



AMERICAN NATIONAL STANDARD
FOR
MEASUREMENT OF LIQUID HYDROCARBONS
BY TURBINE METER SYSTEMS



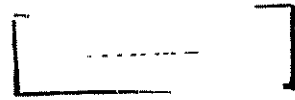
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MEASUREMENT OF LIQUID HYDROCARBONS BY TURBINE METER SYSTEMS



FOREWORD

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INTRODUCTION

This standard has been prepared as a guide for design, installation, and operation of turbine meter systems in liquid hydrocarbon service. Primary emphasis is placed on the turbine meter and its accessories, but many of the concepts and innovations described are adaptable to other devices concerned with the volumetric measurement of liquid hydrocarbons. For details of specific equipment previously documented by the American Petroleum Institute, refer to *API Standard 1101: Measurement of Petroleum Liquid Hydrocarbons by Positive Displacement Meter (ANSI Z11.170-1965)*, *API Standard 2531: Mechanical Displacement Meter Provers (ANSI Z11.171-1965)*, and *API RP 2533: Metering Viscous Hydrocarbons*.

The turbine meter has been recognized as an acceptable quantity measuring device for many years; however, its usefulness to the oil industry has become apparent only during the past decade. Improvements to the measuring element and the ever-increasing rates of flow jointly account for vigorous interest in a compact, mechanically simple, long-lived liquid meter.

The turbine meter consists of a rotor or propeller which senses the linear velocity of a flowing stream. The moving liquid imparts a rotational or tangential velocity to the rotor which is proportional to rate of flow. The movement of the rotor is detected by mechanical, optical, or electrical means and is recorded on an appropriate readout device.

Turbine meters have typical performance characteristics that are best described by meter performance curves (see Appendix A, Fig. A-1). Principal parameters, such as flow rangeability within tolerable limits of linearity and repeatability, are related to fluid properties (i.e., density, viscosity, and vapor pressure) and to mechanical meter characteristics (i.e., rotor mass, bearing friction, magnetic drag, and wetted area relating to fluid imposed drag on the turbine or rotor).

The combination of fluid properties and mechanical meter characteristics produces a deviation from an ideal of meter linearity. Accordingly, turbine meter selection should be governed by an assessment of the characteristic curves of the proposed turbine meter.

Turbine meters selected for the noted operating criteria, when properly installed and carefully proved, will perform continuous measurement with a minimum of inaccuracy.

Mechanically, turbine meters are well able to withstand the rigors imposed by severe flow overranging accompanied by extreme flow pulsations. However, they are susceptible to damage from extraneous solids entrained in the liquid, particularly if these are of significant size, but finely divided solid particles generally pass through the meter without causing damage. In rare cases where large objects become lodged in the meter, even to the point of stalling a rotor, fluid blockage with resultant overpressurization of the system is not likely to occur.



The turbine meter system effectively measures liquid volume, but it does not offer a universal solution to every flow measurement problem — at least not at this time. This standard describes how a turbine meter system works and endeavors to give the reader a technical background to better understand the details of its operation. The descriptive material is incorporated in the appendixes of the standard. A major effort has been made to describe techniques and effects that contribute to the successful attainment of a high degree of metering accuracy and reliability within a demonstrated turbine meter system capability. Achievement of this goal is the responsibility of the equipment manufacturer; but to an even greater degree, it becomes the responsibility of the ultimate user. Should the highest level of precision be unnecessary or unjustifiable, a number of the recommendations in this standard may be compromised. Certain of the recommendations should never be ignored. Therefore, those which, if not followed, would adversely influence the satisfactory performance of a turbine meter system have included the compulsory verb form *shall*. The word *should* indicates provisions which are advisory but not required in every instance. The word *may* indicates provisions which are optional and, consequently, are at the discretion of the user.

The intent of this standard is to give the reader the most complete and comprehensive information currently available. Because of the lack of experience in a number of operational areas, revisions to this standard will be required at some time in the future.

Sufficient leeway has been incorporated into this text so that experimentation and equipment improvements may be encouraged without creating undue hardship, while at the same time a procedure may be implemented to satisfactorily deal with each new application.



MEASUREMENT OF PETROLEUM LIQUID HYDROCARBONS

BY TURBINE METER SYSTEMS

SECTION I—INSTALLATION

SCOPE

1001 This section covers the selection and installation of turbine meters, their accessories, and associated equipment.

CHOICE OF METERS AND AUXILIARY EQUIPMENT

1002 All types of measurement systems must meet certain fundamental requirements. These include accurate proving facilities; adequate protective devices such as strainers, relief valves, and air or vapor eliminators; and dependable pressure and flow controls. A further fundamental requirement is that the proving of a turbine meter should, to the greatest possible extent, duplicate the normal operating conditions of the meter.

1003 Turbine meter installations include the measuring element and its readout devices. These components of a meter system may be installed either remotely from one another or integrally.

1004 Criteria that should be considered in the selection of a meter and its auxiliary equipment are:

- a. Types of liquids the meter will measure, including viscosity, gravity ranges, vapor pressure, and corrosivity.
- b. Range of operating flow rates and type of flow — continuous or intermittent.
- c. Performance characteristics required for the application (see Appendix A, Fig. A-1).
- d. Range of operating pressures and maximum allowable pressure loss through the meter when run at the maximum anticipated flow rate.
- e. Temperature range within which meter will operate and the applicability of automatic temperature compensation.
- f. Space available for meter installation.
- g. Quantity and size of abrasive and corrosive contaminants that may be carried in the liquid stream.
- h. Types of readout devices or indicating systems to be employed and signal preamplification, if required (see Appendix A, Fig. A-2)

i. Compatibility of auxiliary meter readout equipment and flow rate indication, if included in the system; ease and method of meter registration adjustment, if desired.

j. Power supply requirements for continuous or intermittent meter readout.

k. Electrical code requirements.

l. Type and method of proving to be employed.

m. Maintenance methods and cost.

n. Class and type of end connections.

1005 Automatic temperature compensators and gravity selectors, if installed, shall be chosen to respond to operating conditions within volume and temperature measurement tolerances required (see Appendix B, Par. B-23 through B-26).

