operable margin. The recommendations of the meter manufacturer should be considered.

5.3.7 Meter Performance

Meter performance is defined by how well a metering system produces, or can be made to produce, accurate quantity measurement. See API *MPMS* Chapter 5.1.9 for additional details.

5.3.7.1 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 performance curves can be developed from a set of proving results. The curve in Figure 4 is called a meter linearity curve.

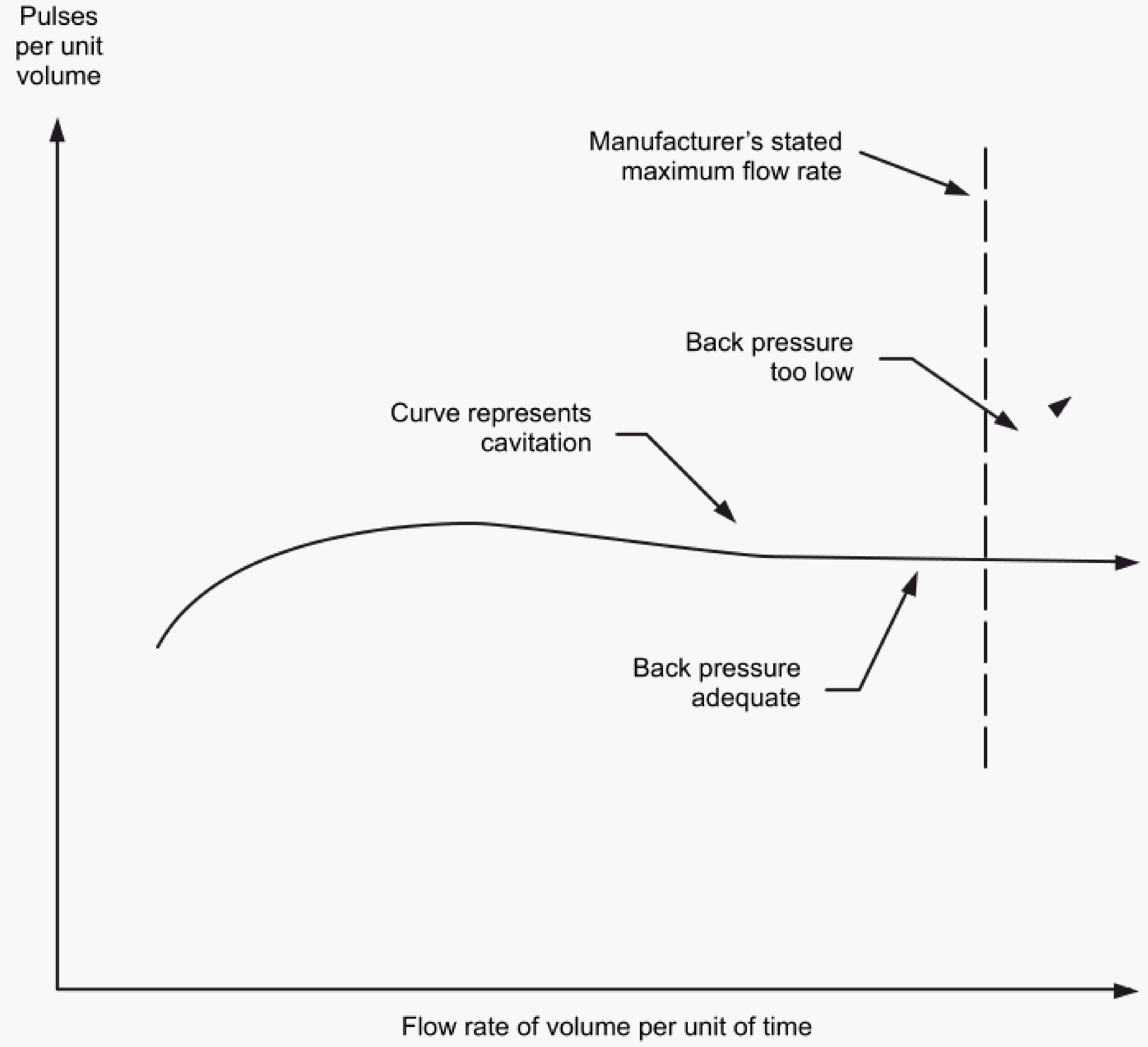
The following conditions may affect the meter performance:

a. Flow rate.
b. Viscosity of the liquid.
c. Temperature of the liquid.
d. Density of the liquid.
e. Pressure of the flowing liquid.
f. Cleanliness and lubricating qualities of the liquid.
g. Foreign material lodged in the meter or flow-conditioning element.
h. Changes in mechanical clearances or blade geometry due to wear or damage.
i. Changes in piping, valves, or valve positions that affect fluid profile or swirl.
j. Conditions of the prover (see API *MPMS* Chapter 4).

