Manual of Petroleum Measurement Standards

Chapter 7—Temperature Determination

FIRST EDITION, JUNE 2001

REAFFIRMED, FEBRUARY 2012

energy API®

AMERICAN PETROLEUM INSTITUTE

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FOREWORD

This forward is for information and is not part of this standard. This standard discusses equipment, methods and procedures for determining the temperature of hydrocarbon liquids under static and dynamic conditions.

This standard contains, and supersedes, information that was formally contained in the following API *Manual of Petroleum Measurement Standards* (MPMS):

- Chapter 7, Section 1, "Static temperature Determination Using Mercury-in-Glass Thermometers"
- Chapter 7, Section 2, "Dynamic Temperature Determination"
- Chapter 7, Section 3, "Static Temperature Determination Using Portable Electric Thermometers"
- Chapter 7, Section 4, "Static Temperature Determination Using Fixed Automatic Tank Thermometers"

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For the purposes of business transactions, limits on error or measurement tolerance are usually set by law, regulation, or mutual agreement between contracting parties. This publication provides guidance on tolerances that are recommended for custody transfer applications, and also describes methods by which acceptable approaches to any desired accuracy can be achieved.

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Suggested revisions are invited and should be submitted to the standardization manager, American Petroleum Institute, 1220 L Street, N.W., Washington, D.C. 20005.

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0 Introduction

The purpose of this standard is to describe methods and practices that may be used to obtain accurate measurements of temperature of petroleum and petroleum products in pipelines, storage tanks, gathering tanks, ships, barges, tank cars, pipe provers, tank provers and test measures under both static and dynamic conditions using electronic temperature measuring devices or mercury-in-glass thermometers.

1 Scope and Safety Considerations

1.1 SCOPE

This chapter describes the methods, equipment, and procedures for determining the temperature of petroleum and petroleum products under both static and dynamic conditions. This chapter discusses temperature measurement requirements in general for custody transfer, inventory control, and marine measurements. The actual method and equipment selected for temperature determination are left to the agreement of the parties involved.

Temperatures of hydrocarbon liquids under static conditions can be determined by measuring the temperature of the liquid at specific locations. Examples of static vessels are storage tanks, field gathering tanks, ships, barges, tank cars, tank provers, and test measures. Three methods are available for determining average static tank temperatures for custody transfer.

- Automatic method using fixed electronic temperature sensors.
- Manual method using portable electronic thermometers.
- Manual method using mercury-in-glass thermometers.

The automatic method covers the determination of temperature using fixed automatic tank temperature (ATT) systems for hydrocarbons having a Reid Vapor Pressure at or below 101 kPa (15 pounds per square inch absolute). ATT systems include precision temperature sensors, field-mounted transmitters for electronic signal transmission, and readout equipment.

The manual method covers:

- nonpressurized tanks and marine vessels
- blanketed tanks and marine vessels
- tanks and marine vessels that have been made inert and are under pressures of less than 21 kPa (3 pounds per square inch gauge)

It does not cover hydrocarbons under pressures in excess of 21 kPa (3 pounds per square inch gauge) or cryogenic temperature measurement, *unless the tank is equipped with a thermowell.*

Temperatures of hydrocarbon liquids under dynamic conditions can be determined by measuring the temperature of the liquid as it is flowing through a pipe. Dynamic temperature can be determined automatically or manually using electronic temperature devices or mercury-in-glass thermometers. The use of thermowells may be required in dynamic measurement to isolate the liquid material from the temperature sensor.

The requirements of this chapter are based on practices for crude oils and petroleum products covered by API *MPMS* Chapter 11.1 (ASTM D 1250). Requirements in this chapter may be used for other fluids and other applications. However, other applications may require different performance and installation specifications.

1.2 SAFETY

Safety considerations must be included in all equipment specifications, installation and operation. Refer to API RP 500, API RP 551 and NFPA 70 for guidance. When loading liquids that can accumulate static charges, refer to the precautions described in the International Safety Guide for Oil Tankers and Terminals and in API *MPMS*, Chapter 3.

2 References and Related Publications

API

Manual of Petroleum Measurement Standards

Chapter 1	“Vocabulary”
Chapter 2	“Upright Cylindrical Tanks”
Chapter 3	“Tank Gauging”
Chapter 4	“Proving Systems”
Chapter 5	“Metering Systems”
Chapter 6	“Metering Assemblies”
Chapter 11	“Physical Properties Data”
Chapter 12	“Calculations of Petroleum Quantities”
Chapter 15	“Guidelines for Use of the International System of Units (SI) in the Petroleum and Allied Industries”
Chapter 21	“Flow Measurement Using Electronic Metering Systems”
RP 500	*Recommended Practice for Classification of Locations for Electrical Installations at Petroleum Facilities Classified as Class I Division 1 and Division 2*
RP 551	*Process Measurement Instrumentation*
RP 2003	*Protection Against Ignitions Arising Out of Static, Lightening, and Stray Currents*

ASTM[1]

D 1250	*Standard Guide for Petroleum Measurement Tables*
E 1	*Standard Specification for ASTM Thermometers*
E 77	*Standard Test Method for Inspection and Verification of Thermometers*
E 344	*Terminology Relating to Thermometry and Hydrometry*

NFPA[2]

70	*National Electrical Code*

OCIMF[3]

International Safety Guide for Oil Tankers and Terminals (ISGOTT)

IMO[4]

Safety of Life at Sea (SOLAS)

3 Definition of Terms

Terms used in this chapter are defined as follows:

3.1 automatic tank thermometers (ATTs): Instruments that continuously measure temperature in storage tanks. An ATT (also known as an automatic tank temperature system) typically includes precision temperature sensors, field mounted transmitters for electronic signal transmission, and receiving/readout device(s).