1006 Valves that may affect measurement accuracy in a measurement system shall be capable of rapid yet smooth opening and closing. They shall provide a positive shutoff and should be equipped with a telltale bleed.

1007 Any bypass around a meter or battery of meters shall be provided with a blind or a positive shutoff device equipped with a telltale bleed.

1008 Spring-loaded or self-closing valves shall be of such design that they will not open to admit air when subjected to hydraulic hammering or to vacuum conditions.

1009 For intermittent flow service, valves shall be of the fast-acting, shock-free type to minimize the adverse effects of low flow rates when starting and stopping liquid movement.

FLOW STRAIGHTENING

1010 Turbine meter performance can be affected by liquid swirl and nonuniform velocity profiles induced by upstream piping configuration, valves, pumps, joint misalignment, and welding projections, icicles, or other obstructions. For these reasons, flow straightening is an important aspect in the design of the meter run.



1011 Flow straightening is an established common practice. It is accomplished by the use of sufficient lengths of straight pipe or a combination of straight pipe and straightening vanes employed in the meter run to condition the fluid flow immediately upstream and downstream of the turbine meter.

1012 When only straight pipe is employed, the fluid shear or internal friction between the fluid and pipe wall must accomplish flow straightening. Consideration should be given to computing the upstream pipe length in accordance with Appendix C.

1013 When straight pipe with an internal element is employed in either the upstream or downstream portions of the meter run, the internal elements usually consist of a cluster of tubes, vanes, or equivalent devices inserted longitudinally in the section of straight pipe (see Appendix A, Fig. A-3). Such straightening elements effectively assist in the flow straightening and conditioning requirement. Where this type of flow straightener is used upstream of the meter, the total straightening section is approximately 10 pipe diameters long and usually incorporates an upstream mixing chamber 2 to 3 pipe diameters long ahead of the straightening vanes, a straightening vane assembly 2 to 3 pipe diameters long, and a terminal mixing chamber — immediately before entry into the meter — approximately 5 pipe diameters long. Internal element flow straighteners may also consist of a series of perforated plates or wire mesh screens to accomplish the desired results, but these forms are less commonly used.

1014 Proper design and construction of the straightening vane assembly used in an internal element flow straightening section is important to ensure that swirl shall not be generated by this assembly, thus negating the function of the entire flow straightening section. It is recommended that:

- a. Elements be manufactured from thin-wall tubing or light-gage metal vanes suitably smoothed on the leading and trailing edges.
- b. No less than four tubes or vanes be employed.
- c. In cross-section, the design be as nearly uniform and symmetrical as possible.
- d. In straightening vane assemblies constructed of tube bundles, the L/D ratio of each individual tube of the bundle be at least 10 to 1 (see Appendix A, Fig. A-3, Item d).
- e. Design and construction be sufficiently rugged to resist distortion or movement at high flow rates.
- f. Alignment of straightening elements be parallel to the pipe axis.
- g. General internal construction be clean and free of

welding icicles, burrs, and oversize weld beads.

1015 In addition to the use of flow straightening sections, there shall be a maximum separation of the meter run from pumps, elbows, valves, and other fittings which may induce swirl. Flanges and gaskets shall be internally aligned.

PIPING INSTALLATION

1016 A schematic diagram for a turbine meter in liquid hydrocarbon service is presented in Fig. I-1 to provide a working basis for the design of a turbine meter run and related equipment. Certain items may or may not be required for a particular installation.

1017 Turbine meters normally are installed in a horizontal position. The manufacturer should be consulted if space limitations dictate another attitude.

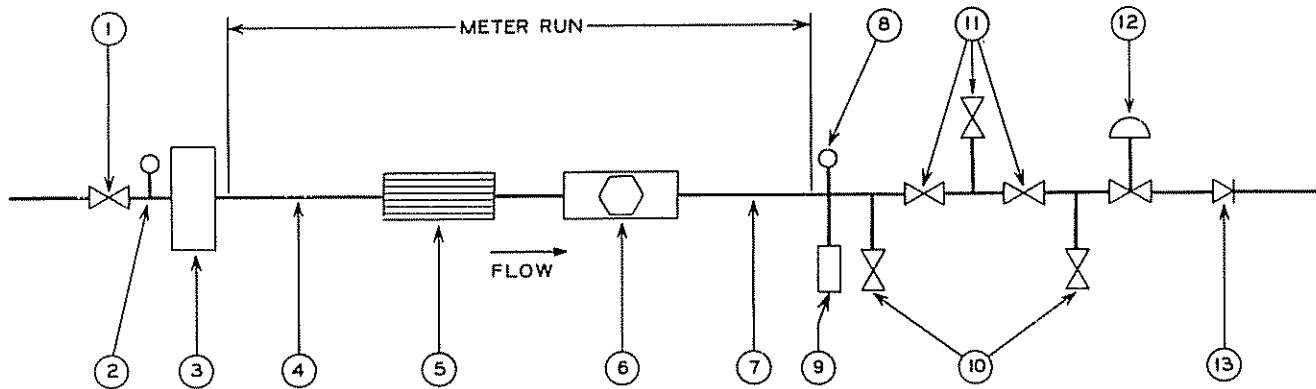
1018 Where the flow range is too great for any one meter or for its proving, the installation of a bank of meters in parallel may be used. If meters are operated in parallel, each individual meter shall be equipped with a readout device.

1019 Meters shall be installed in such a manner that they will not be subjected to undue strain and vibration. Provision should be made to minimize meter distortion caused by piping expansion and contraction.

1020 Measurement systems shall be installed in a manner which will result in maximum dependable operating life. In certain services, this requires that protective devices be installed to remove abrasive from the liquid or other entrained particles which could stop or cause premature wear of the metering mechanism. If strainers, filters, sediment traps, settling tanks, water absorbents, a combination of these items, or other suitable devices are required, they shall be sized and installed to prevent flashing of the liquid prior to its passage through the meter. These protective devices may be installed singly or in interchangeable battery form, depending on the importance of continuous service. In services where the liquid is clean or the installed meter does not require or warrant protection, elimination of protective devices may be desirable.