5.3.7.2 CAUSES OF VARIATIONS IN METER FACTOR

Many factors can change the performance of a turbine meter. Some factors, such as the entrance of foreign matter into the meter, can be remedied only by eliminating the cause. Other factors, such as the buildup of deposits in the meter, depend on the characteristics of the liquid being measured; these factors must 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). Each turbine meter usually has a “universal performance curve”, which is a plot



Note: All curves are for example only.

Figure 3—Effects of Cavitation on Rotor Speed

of k-factor or meter factor versus Re. See Figure 2 above. 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.

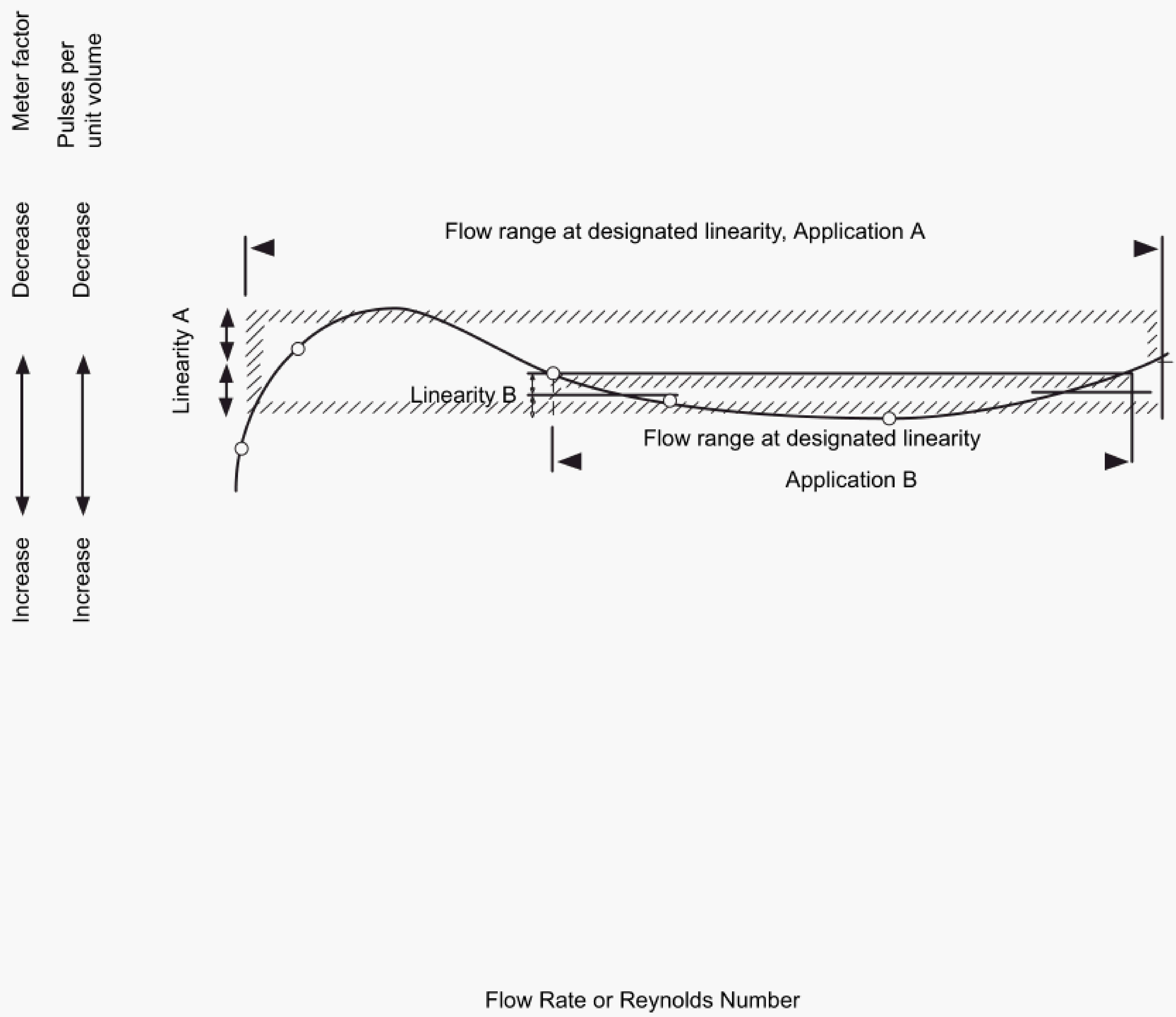
The variables which have the greatest effect on the meter factor are flow rate, viscosity, temperature, deposits, and foreign matter. If a meter is proved and operated on liquids with inherently identical properties (e.g., viscosity), and operating conditions (e.g., flow rate), the highest level of accuracy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