- **single-point (spot) ATT:** Measures the temperature at a particular point in a storage tank where the spot temperature element is located.
- **multiple-spot ATT:** Consists of multiple (usually three or more) spot temperature elements to measure the temperature(s) at selected liquid levels in a storage tank. The readout equipment averages the submerged temperature elements to compute the average temperature of the liquid in the tank. The readout equipment may also display the temperature profile in the tank.
- **averaging ATT:** An averaging ATT may be of the following types:
  1. A multiple-spot ATT. The readout equipment selects the individual, spot temperature element(s) that are submerged in the liquid to determine the average temperature of the liquid in the tank.
  2. A variable length ATT. These ATTs consist of several temperature elements of varying length. All elements extend upwards from a position close to the bottom of the tank. The readout equipment selects the longest, completely submerged temperature element to determine the average temperature of the liquid in the tank.

3.2 Celsius scale (°C): A temperature scale with the ice point of water at 0° and the boiling point of water at 100°. The Celsius scale (°C) is the international name for the centigrade scale. [°C = 5/9 (°F – 32)].

3.3 complete-immersion thermometer: A thermometer designed to indicate temperatures correctly when the entire thermometer is exposed to the temperature being measured. No ASTM thermometer is designed to be used at complete immersion.

3.4 discrimination: The ability to sense and record the actual temperature of a liquid to the specified temperature increments.

3.5 Fahrenheit scale: A temperature scale on which the freezing point of water is 32° and the boiling point 212°, both at standard pressure. [°F = 9/5°C + 32].

3.6 field standard test measure: A portable certified vessel which is primarily used for the purpose of prover water draw calibrations.

3.7 lightning or surge: A high-energy, fast-rising voltage pulse that temporarily causes an increase in line voltage over the operating tolerances normally permitted.

3.8 partial-immersion thermometer: A thermometer designed to indicate temperatures correctly when the bulb and a specified part of the stem are exposed to the temperature being measured.

3.9 resistance temperature detector (RTD): An electrical temperature-sensing element in common use to measure the temperature of the contents of a storage tank or the contents of a pipeline.

3.10 temperature measurement device: Consists of a sensor, transmission medium, and readout equipment in an operating configuration used to determine the temperature of a liquid for measurement purposes.

3.11 temperature sensor: Consists of a sensing element and its housing, if any, and is defined as the part of a temperature device that is positioned in a liquid, the temperature of which is being measured.

3.12 temperature transmitter: A device that typically provides electrical power to the temperature element(s), converts the temperature measured by the element(s) to electrical or electronic signal, and transmits the signal to a remote readout. A local readout may be provided. Often, the function of the temperature transmitter is provided by the level transmitter of the automatic tank gauge (ATG).

[1]American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshocken, Pennsylvania 19428, USA.
[2]National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02269, USA.
[3]Oil Companies International Marine Forum, 6th Floor, Portland House, Stag Place, London SW1E 5BH, UK.
[4]International Maritime Organization, 4 Albert Embankment, London SE1 7SR, UK.

3.13 total-immersion thermometer: A liquid-in-glass thermometer designed to indicate temperatures correctly when just that portion of the thermometer containing the liquid is exposed in the temperature being measured.

3.14 transient: As used in this standard, refers to high-voltage, fast-rising, lower-energy pulses. The disturbances caused by transients usually have duration of 0.2 seconds.

4 Significance and Use

Temperature has the most significant effect on the accurate determination of liquid quantities when correcting to standard conditions for custody transfer and inventory control purposes. As a result, the most accurate means for temperature determination should be used for these applications.

The average temperature of a liquid is required to calculate its volume at a standard temperature, so it is imperative that temperatures be determined accurately.

For custody transfer, the means of temperature determination should be agreed to among the parties involved.

This standard presents both Metric (SI) and US Customary units, and may be implemented in either system of units. The presentations of both units are for convenience of the user, and are not necessarily exact conversions. The units of implementation are typically determined by contract, regulatory requirement, the manufacturer, or the user's calibration program. Once a system of units is chosen for a given application, it is not the intent of this standard to allow arbitrarily changing units within this standard.

5 Equipment and Apparatus

Many types of temperature devices are available. The temperature device used must be selected to match application requirements. Considerations should include temperature range, scale (°C or °F), response time, accuracy, discrimination, repeatability, and ambient temperature and atmospheric conditions where the device is installed. The ultimate use of the temperature data must also be considered.

Accuracy requirements, mechanical limits, operating limits, ambient conditions, and individual preferences must be considered when selecting a temperature device to be used for temperature determination on a metered stream or meter prover. In addition, the ability of the device to sense and record the actual temperature of a liquid to the specified temperature increments (temperature discrimination) must be evaluated. API *MPMS* Chapter 12 provides temperature discrimination requirements for various measurements and calculations.