1021 Measurement systems shall be installed so that the meter will operate within its viscosity, pressure, temperature, and flow range.

1022 Meters shall be adequately protected from pressure pulsations and excessive surges as well as excessive pressures caused by thermal expansion of the liquid. This may require the installation of surge tanks, expansion chambers, relief valves, and/or other protective devices.



Legend:

- | | |
|--|---|
| 1. Block valve | 8. Pressure gage |
| 2. Pressure gage (optional) | 9. Thermometer |
| 3. Filter, air eliminator, and/or strainer (as required) | 10. Proving connections (should be downstream of meter run) |
| 4. Straight pipe (Appendix C) | 11. Valve with double-block and bleed or valves with a telltale bleed |
| 5. Straightening vane (as required) | 12. Control valve (as required) |
| 6. Turbine meter | 13. Check valve (as required) |
| 7. Straight pipe (with straightening vane, as required) | |

NOTE: All sections of line which may be blocked between valves should have provisions for pressure relief.

FIG. I-1--Turbine Meter System Schematic Diagram.



1023 When an automatic device, such as a flow-limiting valve or restricting orifice, is required to prevent flows in excess of the maximum rated capacity of the meter, it should be installed downstream from the meter run, whenever possible. If a pressure-reducing device is used on the inlet side of the meter, it shall be installed as far upstream from the meter run as possible. It shall be adjusted so that sufficient pressure will be maintained on the outlet side of the meter run to prevent any vaporization of the metered liquid.

1024 Any condition that tends to contribute to the release of vapor from the liquid shall be avoided by proper system design and by operation of the turbine meter within the combined rated flow range and back-pressure requirement. Flow separation and vaporization in the turbine meter are best controlled by operating the meter within the manufacturer's rated range and at a minimum back pressure, *BP*, immediately downstream of the meter, equivalent to twice the pressure drop, $\Delta P'$, across the meter at maximum flow plus 1.25 times the vapor pressure at maximum operating temperature ($BP = 2\Delta P' + 1.25$ absolute vapor pressure). Location of the meter run should determine the need for incorporating or considering a back-pressure valve or a pressure-reducing valve (see Appendix A, Fig. A-4.)

1025 Each meter shall be installed in such a manner as to prevent passage of air or vapor through it. In some cases, it may be necessary to install vapor elimination equipment ahead of the meter to accomplish this objective. When air elimination equipment is used, the air-release vents shall be adequately piped to an appropriate and safe location.

1026 Meters and piping shall be installed so that accidental drainage or vaporization of liquid is avoided. The piping shall have no high points or pockets where air or vapor might accumulate and be carried through the meter by the added turbulence resulting from increased flow rate. The entire installation shall be such that air will not be introduced into the system through holes, leaky valves, piping, glands of pump shafts, or connecting lines.

1027 Lines from the meter to the prover shall be installed so that the possibility of trapping air or vapor is minimized. This can sometimes be accomplished by sloping the meter calibration line upward to the prover. The distance between a meter and its prover should be as short as possible. The size of the connecting lines shall be large enough to prevent a significant decrease in flow rate during proving.

1028 Piping shall be designed so that the volume of liquid retained in the piping from the meter to the

point of delivery into the prover shall be the same at the end of each delivery.

1029 Special consideration should be given to locating each meter, its auxiliary equipment and piping to minimize commingling if different liquids are handled through them.

1030 Most turbine meters will register flow in both directions. When this is not desired, flow reversal should be prevented.

1031 A reliable thermometer, or a thermometer well permitting the use of a temperature-measuring device, shall be installed immediately downstream of a meter run to permit determination of metered stream temperatures. The thermometer specifications and installation details are the same as those prescribed for prover tank thermometers in API Standard 1101, Par. 2014 through 2017. If temperature-compensated meters are used, a suitable means for checking the operation of the compensating devices is required.

1032 A reliable recording or indicating pressure gage of suitable range and accuracy shall be installed in or near the inlet or outlet of every meter run where determination of the meter case pressure is required (see API Standard 1101, Par. 2018).

1033 Measurement systems shall be provided with either manual or automatic means to permit proving the meter under the same conditions of flow rate, pressure, temperature, and liquid characteristics as exist during the normal operation of the meter.

ELECTRICAL INSTALLATION

1034 Every turbine meter has the capability of producing an electrical output which may be used to operate a wide variety of readout devices. Many of the methods employed to produce this electrical signal are described and discussed in Appendix D.

1035 The output signal of a turbine meter may be considered to be a train of electrical pulses, with each pulse representing a discrete volume of liquid throughput. Two approaches have been taken to produce electrical pulses. The first method directly translates the mechanical motion of the rotor, or metering element, into electrical energy through magnetic induction. The second method requires that external electrical power be supplied to a proximity or photo-sensing device, which may be externally shaft driven, but does not actually generate electrical energy by the rotational movement of the metering element. In the first method, generally both pulse frequency and magnitude are proportional to flow rate. In the second method, only pulse frequency is proportional to

flow rate since output voltage is virtually of constant magnitude.

1036 Most electronic readout devices condition a wave form for the counting of each pulse or measure the meter output frequency for flow rate indication. Signal strength may be of a relatively low-power level; thus installation conditions should be dealt with as necessary. Recommendations described herein will be applicable to all turbine meters but will be required for low-power-level signals.

1037 A turbine meter system is composed of a minimum of three components: the meter (pulse producer), the transmission line (pulse carrier), and the readout device (pulse counter and display). It is essential that these three components be compatible with one another and that each of the components meet the recommended specifications of the turbine meter manufacturer.

1038 Every turbine meter system must meet two general requirements to operate properly. First, the readout device shall be sufficiently sensitive to respond to every pulse produced by the turbine meter throughout its operating range. Second, the signal-to-noise ratio shall be sufficiently high so that spurious electrical signals will not influence the readout device.