5.3.7.2.1 FLOW RATE CHANGES

At the low end of the flow rate range the meter factor curve may become less linear and less repeatable than it is at the medium and higher rates (see Figure 4, 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.

5.3.7.2.2 VISCOSITY CHANGES

Turbine meters are sensitive to 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 sensitive to viscosity changes than conventional multi-bladed turbine meters. Also they gener-



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 a turbine meter under stable operating conditions for flow rates within the manufacturer's capacity rating.

Figure 4—Turbine Meter Performance Characteristics

ally operate satisfactorily at higher viscosities (i.e., at lower Re) than conventional multi-bladed turbine meters.

5.3.7.2.3 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.

A calculated temperature correction based on the volume weighted average temperature of the delivery, may be used to correct indicated volume to a volume at a base or reference temperature.

5.3.7.2.4 DENSITY CHANGES

A change in the density of the metered liquid can result in significant differences in meter factor, thereby requiring the meter to be proved. For liquids with a relative density of approximately 0.7 or less, consideration must be given to raising the value of the meter's minimum flow rate to maintain linearity. The driving torque of the flowing stream on the rotor is proportional to the liquid density multiplied by the square of the liquid velocity.

The driving torque at the minimum flow rate can be maintained by increasing the minimum flow rate for low density liquids. The amount of increase in minimum flow rate will vary depending on meter size and type, and the magnitude of the change in fluid density. To establish the minimum flow rate, several provings should be made at different rates until a meter factor that yields an acceptable linearity and repeatability can be determined.

To maintain meter rangeability the maximum flow rate can also be increased, up to the limit allowed by the meter manufacturer.

5.3.7.2.5 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 will 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. For greatest accuracy, the meter should be proved at the operating conditions (see API *MPMS* Chapters 4 and 12).

Volumetric corrections for the pressure effects on liquids with vapor pressures above atmospheric pressure are referenced to the equilibrium vapor pressure of the liquid at the standard temperature, 60ºF, 15ºC, or 20ºC, rather than to atmospheric pressure, which is the typical reference for liquids with measurement temperature vapor pressures below atmospheric pressure. Both the volume of the liquid in the prover and the registered metered volume are corrected from the measurement pressure to the equivalent volumes at the equilibrium vapor pressure at the standard temperature, 60ºF, 15ºC, or 20ºC. This is a two-step calculation that involves correcting both measurement volumes to the equivalent volumes at equilibrium vapor pressure at measurement temperature. The volumes are then corrected to the equivalent volumes at the equilibrium vapor pressure at the standard temperature, 60ºF, 15ºC, or 20ºC. A detailed discussion of this calculation is included in API *MPMS* Chapter 12.2.

5.3.7.2.6 DEPOSITS OR DEBRIS

Deposits or debris on the turbine meter rotor will decrease the flow area, thereby increasing the liquid velocity, through the rotor. This will increase the rotor velocity, and thus the meter k-factor, for a given flow rate. The effect is less for two-bladed helical turbine meters, but may still be substantial, depending on the coating thickness and the size of the meter. Deposits or debris on other internal components of the turbine meter, or on the flow conditioning element, may also have a significant effect on meter performance.

APPENDIX A—FLOW CONDITIONING TECHNOLOGY WITHOUT STRAIGHTENING ELEMENTS

A.1 Scope

Effective flow conditioning can often be obtained by using adequate lengths of straight pipe upstream and downstream of the meter. Appendix A presents an empirical method for computing the length of upstream straight pipe required for various installation configurations and operating conditions. Experience has shown that a nominal length of 20 diameters of meter-bore piping upstream of the meter and 5 diameters of meter-bore piping downstream of the meter provide effective conditioning in many installations downstream of a simple elbow or tee. However, the required length of upstream piping should be verified for each installation, using the method presented in this appendix. This technique does not predict the length of straight pipe required downstream of the meter. A minimum of 5 diameters of meter-bore piping should be provided downstream of the meter unless a different length is supported by the manufacturer's recommendations or tests.