The use of a temperature device that can perform to a more stringent discrimination than required in Chapter 12 is acceptable and preferred. However, the selection, installation, maintenance, operation, and calibration of such equipment must be adequate to ensure temperature-device performance to the level chosen and agreed to by all parties involved.

The operational range limits, as well as the ambient impact on the measurement accuracy of all equipment as part of a temperature measurement system shall be clearly stated and provided by the equipment manufacturer.

The following equipment and apparatus are used in temperature determination:

5.1 FIXED AUTOMATIC TANK THERMOMETERS (ATTs)

An ATT system may be used for either custody transfer or inventory control purposes. The use of an ATT system for custody transfer normally requires mutual contractual agreement between the buyer and the seller and may be subject to federal, state, or local regulations.

An ATT system typically consists of temperature element(s), fixed thermowell(s), and telemetry and readout equipment.

Most aboveground bulk storage tanks are equipped with at least one local direct-reading thermometer (described in Appendix B) mounted in a fixed thermowell. This local thermometer is not considered part of the ATT system, and it is not recommended for custody transfer temperature determination.

For custody transfer temperature measurement, local direct-reading thermometers are *not* recommended. Copper or platinum temperature element bulbs, that is, resistance temperature detectors (RTDs), are normally used for this application.

The selection of a single-point (spot), mid-level, multiple-point, or an averaging ATT should be made based on the expected tank temperature stratification and the accuracy requirements (custody transfer versus inventory control).

Safety and material compatibility precautions should be taken into consideration when using fixed ATT systems. The manufacturer's recommendations on the use and installation of the equipment should be followed. Users of fixed ATT systems should comply with all applicable codes, regulations, API standards and the National Electric Code (NEC).

5.1.1 Selection of ATTs

The selection of a suitable ATT should be made based on the following criteria:

a. The accuracy required.

b. The operating conditions which may affect the accuracy (e.g., expected tank temperature stratification).

c. The minimum level in the tank at which temperature measurement is required.

d. Environmental conditions.

e. Number, type and, size of the tanks.

f. Requirement for local and remote readout, signal transmission, and cabling.

5.1.2 Precautions

The following general precautions affect the accuracy and performance of all types of ATT systems. These precautions should be observed where they are applicable.

- All ATTs should be capable of withstanding the pressure, temperature, and other environmental conditions likely to be encountered in the designated service. When an ATT is installed in a corrosive service, any parts exposed to the liquid or vapor should be of durable, corrosion-resistant construction to avoid both product contamination and ATT corrosion. All ATTs should be sealed to withstand the vapor pressure of liquid in the tank. ATTs mounted on marine vessels with an inert gas system (IGS) should be designed to withstand the operating pressure of the IGS.
- Compatibility—To avoid both product contamination and equipment corrosion, all parts of the ATT equipment in contact with the product should be compatible with the product. The ATT equipment should be designed to meet the operating conditions.

  Note 1: This protection may require mounting the ATT sensor(s) in a thermowell.

  Note 2: ATT sensors can be an integral part of the automatic tank gauging system (ATG) level sensor assembly (e.g., float and tape, pole). Some designs (e.g., float and tape) may need the level/temperature sensor assembly to be raised to a "store" position when it is not being used. Note that such ATTs cannot be used during tank washing on marine vessels.

- All marine ATTs should be specified and installed in accordance with the appropriate National and/or International (IMO, USCG, IEC, NEC, ISGOTT, ISO, etc.) marine electrical safety standards.
- ATTs should be certified for use in the hazardous area classification appropriate to their installation.
- All external metal parts of ATTs mounted on tanks should be firmly connected to an electrical earth. This will be the ship's hull in the case of marine ATTs.
- All ATT equipment should be maintained in safe operating condition and manufacturers' maintenance instructions should be complied with.

  Note: The design and installation of ATTs may be subject to the approval of the national measurement organization and/or classification societies, who may have issued a general type approval for the design of the ATT for the particular service for which it is to be employed. Type or pattern approval is normally issued after an ATT has been subjected to a specific series of tests and is subject to the ATT being installed in an approved manner. Type approval tests may include the following: visual inspection, performance, vibration, humidity, dry heat, inclination, fluctuations in power supplies, insulation, resistance, electromagnetic compatibility, and high voltage.

- Tank Levels—Tank levels should be measured at the same time the tank temperature is measured.
- Recording Temperatures—Temperatures should be recorded as soon as they are taken, unless the remote readout of the ATT system automatically records the temperatures periodically.
- Opening and Closing Gauges—The same procedures should be used to measure a tank temperature before the product transfer (opening gauge) and after the product transfer (closing gauge).
- Sludge and Water Bottoms—The temperature elements should be located so that the temperature of any sludge deposits or water bottoms in the tank is not measured.
- Security—ATT systems should provide security to prevent unauthorized adjustment or tampering. ATT systems used in fiscal/custody transfer application should provide facilities to allow sealing for calibration adjustment.