1039 The signal output characteristics (see Appendix A, Fig. A-1) normally associated with turbine meters and their influence upon proper system operation are:

- a. *Pulse amplitude:* Each readout device directly connected to the meter (pulse producer) must have proper sensitivity to operate with the pulse amplitudes generated over the rated operating flow range.
- b. *Pulse frequency:* The maximum frequency limit of each readout device must be equal to, or greater than, the maximum output frequency of the turbine meter at its highest expected flow rate.
- c. *Pulse width:* The duration of every pulse generated by a turbine meter must be long enough to be detected by the readout device.
- d. *Pulse shape:* A sine wave output cannot be used to operate a readout device requiring a square wave input without adding proper preamplification and shaping.

1040 Great care must be exercised in the electrical transmission installation so that signal amplitude from the turbine meter can be maintained at the highest level while reducing the magnitude of the noise signals, whenever possible. Optimum signal level is maintained by:

- a. Limiting the length of transmission line from the

meter to the readout devices.

- b. Observing the importance of proper impedance selection (see Appendix D, Par. D-10).

- c. Using the best available and technically compatible signal transmission cable (see Par. 1042).

- d. Introducing a signal preamplifier into the transmission system at the turbine meter, if transmission distance or manufacturer's requirements so dictate.

- e. Ensuring that supply voltages to preamplifiers and constant amplitude pulse generating systems are of proper magnitude and do not exceed noise level or ripple requirements as specified by the equipment manufacturer.

- f. Ensuring that all pickup coils are securely mounted and properly located.

- g. Periodically inspecting and cleaning all terminals, connectors, connector pins, and wiring junctions.

- h. Replacing components which, through deterioration, result in a weakened signal.

1041 Electrical noise may be the most troublesome element in turbine meter systems employing low-level signal outputs. Even high-level output systems require that proper steps be taken to eliminate false noise signals. Noise signals are superimposed on meter signals by three distinct methods: electromagnetic induction, electrostatic or capacitive coupling, and electrical conduction (see Appendix D).

1042 As the operation of the turbine meter system is the responsibility of the user, proper initial installation is of utmost importance. Great care must be exercised in effectively isolating the system from external electrical influences. To minimize unwanted noise signals, proper grounding and shielding of meter and proper detector transmission cables are mandatory. Major considerations are:

- a. A shielded and jacketed signal cable shall be used. The recommendation of the meter manufacturer should be followed in selecting the proper number and size of conductors, the type and material used in the shield, the outer insulation requirements, and other considerations. At a minimum, twisted two or three conductor, stranded No. 18 to No. 22 Awg, braided shield, plastic or oil-resistant rubber insulated transmission wire is suggested.

- b. The shield of the transmission cable shall be grounded only at one point to prevent the formation of a ground loop; grounding of the shield only at the readout is recommended.

- c. A continuous run of transmission cable should be



used, wherever possible. Where splices are absolutely necessary and totally unavoidable, continuity of the shield must be assured. The splice shall be wrapped with electrical tape to prevent inadvertent grounding.

d. When multiple readout devices are used and wired in parallel, shielded cable shall be used for interconnecting wiring. Grounding of each shield shall be at the same point.

e. The transmission line should be installed in a metallic conduit, wherever possible. This usually provides additional shielding against unwanted electromagnetic radiation.

f. The transmission line shall not share a conduit with anything other than shielded cables. The conduit may contain shielded cables from multiple turbine meters, detector switches operating a prover totalizer gating circuit, direct-current bridge-type temperature sensors, and the like. However, if the maximum electrical power — in terms of microwatts, milliwatts, or watts — carried by any one transmission cable is 10 or more times greater than the minimum power carried by any meter signal transmission cable, separate conduits should be provided.

g. Routing of the transmission line and conduit should not closely parallel conduits carrying power to electric motors, starters, and the like. Areas of stray electromagnetic radiation, such as motor starters and underground sump pumps, should be avoided.

h. When transmission cable is run in ducts, as well as inside control cabinets, every attempt should be made to keep the shielded cable bundle intact and separate from other conductors. When two or more transmission cables constitute a bundle, they should be twisted together so that neither transmission cable is subjected to heavy noise induction.

i. Band-pass filters and isolation transformers may be used as a method of attenuating spurious noise signals. These should be installed in accordance with the manufacturer's instructions.

j. Under conditions of extreme noise, it may be necessary to isolate the turbine meter from the piping system by installing gaskets and insulated bolt bushings and washers. This may be particularly necessary when cathodic protection rectifiers used for corrosion control are being interrupted during test periods.

k. Spare transmission cable run in a conduit with an active transmission line shall have the shield grounded at the same single point as the active line.

1043 The following formulas are suggested as a

guide for approximating maximum transmission line length for any given turbine meter system. In areas where little noise is anticipated, these formulas are considered conservative.

a. For pickup output voltage of less than 1.000 v (1,000 mv) at minimum expected flow rates:

$$\text{Transmission run length, in feet} = \frac{\text{mv (rms) output} \times 1.0 \text{ ft per mv}}{\text{mv (rms) output}}$$

b. For pickup output voltage from 1.000 v to 5.000 v (5,000 mv) at minimum expected flow rates:

$$\text{Transmission run length, in feet} = \frac{\text{mv (rms) output} \times 1.5 \text{ ft per mv}}{\text{mv (rms) output}}$$

c. For output voltages of 5 v or more, including outputs from meter-mounted preamplifiers, at minimum expected flow rates:

$$\text{Transmission run length, in feet} = \frac{\text{mv (rms) output} \times 2.0 \text{ ft per mv}}{\text{mv (rms) output}}$$

d. For frequency-modulated, wave absorption or other special pickup devices, the advice of the manufacturer should be followed.

e. In items (a) and (b) where the desired run length is greater than the values derived, it is recommended that a preamplifier be added to the transmission system. It should be mounted as close as practicable to the turbine meter.

1044 Special consideration must be given to the selection of readout devices for the turbine meter system. Initial considerations should include:

a. *Environment:* Ascertain the need for explosion-proof, weatherproof, corrosionproof, or fungusproof devices. Evaluate the high- and low-temperature extremes.

b. *Maintenance:* Provide easy access for maintenance and obtain recommended spare parts for items that have a predictable failure rate such as nixie tubes and electromechanical registers. Alternative or back-up devices and standby power supplies are suggested where continuous service is mandatory.

c. *Compatibility:* All readout devices shall be compatible with the turbine meter and the transmission system to which they are connected. In those instances where a readout device is a link in a data transmission system, special care must be taken to

assure that it has an output compatible with the data transmission system.