A.2 Calculation of Upstream Flow-Conditioning Length

Based on empirical data, the length of straight pipe required upstream of the meter can be calculated using Equation A-1 below:

$$L = (0.35D)(K_s/f)$$

where

L = length of upstream meter-bore piping, in feet,

D = nominal meter bore, in feet,

K_s = swirl-velocity ratio, dimensionless,

f =Darcy-Weisbach friction factor, dimensionless.

Note: During the 1984-86 review and update of API *MPMS* Chapter 5.3, First Edition, it was discovered that the friction factor, f, in Equation A-1 was incorrectly identified as the Fanning pipe friction factor. The 1984-86 working group determined, by reviewing the original technical report (found in the API files), that the factor is actually the Darcy-Weisbach friction factor.

Values of the swirl-velocity ratio, K_s, for several piping configurations are shown in Figures A-1 through A-5.

A.3 Sample Calculation

A.3.1 PROBLEM

Determine the length of straight pipe run upstream of a 6-inch turbine meter for each of the configurations shown in Figures A-1 through A-5 under the following conditions:

$$Q = 2000 \text{ gallons per minute}$$

$$\text{Viscosity}(v') = 1.9 \text{ centistokes}$$

$$D = \frac{6}{12} = 0.5 \text{ feet}$$

$$\text{Reynolds number } (R_e) = \frac{263.6Q}{Dv'}$$

$$= \frac{(263.6)(2000)}{(0.5)(1.9)}$$

$$= (5.55)(10^5)$$

$$f = 0.0175$$

Note: The value for f is for $R_e = (5.55)(10^5)$ and a relative roughness of 0.0004 for new steel pipe. The value is taken from L.F. Moody, "Friction Factors for Pipe Flow," *Transactions of the American Society of Mechanical Engineers*, November 1944, Vol. 66 p. 671.

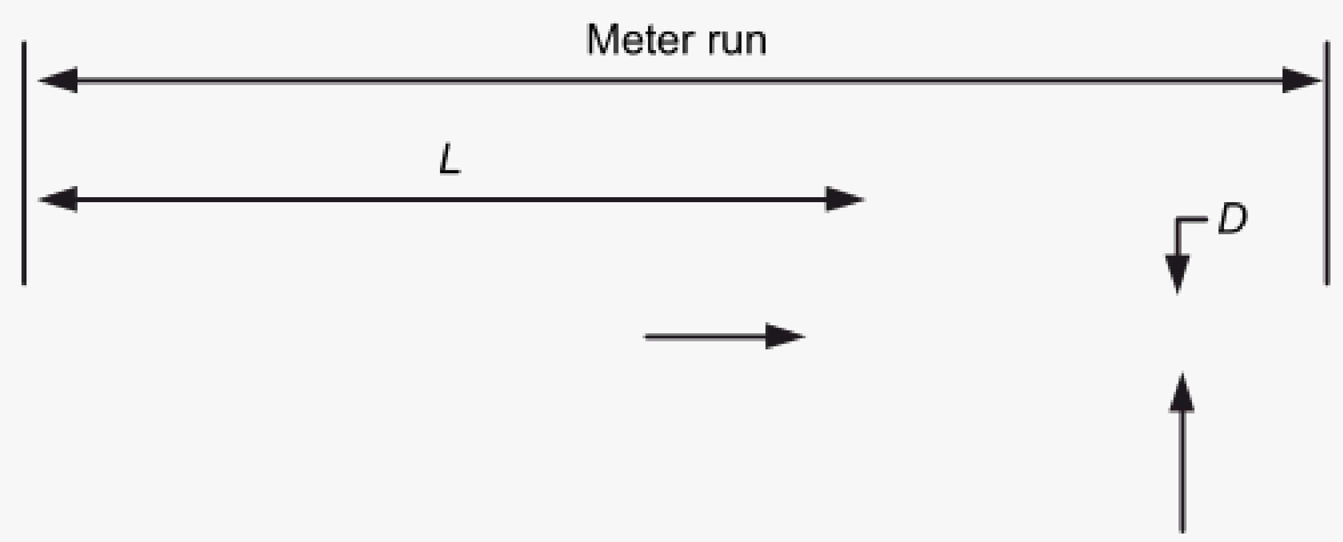


Figure A-1—Piping Configuration in Which a Concentric Reducer Precedes the Meter Run (K_s = 0.75)