5.1.3 Electronic Temperature Elements in ATTs

Resistance Temperature Detectors (RTD)

Copper or platinum electrical-resistance bulbs or RTDs are normally used for custody transfer temperature measurement because of their high accuracy and stability. The RTD may be a resistance wire wound on a supporting nonconductive core, a thin film type, or other type. The element should be properly encased in a stainless steel enclosure. The electronic circuits should be intrinsically safe as required. The length of the temperature sensitive portion of a single-point (spot) element should not exceed 100 millimeters (4 inches).

Other Temperature Elements

Other types of temperature elements (e.g., thermocouples, thermistors, semiconductors, etc.) are also available and may be suitable for custody transfer purposes.

5.1.4 Installation of ATTs

ATTs should be installed in accordance with the ATT and Automatic Tank Gauge (ATG) manufacturers' instructions.

5.1.4.1 Single-Point (Spot) ATTs

Single-point (spot) temperature elements should be installed close to a gauging hatch, vapor lock valve, or other suitable gauging access point. The following methods of installation are in general use:

a. Installed in a metal thermowell through the tank shell (deck for marine vessel applications), projecting at least 900 millimeters (36 inches) into the tank, at an elevation of at least 900 millimeters (36 inches) from the tank bottom.

b. Installed suspended from the tank roof in a suitable metallic or nonmetallic tube or hose secured to the tank bottom or stabilized by anchor weights. The element should be located approximately 900 millimeters (36 inches) from the tank

Table 1—Elevation of Temperature Elements

Tank Heights	Number of Elements	Element Elevation
< 9 m (30 ft)	4	1 m (3 ft), 40%, 60%, 80%
9 m (30 ft) to 15 m (50 ft)	5	1 m (3 ft), 20%, 40%, 60%, 80%
> 15 m (50 ft)	6	1 m (3 ft), 20%, 35%, 50%, 65%, 80%

Note: The number of temperature elements and the locations shown are a suggested minimum. This minimum generally meets the criteria of providing a single mid-level temperature where the oil level is 3 meters (10 feet) or less and providing an upper, middle, and lower temperature where oil levels are greater than 3 meters (10 feet).