1045 Readout devices are available to perform a number of different functions. They should be selected to assure readout in the desired form. The limits of each individual readout device should be noted so that it may perform optimally within the turbine meter system. Readout devices may be either analog or digital. Both devices are electronic units which sense turbine meter frequency but not voltage magnitude.

1046 Analog devices are used extensively in flow rate indication, multiple stream blending, process control, and similar applications. An analog output is obtained by conversion of frequency to a proportional direct-current or voltage. The proportional direct-current output usually displayed on a visual scale may be used to drive separate control circuits. Readout may be scaled in units of flow rate, such as barrels per hour, liters per minute, or percent of flow. The overall accuracy of an analog readout device varies between 0.1 to 2.0 percent of full-scale indication.

1047 Highest precision is obtained with a digital readout device which totalizes the individual pulses produced by the turbine meter throughout an interval to an accuracy of plus or minus one count. In its simplest form, the digital readout device indicates either total pulses received or pulses received per unit time from the meter. The basic pulse counter or pulse totalizer does not necessarily display flow or volumetric units until after calculations are performed with the appropriate factors to convert the accumulated pulses into units of volume or flow rate.

1048 A variety of electronic digital readout devices are available for use with turbine meter systems. The following outline indicates the types and classes in general use and includes devices for special applications. Readout resolution will be plus or minus one indicated unit; thus, the value of this unit of registration can be of extreme importance.

A. Pulse Totalizing Counters

Those which indicate every pulse received from the turbine meter and afford the highest degree of readout resolution. They usually incorporate two or more illuminated display units. These counters may be classified as follows:

a. Prover counters: Those in which a special gating circuit in the counter is triggered by switches in the proving system to start and stop the counter.

b. Digital flow rate indicators: Those in which a gating circuit in the counter starts and stops the counter over a preselected time interval. A fixed preselected time base provides uncorrected flow rate indication; a variable preselected time interval can provide corrected digital flow rate indication, since meter, temperature, and pressure factors may be incorporated, and corrected for, in the time base.

B. Computing Counters

Those in which readout is in terms of the number of multiples or pulses received by the counter. The readout of these counters may be by means of illuminated display but is normally accomplished with an electromechanical or mechanical register which requires that the incoming pulses be divided. These counters may be classified as follows:

a. Fixed ratio computing counters: Those in which the incoming pulses are normally divided by 10, 100, 1,000, etc., so that display is 1/10, 1/100, 1/1,000, etc., of the total pulses received. Some of these units are designed to divide by a fixed number other than a multiple of 10.

b. Variable ratio computing counters: Those in which the incoming pulses are divided (or multiplied and then divided) by variable divide circuits. The divide circuits are selected manually by means of external knobs or patch boards based on turbine meter pulses per volume under specific operating conditions. The selection is made on pulses per volume or the reciprocal of pulses per volume depending on the counter manufacturer. Readout is in direct units for a specific operating condition. Such counters may incorporate the meter, temperature, and pressure corrections into the variable ratio and read out the true net volume, where desired.

c. Quantity predetermining counters: Those in which contact closure is provided after a preset quantity is delivered. Quantity may be in terms of pulses for some devices or may be in terms of volume if the device also performs the function of a variable ratio computing counter. Repeat quantity measurement and batch quantity plus total quantity measurement options are available for some units.

d. Stepper-motor-driven counters: Those in which readout is by a mechanical counter driven by a stepper motor. The stepper motor is driven by an electronic converter. The converter divides total pulse input; stepper motor revolutions are directly related to converter pulse input.



C. Add-Subtract Counters

Those which discriminate between forward and reverse flow. Increasing registration results from flow in one direction, whereas flow in the opposite direction causes the unit to subtract digits.

1049 A totalizer is usually equipped with some form of visual display and may include a printing mechanism. The most commonly used methods for translating pulse information into numerical display, within certain limitations, are as follows:

- a. *Electromechanical registers:* The first register wheel is driven by a relay and ratchet assembly; most units have a maximum counting rate of 50 counts per second. The numerals are either displayed or printed.
- b. *Stepper-motor-driven registers and ticket*

printers: Incremental rotation or a step per input pulse is used to revolve the register wheels. The numerals on the wheels can be read either directly or printed on paper.

c. *Electronic or illuminated display:* The display usually takes the form of inert-gas-filled tubes or backlighted projection units that are capable of counting at a frequency higher than that encountered in turbine meter systems. Neither unit is capable of printing, although photographic recording systems are available.

d. *Memory or storage registers:* The registers display or print information only on command. This method is used for remote inquiry and data transmission, although a visual display may appear locally in illuminated form.



SECTION II—METER PROVING PROCEDURES

SCOPE

2001 This section covers proving procedures applicable to turbine meters in liquid hydrocarbon service. Meter proving procedures stated in API Standard 1101, Sect. III, and API Standard 2531, Sect. VIII, are applicable.

2002 Either of the two types of provers, volumetric or gravimetric, described in API Standard 1101, Sect. II, can be used to prove turbine meters. However, turbine meters, particularly in larger sizes, are capable of measurement at very high flow rates; therefore reference volumes should be designed especially for such use.

2003 With the volumetric or gravimetric method, either of the following types of provers can be employed:

- a. Open provers:* Those which are open to the atmosphere through unrestricted openings.
- b. Closed provers:* Those in which a pressure greater than atmospheric is or may be maintained during the meter-proving operations.

PROVISIONS

2004 A turbine meter should be proved in its permanent installation at the expected operating rates of flow, pressure, temperature, and viscosity on the liquid which it will measure in normal operation. When a meter is used to measure more than one product or grade of crude oil, the meter shall be proved on each such product or grade of crude oil which shows a significant difference in physical properties affecting overall measurement accuracy. The meter shall be oriented in the same position during proving as during operation so that an unusual bearing load does not adversely affect the performance.