A.3.2 SOLUTION

From Equation A-1,

$$L = (0.35D)(K_s/f)$$

$$L/D = (0.35)(K_s/f)$$

$$= (0.35K_s)/(0.0175)$$

$$= 20K_s$$

Table A-1—Values for L and L/D for Figures A-1 Through A-5

Figure No.	K_s	L (inches)	L/D (feet)	Ratio
A-1	0.75	90	7.5	15
A-2	1.00	120	10.0	20
A-3	1.25	150	12.5	25
A-4	Unknown			
A-5	2.50	300	25.0	50

Table A-1 lists values for L and L/D in Figures A-1 through A-5 based on $L/D = 20K_S$. Since values of K_S are treated as relative coefficients, the empirical coefficient K_S is assigned a value of 1.00 to agree with the basic recommendation of 20 diameters of straight pipe for the average installation downstream of a simple elbow.

A.4 Conclusions

The L/D ratio is inversely proportional to the pipe friction factor, f, and directly proportional to the swirl-velocity ratio, K_S.

Since $1/f$ is minimum for conditions of maximum pipe roughness for any given Reynolds number in the region of turbulent flow, the best flow conditioning for a minimum length of straight pipe occurs with a pipe of maximum roughness.

Equation A-1 is the result of grouping many relatively indefinable conditions in the flow stream and should therefore not be considered a rigorous presentation. However, the simplicity of the equation and its ability to provide answers commensurate with experience suggest that it can be used reliably.

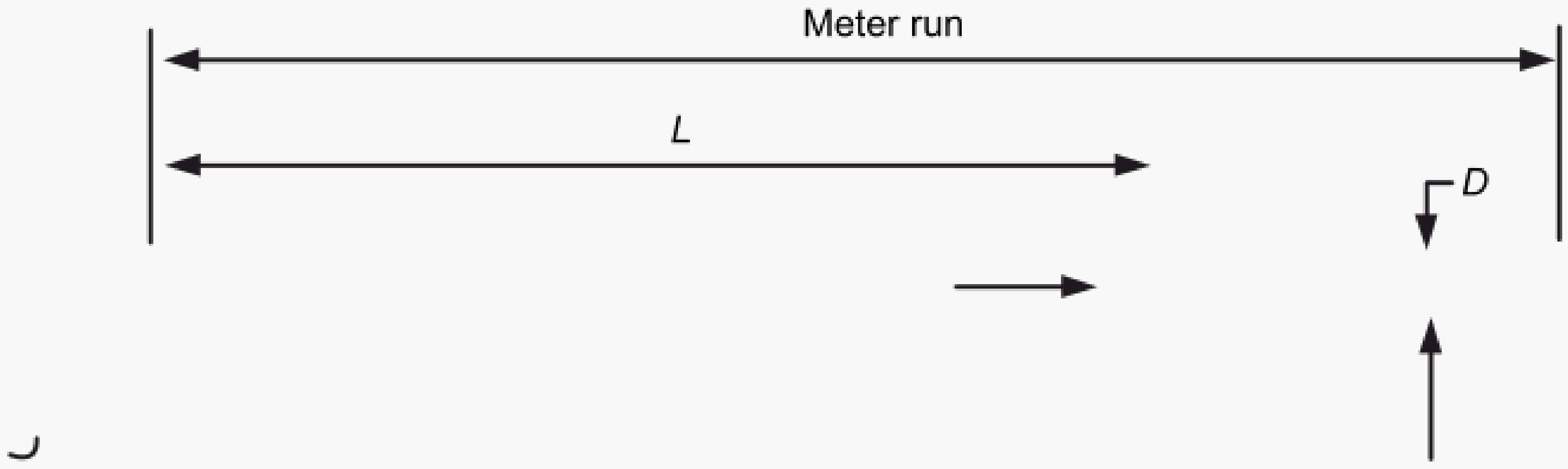


Figure A-2—Piping Configuration in Which a Sweeping Elbow Precedes the Meter Run (K_S = 1.0)