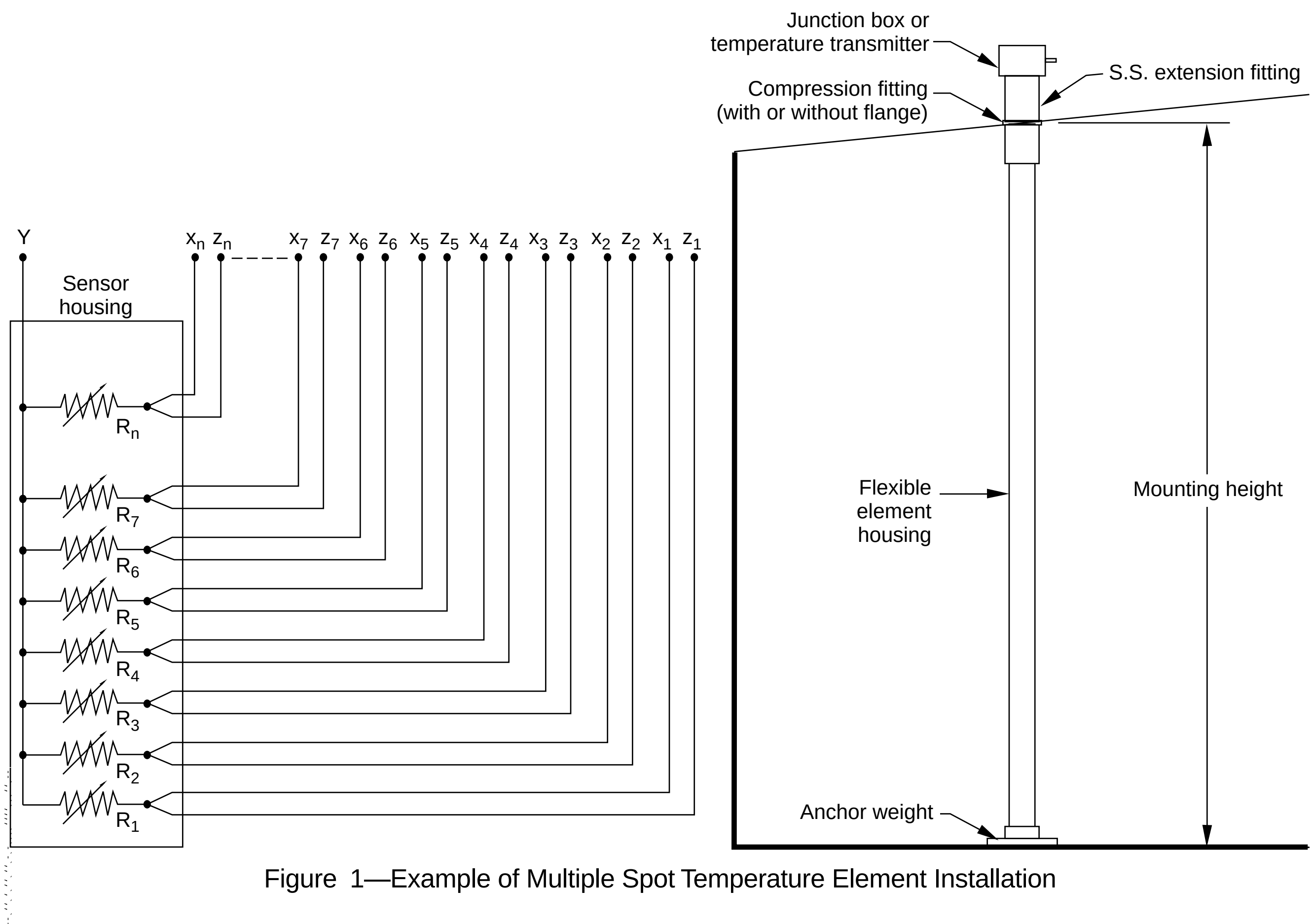


Figure 1—Example of Multiple Spot Temperature Element Installation

shell and the low point at an elevation of approximately 900 millimeters (36 inches) from the tank bottom.

Adequate clearance should be provided between the sensor assembly and the thermowell for ease of installation. To prevent measurement errors due to thermal convection circulation in the gap between the thermowell and the sensor assembly, the well should be filled with a heat-conductive fluid. Adequate provision for thermal expansion of the fill fluid should also be provided.

c. Installed by either attaching the temperature element to the flexible elbow of the swing suction line or by suspending the element on a pulley arrangement from the floating roof.

5.1.4.2 Multiple Spot and Averaging Temperature ATTs

The installation of the temperature elements for fixed averaging temperature equipment should conform to the same requirements as those for single-point or spot temperature elements. The configurations described below are in general use.