2005 Turbine meters can be proved satisfactorily by either the standing start-and-stop or the running start-and-stop method, as described in API Standard 1101, Sect. III. The standing start-and-stop method is considered less desirable; however, if used, the following precautions must be observed:

- a.* The prover volume shall be sufficient for at least 1 min of flow at the maximum anticipated flow rate.
- b.* The start-stop valve is to be opened to the proving rate in as short a time as possible, but not so quickly as to cause shock or cavitation to occur within the meter run.

c. The valve must be closed quickly but without causing shock or damage to the meter or the manifold. Reversed or oscillating flow must not occur when the valve is closed.

2006 The running start-and-stop method of proving is recommended for a turbine meter. In most applications, this method is considered the best universal technique for either the volumetric or gravimetric proving of a turbine meter.

2007 All turbine meters are capable of producing an electrical pulse output for proving. Highest readout precision is obtained with a pulse totalizing counter which accumulates the pulses generated by the meter during a proving run to within plus or minus one pulse. Such a proving counter will not necessarily readout directly into units of volume without a mathematical correction to convert indicated pulses to the units desired (see Par. 1048).

2008 For meter proving, the following points should be observed:

- a.* Prover counter shall display a minimum of five digits to within plus or minus one count.
- b.* Total count for a proving run should not be less than 10,000 discrete pulses and preferable more so that counter error of plus or minus one count will become ± 0.01 percent or less.
- c.* Input sensitivity shall be sufficient to have the capability of counting every input pulse of the amplitude generated by the meter at the proving rate.
- d.* Counter shall be equipped with a manual or electrical reset.
- e.* Prover counter shall have provisions for external start-and-stop through a gating circuit which is actuated by contact closures or equivalent. Mechanical latching relays are undesirable.
- f.* An acceptable form of pulse-doubling for a prover counter employs the technique of counting positive and negative pulses, or the equivalent, of the generated signal. Simple electronic frequency multiplication is not acceptable.

2009 The minimum proof volume should be such that a total of at least 10,000 pulses, preferably more, will be counted by a normal proving counter. Thus, if a meter produces 1,000 pulses per barrel, and a standard proving counter is used, the 10 bbl of volume



will be needed; if the same meter is used with a doubling prover counter (see Par. 2008, Item f), then not less than 5 bbl of volume will normally be satisfactory.

2010 It is suggested that a minimum of five runs be made for each proof and the results averaged. This is particularly necessary in the early life or breaking-in period of a measurement system and after an overhaul (see Sect. IV, Par. 4006). Once the performance of a measurement system has been established, check provings of less than five runs may be considered satisfactory. Maintaining system factor control charts (see Appendix B) facilitates determining what is acceptable in the matter of repeatability and sets "action limits" within which all system factors can be deemed satisfactory.

MECHANICAL DISPLACEMENT PROVERS

2011 The preferred method of proving utilizes the mechanical displacement meter prover, described in API Standard 2531, and offers the following advantages for turbine meters:

- a. Meters can be proved under actual operating conditions, at actual pressures, and on fluids which might otherwise be difficult to handle.
- b. Stable-state flow conditions may be maintained throughout the meter proving run.
- c. Time required for proving can be greatly reduced.
- d. Combined elements of meter and prover lend themselves to automatic as well as remote operation.

MASTER METER PROVERS

A. General

2012 Any meter or battery of meters having an established master factor, which is maintained whenever the master meter is relocated, may be used to prove a turbine meter by the running start-stop method (see Appendix B, Par. B-5, and B-25, Example 1). The master factor shall be established with the same liquid and under similar operating conditions as the meter to be proven. Master meter proving is less precise than proving against a known volume, and reasonable results can be obtained only if extreme care is taken to guard against experimental errors. The most commonly encountered experimental errors are:

- a. Inaccuracies in thermometry (see Appendix B), particularly when observed temperatures are

"rounded off" to the nearest degree, can introduce errors of magnitude far greater than any other likely source. Therefore, it is recommended that the master meter, or meters, and the run of the turbine meter being proven be located as close together as is practicable. When this is done, temperatures and pressures may be assumed equal for purposes of volume correlation between the master meter and meter to be proven. When it is not possible to assure that the master meter and the meter to be proven are operating under nearly identical pressure and temperature conditions, then pressure and temperature shall be observed with the greatest possible precision, and appropriate corrections made.

- b. Preferably, both master unit and meter to be proved should be equipped with prover counters connected in such a way that all counters can be started and stopped simultaneously.

- c. Master meters should be installed downstream of the meter to be proved, whenever possible. In particular, the temporary installation of a master meter upstream of the meter to be proved may adversely affect the desired long-term performance of the turbine meter system.

B. Positive Displacement Meters with Master Factors

2013 If positive displacement meters with master factors are utilized, it is suggested that the units be equipped with pulse generators, or similar devices, capable of producing a high-resolution output. When so equipped, the reference volume for proof becomes the same as that described in Par. 2009, except that the meter producing the least number of pulses per unit volume shall be used to determine the minimum required length of run.

2014 Less sophisticated methods may be used to prove a turbine meter with positive displacement meters having master factors providing the following conditions are understood and acceptable:

- a. Error resulting from reading the displacement meter register "on the fly" may cause an excessive scatter in readings.
- b. Rate changes occurring during the proving cycle may cause the turbine meter to respond more rapidly than the displacement meter, resulting in possible scatter.
- c. When a pulse generating device is not used with the positive displacement meter, the minimum run length should equal the least reading of the register times 10,000. That is, if the register can be consistently and precisely read to the nearest 1/10 bbl, the

minimum proof volume would be 1,000 bbl; if to the nearest 1/100 bbl, the proof volume would be 100 bbl. If proof runs conducted in this manner are not satisfactory, a series of runs of larger volumes should be made until repeatability is satisfactory to all parties concerned.

C. Turbine Meters with Master Factors

2015 A turbine meter with a master factor may be utilized as a proving standard provided the following precautions are observed:

- a. Both units have sufficient flow-straightening devices so that one unit does not adversely affect the performance of the other.
- b. Electronic readouts are all properly grounded at the same single point.
- c. Both counters are noise-free under zero flow and "open gate" conditions.
- d. Both counters are started and stopped by the

same initiating signal or contact closure. (Internal electronic gating circuits are recommended.)