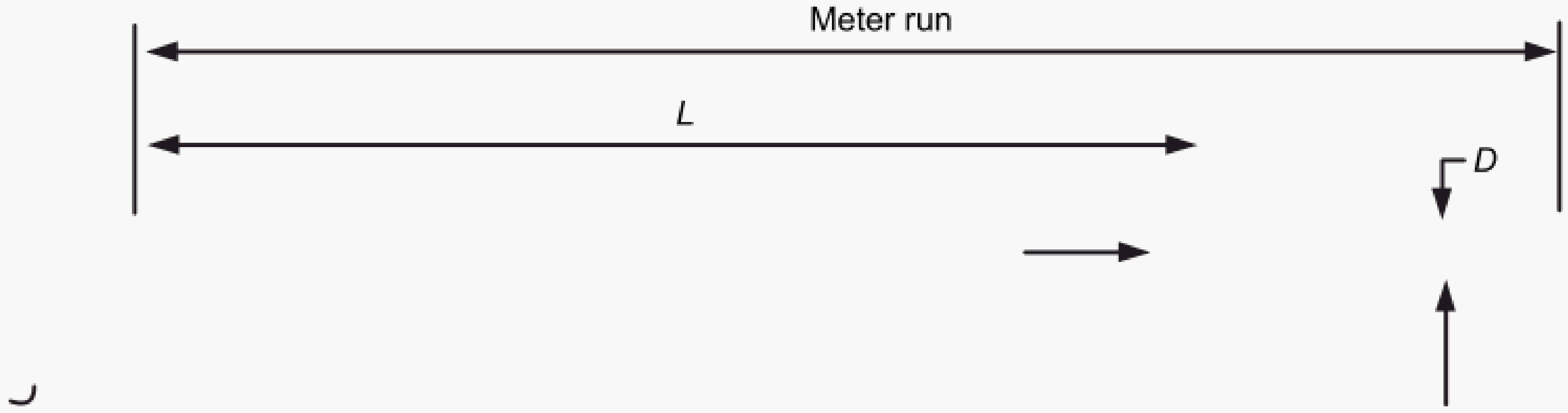


Figure A-3—Piping Configuration in Which Two Sweeping Elbows Precede the Meter Run (K_S = 1.25)

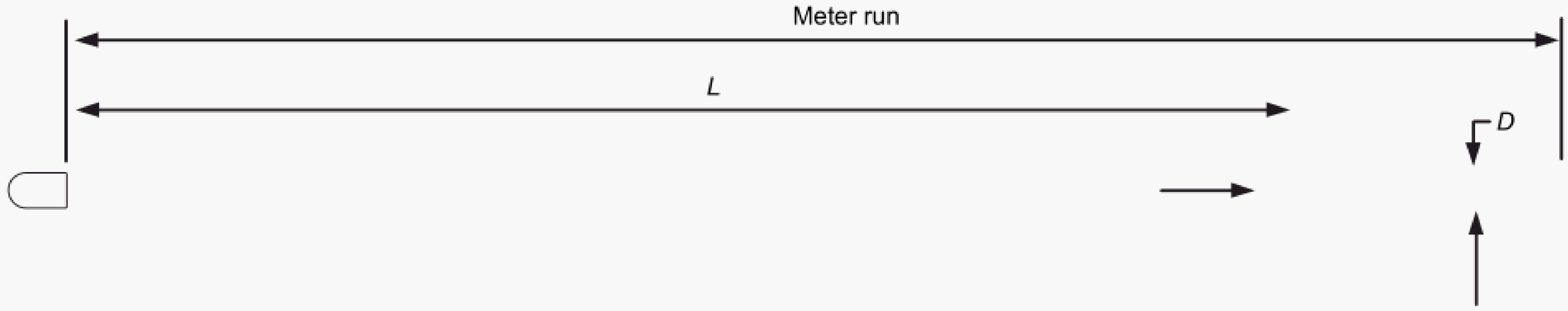


Figure A-4—Piping Configuration in Which Two Sweeping Elbows at Right Angles Precede the Meter Run (K_s = unknown)