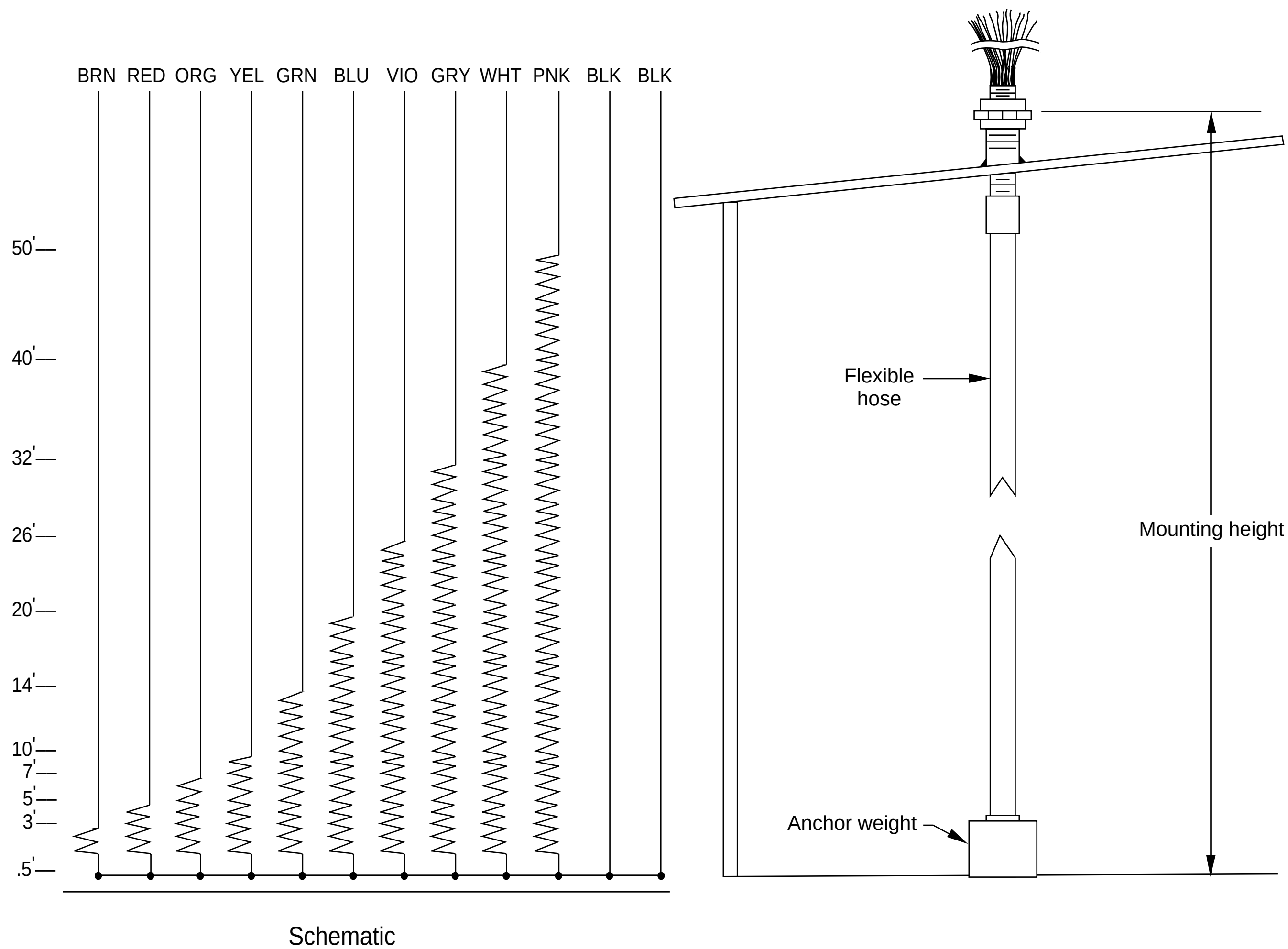


Figure 2—Example of Variable Length ATT Temperature Element Installation

5.1.4.2.1 Upper, Middle, and Lower Temperature Elements

The upper temperature element is suspended about 1 meter (3 feet) below the liquid surface. The mid-level temperature element is suspended at the mid-point of the liquid. This can be accomplished either by attaching the element to the flexible elbow of the swing suction line or by suspending the element on a pulley arrangement. The lower temperature element is installed about 1 meter (3 feet) from the tank bottom. The resistances of the three elements are electrically combined, or their readings averaged, to give the average temperature.

5.1.4.2.2 Multiple Spot Temperature Elements

Multiple spot temperature elements are installed at approximate 3 meter (10 feet) intervals with the lowest element approximately 1 meter (3 feet) from the bottom of the tank, as shown in Table 1.

In fixed-roof tanks, the elements may be installed in thermowells extending through the tank shell. In floating-roof or internal floating (pan-roof) tanks, the elements may be installed in a special slotted or perforated temperature standpipe or similar device passing through a proper sleeve or bushing. All temperatures are generally measured and transmitted to a central temperature read-out device with computing ability integral to the ATG system. The temperature readout device averages only the submerged elements. Alternatively, the device may transmit the individual temperatures of the submerged elements to provide a vertical profile of the temperature. A typical multiple-point temperature element installation is shown in Figure 1.

5.1.4.2.3 Variable Length Temperature Elements

A number of RTDs of varying lengths, all of which extend from the bottom of the tank, are encased in a flexible sheath. Only the longest, fully submerged RTD is used to determine the average temperature of the liquid in the tank. The correct

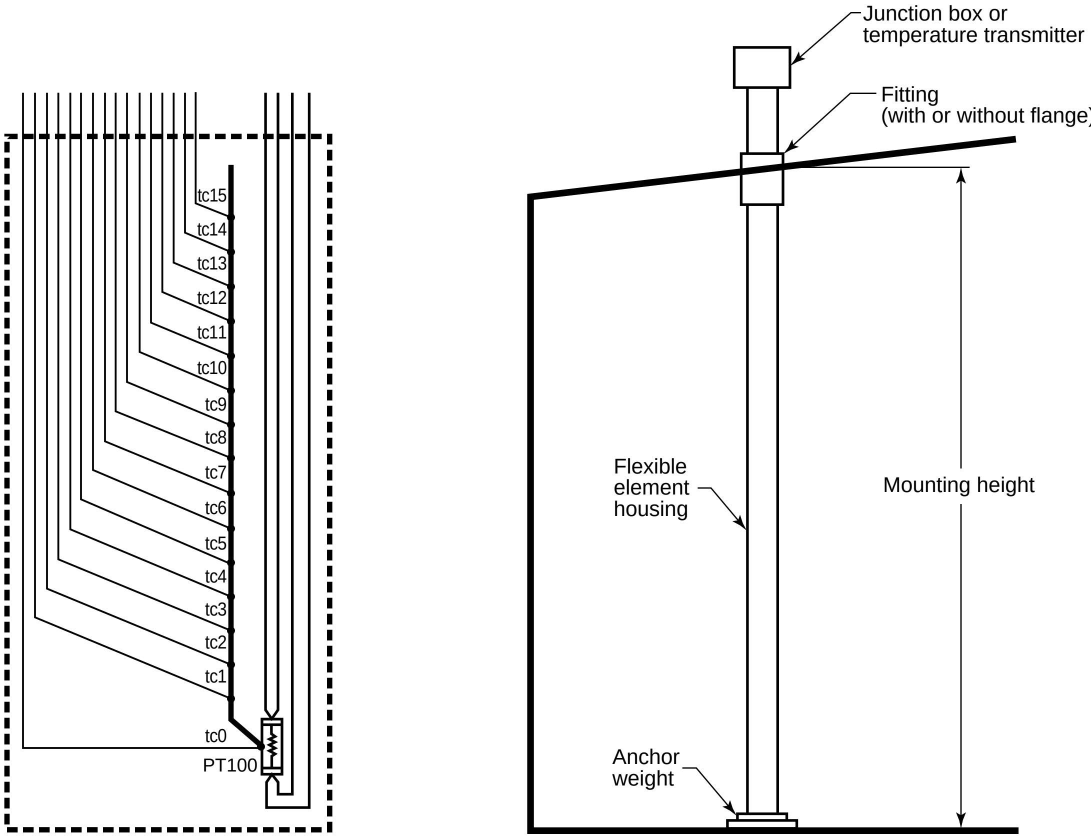


Figure 3—Example of Thermocouple System Installation

RTD is selected either by a switching device in the ATG or by software in the ATG system's remote readout device (typically a computer). The multiple element assembly can be installed in the tank in a closed thermowell that is filled with heat conductive oil or directly immersed in the liquid and suspended from the tank roof or gauging platform. A typical variable length RTD temperature element installation is shown in Figure 2.

A typical multi-junction thermocouple system is shown in Figure 3.