VERIFICATION OF COUNTER REGISTRATION

2016 When a prover counter is used to determine a factor that is to be applied to a computing counter, the result of this factor as applied to, or performed by, the computing counter must be verified. This may be accomplished by operating both counters simultaneously for a period of time to assure readout resolution of one part in 10,000 for both counters. The appropriate factors to arrive at net volume for each counter are applied and these two net volumes compared. The difference between the two readout systems should be minimal and, if warranted, the cause of error should be determined and corrected. The registration of the computing counter may be verified by the proving counter. This is accomplished by gating the prover counter when it displays a nominal 10,000 pulses and by gating the checked counter when a whole digit is exactly displayed on the latter.



SECTION III—EFFECTS OF TEMPERATURE AND PRESSURE VARIATION ON METER MEASUREMENT

SCOPE

3001 This section describes the physical effects on a meter as the result of changing its internal liquid temperature or pressure, or both. These effects include mathematical corrections by which the quantity flowing through a meter may be determined for a condition of temperature and pressure other than that at which the meter was proved.

PROVISIONS

3002 Turbine meters tend to be viscosity sensitive. While for an individual meter it may be possible to develop an empirical equation whereby the meter factor at y centistokes can be computed if the meter factors are known at x and z centistokes, this cannot be done for turbine meters as a class. Although the viscosity of liquids is related to temperature, the sensitivity of turbine meters to viscosity variation implies a corresponding sensitivity to temperature changes which cannot be expressed in a quantitative way. However, the viscosity sensitivity of turbine meters is usually negligible at lower viscosities, and so for these liquids the unknown component is negligible. For these liquids, the temperature effects on turbine meters may be calculated by the methods described in this section and in Appendixes E and F.

Turbine meters also tend to be nonlinear over a flow rate range, but a general expression has not been derived to predict this deviation. As pressure changes normally result in changes in flow rate, a generally applicable expression for the pressure sensitivity of turbine meters cannot be isolated. However, the meter factor curve on low-viscosity liquids may be nearly linear over a wide range of flow rate, and in these conditions the pressure effects on turbine meters may be calculated by the methods described in this section and in Appendixes E and F.

The procedures described in this section and in Appendixes E and F are therefore applicable to turbine meters which are measuring lower viscosity liquids, but it is difficult to specify the lower viscosity limit. On light products and gasolines with a viscosity less than 1 cSt at 60 F, the procedures should predict the behavior of most turbine meters. As the liquid viscosity increases above 1 cSt at 60 F, the behavior may start to deviate because of the increasing sensitivity of the meter to viscosity and flow

rate. As deviation depends on the size and the type of meter, it is impossible to stipulate an exact viscosity range. The procedures described should be applied only after accurate measurement has been achieved and all parties to the transaction are agreeable to the procedure. *For liquids more viscous than 15 cSt at 60 F, and for all crude oils, the mathematical treatment does not apply and is not recommended. Turbine meters for these liquids should always be proved at the metering conditions.*

3003 A limited change in the temperature or pressure of the more commonly metered light, refined liquids usually does not give rise to sufficient changes in viscosity, density, lubricity, etc., to cause significant effect on turbine meter accuracy. However, this is not necessarily the case with heavier hydrocarbon liquids or lighter liquefied gases. Therefore, when metering liquids where slight changes in physical properties from temperature and pressure are known to have little effect on meter performance, and where it is necessary to operate a meter (without reproofing) at some pressure and/or temperature other than that at which the meter was proved, use of the mathematical corrections in this section will enable the maintenance of a reasonable degree of metering accuracy. The derivations of the correction factors C_{ismpe} and C_{psmpe} which follow are based on metal properties and include a number of assumptions detailed in Appendix E. Although these are logically sound, it is preferable to prove a turbine meter at conditions which are identical to its expected operating conditions, whenever possible. The use of the mathematical correction procedure to get from one set of temperature and pressure conditions to another should be employed only with the knowledge that:

1. Potential error increases as the magnitude of the difference between the proving and operating conditions increases.
2. Meter proof establishes the accuracy of the meter at the proving conditions and, in so doing, physically accounts for all variables at those conditions.

DESCRIPTION OF EFFECTS

3004 The effect of changing the flow rate, viscosity, density, lubricity, and related variables in an

operating meter cannot be conveniently expressed mathematically for all makes and sizes of meters. If only the variables temperature and pressure are isolated from those nonuniform effects, and if limited temperature and pressure changes have little or no significant effect on flow rate, viscosity, density, and so forth, it may be concluded that changing the temperature or pressure inside a meter changes only the physical dimensions of the liquid and the meter. The extent of these latter effects may be obtained from tables for the liquid and calculated for the meter. Changing the temperature of the metered liquid within a meter from that which existed during proof results in: 1, changes in the relative volume of the liquid, C_{tlm} , in accordance with *ASTM D 1250: Standard Petroleum Measurement Tables*; and, 2, changes in the physical dimensions of the meter due to ther-

mal expansion or contraction of its housing and parts, C_{tsm} , as calculated in Par. 3010 and Appendix E. Changing the pressure of the metered liquid within a meter from that which existed during proof results in: 3, changes in the relative volume of the liquid due to compressibility, C_{plm} , in accordance with API Standard 1101, Table II; and, 4, changes in the physical dimensions of the meter arising from mechanical strain of its housing due to pressure, C_{psm} , as calculated in Par. 3016 and Appendix E. Only the foregoing four effects can be expressed in proper mathematical terms to permit reasonable measurement accuracy under varying operating conditions of temperature and pressure for all meters. Even then, the reliability of this mathematical technique diminishes as the extent of temperature and pressure variations increase.

BASIC FORMULA FOR METER FACTOR

3005 Insofar as flow rate, viscosity, density, lubricity, frictional resistance, and related variables are considered, a meter factor is valid only so long as the meter is measuring under the conditions of the variables which existed when the meter was proved and for which the meter factor was established. Therefore, reference conditions of a meter factor, insofar as the variables are concerned, are based on the con-

ditions which existed when the meter was proved; the meter factor is applicable only so long as those proving conditions exist.