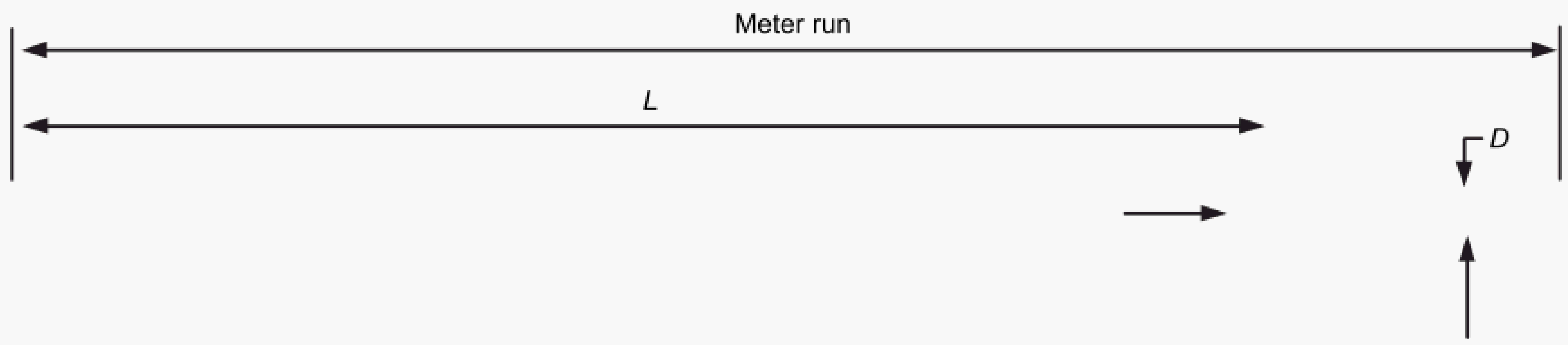


Figure A-5—Piping Configuration in Which a Valve Precedes the Meter Run (K_s = 2.50)

Note: The material presented in this appendix is based on "Factors Influencing *L*/*D* Ratio for Straight Pipe Flow Straighteners Associated With Turbine Flowmeters" by M. H. November, Engineering Report No. 65, Potter Aeronautical Corporation, (Union, New Jersey), January 4, 1967. Revision A to the report is dated February 16, 1967, and Revision B is dated February 26, 1967. According to the copies of the correspondence with Mr. November that are now on file with the API Measurement Coordination Department, many individuals, as well as a committee, reviewed this method. The material was published in API Standard 2534 (now out of print) and subsequently in API *MPMS* Chapter 5.3.

APPENDIX B—SIGNAL GENERATION

B.1 Introduction

Appendix B supplements and clarifies the information on electrical installation requirements.

B.2 Generation of Electrical Signals

The principal types of devices that produce electrical signals and are used with turbine meters are described in Sections B.2.1 and B.2.2.

B.2.1 INDUCTANCE SYSTEM

In an inductance system, the rotating element of the turbine meter employs permanent magnets that may be 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 a moving magnet induces a voltage in a pickup coil that is located near the magnetic field.

B.2.2 VARIABLE RELUCTANCE SYSTEM

In a variable reluctance system, a pickup coil 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 coil. A permanent magnet, located in the pickup coil, 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 coil. A rimmed rotor utilizes paramagnetic buttons or slots to cause the variation in the magnetic flux.

B.3 Summary

The inductance and variable reluctance systems are true generators, since both output frequency and voltage magnitude are proportional to rotor speed. The frequency of the output signal is directly proportional to rotor speed. The inductance and variable reluctance systems are low power level devices because they generate only a few milliwatts of electrical power and the signal amplitude is proportional to rotor speed.

This output may be locally amplified, and in some instances shaped, at the turbine meter. The amplifier output may then be considered a high-level output. Ideally, devices that have a high power level are less susceptible to noise problems because of the increased signal-to-noise ratio.

APPENDIX C—RECOMMENDED PRACTICE FOR PROVING TURBINE METERS AT MANUFACTURERS' FACILITIES

The API recommended practice for proving turbine meters at manufacturers' facilities is as follows:

a. The meter must be tested with the current API 5.3 recommendation for upstream, and downstream flow conditioning or flow conditioning as specified by the customer.
b. The meter is to 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 equally spaced points between the minimum and the maximum flow rates. A minimum of 2 runs per point is required. The liquid for proving the meter is to be specified by the manufacturer.
c. The data must be calculated as follows:

1. Repeatability at each point is to be calculated as follows:

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

2. Linearity over the specified range is to be calculated as follows:

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

Note: 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.

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	H05023	MPMS 5.2, Measurement of Liquid Hydrocarbons by Displacement Meters			
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