Table 2 shows the nominal lengths of elements in a typical variable 50-foot length RTD temperature element system (in practice, a longer ATT for a taller tank may contain more than 10 elements). The number of elements contained in the RTD should be such that the longest element is less than the maximum liquid level in the tank.

5.1.4.2.4 Mid-Level Temperature Element

A mid-level temperature element is a single temperature element suspended at the mid-point of the liquid. This can be accomplished either by attaching the element to the flexible elbow of the swing suction line or by suspending the element on a pulley arrangement from the floating roof.

Note: The mid-level temperature might not be the tank average temperature, and as such, shall not be used for custody transfer measurements.

Calibration of a mid-level temperature element-based ATT system is the same as for a single-point temperature element-based ATT system.

Table 2—Normal Lengths of Elements of a Typical Variable Length RTD Temperature Element System

0 – 0.91 meters (3 feet)	0 – 6.1 meters (20 feet)
0 – 1.52 meters (5 feet)	0 – 7.92 meters (26 feet)
0 – 2.13 meters (7 feet)	0 – 9.75 meters (32 feet)
0 – 3.0 meters (10 feet)	0 – 12.19 meters (40 feet)
0 – 4.27 meters (14 feet)	0 – 15.24 meters (50 feet)

Note: In practice, the sensitive portion of the element is 0.15 meters (6 inches) less than shown above so that the lowest 0.15 meters (6 inches) in the tank is not measured.

5.1.4.3 Marine Vessel Applications

On cargo tanks connected to the vessel's inert gas system (IGS), the ATT should be designed and installed so that it can be maintained and calibrated without de-pressurizing the IGS.

To permit accurate comparison between manual and automatic temperature measurement, the ATT deck penetration should be close (e.g., preferably within 1 meter) to a location where manual gauging can be performed.

5.1.4.3.1 Location of Temperature Sensing Element(s)

The single-point (spot) and/or multiple-point temperature sensing elements should be installed close to a vapor lock valve, gauging hatch, or other suitable gauging access point. The following methods of installation are in general use:

a. Installed in a metal thermowell through the deck (tank roof). This vertical thermowell should allow for one or more (usually three) temperature sensing elements to be mounted from the deck, suspended by their individual metal cabling, down to various depths in the tank. When three temperature sensing elements are used, they should be located respectively in the upper third (approximately 70% to 80% of the tank height), in the middle (approximately 40% to 50% of the tank height) and in the lower third (approximately 15% to 20% of the tank height).

b. Installed as an integral part of ATGs with level-sensing element(s) in contact with the liquid. The height of each temperature element may depend on the ATG mounting.

For both of the above methods, the ullage corresponding to the depth of each individual temperature sensing element for each tank should be readily available for the operator together with other ATG/ATT system data.

5.1.5 Thermowells for Fixed Electronic Temperature Elements

Thermowells for fixed electronic temperature elements should extend through the tank shell for at least 900 millimeters (36 inches) to reduce errors due to temperature differences between the liquid in the tank and the ambient conditions. The thermowell material should be compatible with the liquid product. Usually Type 304 or 316 stainless steel is specified.

The thermowells should be located near the ladder or stairway to facilitate maintenance and located as far as possible from the heating coils and the tank inlet and outlet.

Thermowells extending through the tank shell cannot be used on floating-roof or pan-roof tanks above the minimum roof height. Various vertical proprietary thermowells are available to support averaging temperature elements in floating-roof or pan-roof tanks.

5.1.6 Telemetry and Readout Equipment

Refer to 5.6 of this standard. Additional information may be found in API *MPMS* Chapter 21.

5.2 PORTABLE ELECTRONIC THERMOMETERS (PETs)

Portable electronic thermometers used for custody transfer shall meet the accuracy requirements of Table 3 and shall come to equilibrium within the immersion time requirements of Table 6.

The temperature probe or sensor head of a PET contains the temperature-sensing element, which is electrically connected to electronic circuits contained in the readout device. Means for adjustment should be provided so that the thermometer can be calibrated to meet the specified accuracy (See Table 3). These adjustments should not be accessible from outside the thermometer case. Only trained personnel in a location with proper calibration equipment shall perform calibration of the equipment. By mutual agreement, the user may provide paper seals (or similar devices) to indicate that the calibrations adjustment have not been tampered with. Each unit shall include a test system or switches to indicate low battery voltage. Each unit shall include provision for attaching an earth ground cable.

All units, including the probe and the cable, must be certified by a suitable agency as safe for use in flammable atmospheres and with liquids that can accumulate static charges. The display should be capable of being read to the nearest 0.1°C or 0.1°F.

Table 3—Portable Electronic Thermometer Specifications

Minimum Graduation	Accuracy	Range of Required Accuracy
0.1°F	± 0.2°F	0 – 200°F
	± 0.5°F	> 200°F
0.1°C	± 0.1°C	0 – 100°C
	± 0.3°C	> 100°C

Note 1: The specifications in this table represent minimum acceptable accuracy for portable electronic thermometers used for custody transfer. Thermometers with better accuracy are available and may be specified by mutual agreement.

Note 2: PETs shall be provided with displays that provide a resolution of 0.1°C or 0.1°F or better.