3006 With respect to the variables of temperature and pressure only, the reference conditions of a meter factor may be selected at any desired values. The most common technique (an alternative is described in Appendix F) uses reference conditions of temperature and pressure as follows:

Liquid temperature in the meter	= 60 F.
Liquid pressure in the meter	= pressure in meter at time of proving.
Meter housing temperature	= temperature of meter at time of proving.
Pressure in the meter housing	= pressure in meter at time of proving.

3007 The general formula for determining a meter factor having reference conditions as described in Par. 3006 is:

$$MF_{60 \& pc} = \frac{(BV) (C_{tlp60}) (C_{plpr}) (C_{tsp60}) (C_{pspr})}{(MR) (C_{tlm60}) (C_{plmpc}) (C_{tspm c}) (C_{psmpc})}$$

However, the preceding formula is greatly simplified in normal applications so that:

$$MF_{60 \& pc} = \frac{(BV) (C_{plpr}) (C_{tsp60}) (C_{pspr})}{(MR)}$$

This assumes that a turbine meter is proven:

1. Against a mechanical displacement meter prover; and
2. Operated at the conditions which existed at the time of proving.



Then, the liquid temperature in the meter is identical to that in the prover so that C_{tlp60} and C_{ilm60} have an identical mathematical value and are self-cancelling. Also, the last three factors shown in the denominator are all unity (1.0000) since they are mathematically incorporated into the meter factor for identical operating and proving conditions.

In summary, the remainder of Sect. III may be ignored if the aforementioned two conditions are met in a turbine meter installation.

NOMENCLATURE

$MF_{60 \& pc}$ = meter factor having reference conditions of temperature and pressure as follows:

Liquid temperature = 60 F.

Liquid pressure = pressure in meter at proving condition.

Meter temperature = temperature of meter at proving condition.

Meter pressure = pressure in meter at proving condition.

BV = base volume of mechanical displacement meter prover or prover tank when its internal pressure is 0 psig and its temperature is 60 F.

C_{tlp60} = correction factor for the temperature of the liquid in the prover to reduce the volume of liquid observed in or displaced from the prover at prover temperature to its equivalent volume at 60 F. To obtain C_{tlp60} , see ASTM D 1250.

C_{plpr} = correction factor for the pressure on the liquid in the prover to reduce the volume of liquid observed in or displaced from the prover at prover pressure to its equivalent volume at the reference pressure of measurement. The reference pressure of measurement for liquids having vapor pressures equal to or less than atmospheric is 0 psig. C_{plpr} is derived from the formula

$$V_l = (V_h) \left[\frac{1 - (P_l - P_e)(F)}{1 - (P_h - P_e)(F)} \right]$$

for converting a volume at a high pressure to its equivalent volume at a lower pressure (see API Standard 1101, Par. 3046). If

$$C_{plpr} = \frac{V_l}{V_h}$$

then,

$$C_{plpr} = \frac{1 - (P_r - P_e)(F)}{1 - (P_h - P_e)(F)}$$

Where:

P_r = reference pressure of measurement in pounds per square inch gage normally considered as 0 psig for liquids having vapor pressures less than atmospheric.

P_e = equilibrium pressure in pounds per square inch gage for the liquid in the prover, normally considered 0 psig for liquids having vapor pressures less than atmospheric.

- F = compressibility factor in pounds per square inch for the liquid in the prover at prover temperature from API Standard 1101, Fig. 33 or Table II.
- P_h = average pressure on liquid in the prover, in pounds per square inch gage.
- C_{tsp60} = correction factor for the temperature of the steel in the prover to reduce the base volume of the prover at 60 F to its equivalent volume at the observed prover temperature. C_{tsp60} for mechanical displacement provers is obtained from API Standard 2531, Appendix B, Table I. C_{tsp60} for prover tanks is obtained from the C_{ts} values in API Standard 1101, Par. 3045.
- C_{pspr} = correction factor for the pressure on the steel of the prover to reduce the base volume of the prover at 0 psig to its equivalent volume at the observed prover pressure. C_{pspr} for mechanical displacement provers is obtained from API Standard 2531, Appendix B, Table II. C_{pspr} for prover tanks is obtained as described in API Standard 1101, Par. 2116 through 2122. C_{pspr} for all meter provers operating at atmospheric pressure is equal to 1.0000.
- MR = meter registration, closing meter reading minus opening meter reading during a meter proof or during any measuring period.
- C_{tlm60} = correction factor for the temperature of the liquid in the meter to reduce the meter registration volume at the observed meter temperature to its equivalent volume at 60 F. C_{tlm60} is obtained from ASTM D 1250.
- C_{plmpc} = correction factor for the pressure on the liquid in the meter to reduce the meter registration volume at meter operating pressure to the equivalent volume at meter proving pressure. When a meter is being proved, the proving and operating pressure are the same and C_{plmpc} is equal to 1.0000. When a meter is operated at the pressure at which it was proved, C_{plmpc} is equal to 1.0000. C_{plmpc} is obtained by use of the following formula (see API Standard 1101, Par. 3046):

$$C_{plmpc} = \frac{1 - (P_p - P_{ep})(F_p)}{1 - (P_o - P_{eo})(F_o)}$$

Where:

- P_p = internal meter case pressure during meter proving, in pounds per square inch gage.
- P_{ep} = equilibrium pressure at proving temperature.
- F_p = compressibility factor per pounds per square inch for the liquid involved at the proving temperature from API Standard 1101, Fig. 33 or Table II.
- P_o = internal meter case pressure during meter operation, in pounds per square inch gage. When proving a meter, $P_p = P_o$.
- P_{eo} = equilibrium pressure at operating temperature. When proving a meter, $P_{ep} = P_{eo}$.
- F_o = compressibility factor per pound per square inch for the metered liquid at the operating temperature from API Standard 1101, Fig. 33 or Table II. When proving a meter, $F_p = F_o$.