Note 3: The portable electronic thermometer shall maintain the specified accuracy and its display shall be readable over the ambient and operational temperature ranges expected at the location of use.

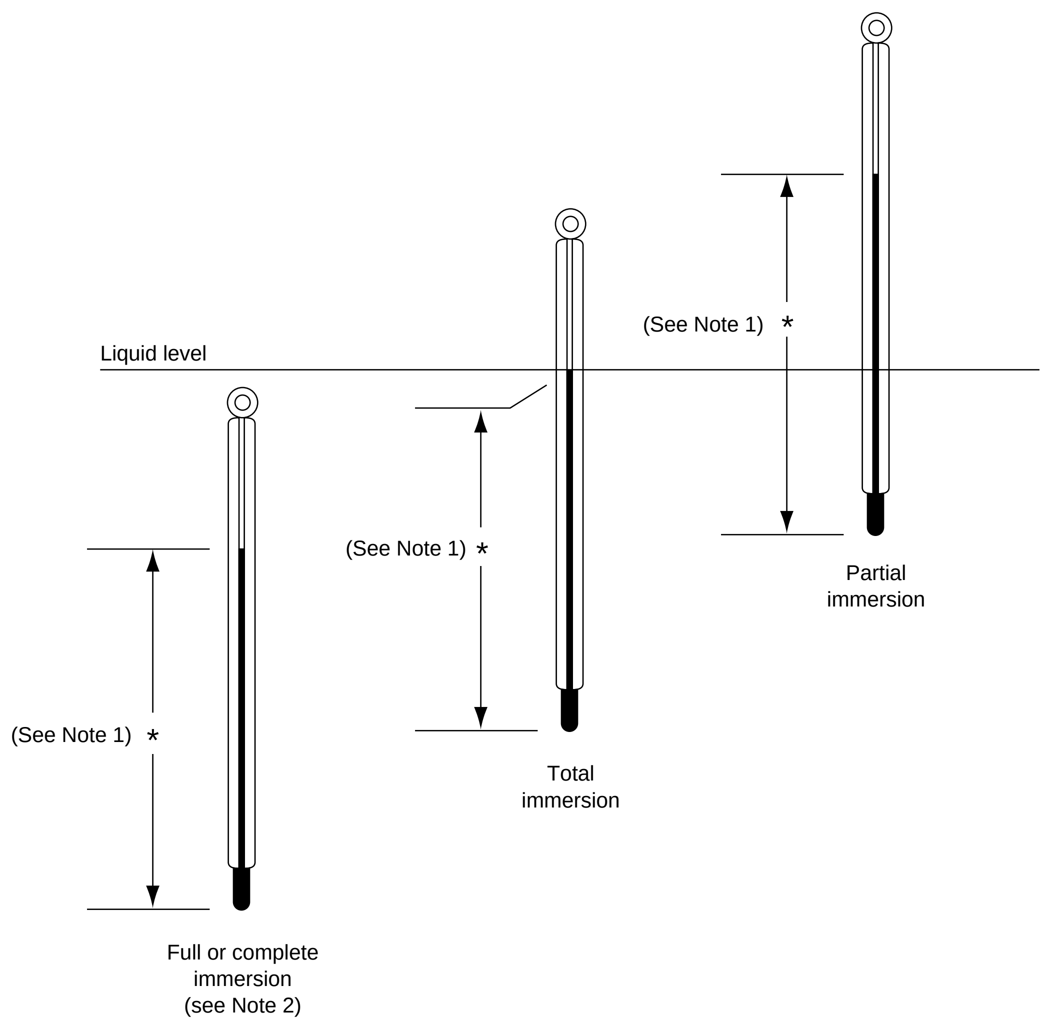
5.3 GLASS THERMOMETERS

Glass reference thermometers include complete-immersion thermometers, partial-immersion thermometers, and total-immersion thermometers (see Figure 4 and refer to ASTM E 344). These thermometers should conform to ASTM E 1 specifications for thermometers or to National Institute of Standards and Technology[5] (NIST) specifications. Calibration must be traceable to NIST-certified instruments.

CAUTION: No ASTM thermometer is designed to be used at complete immersion. See Figure 4.

[5]NIST, 100 Bureau Drive, Stop 3460, Gaithersburg, Maryland 20899-3460, USA.

ASTM E 1 glass thermometers that meet the discrimination requirements for meter prover calibration and for checking and calibrating temperature devices used in prover calibration and meter proving are normally the total-immersion type. These glass thermometers are designed and calibrated for immersion to the scale level corresponding to the temperature of the liquid. These thermometers normally have a scale graduation of 0.05°C (0.1°F) or 0.10°C (0.2°F) and a tolerance of 0.10°C (0.2°F). When they are used in a manner other than total immersion, they may experience errors due to the differential expansion of the glass and liquid column in the stem.



Notes:
1. * = Liquid-In-Glass
2. No ASTM thermometer is designed to be used at complete immersion.

Figure 4—Types of Glass Thermometers and Their Use

When used for meter prover calibration and for checking and calibrating temperature devices used for meter proving, potential scale errors and stem corrections should be analyzed, and corrections should be applied. Normally, stem corrections are not significant unless the difference between the average stem temperature and liquid temperature is greater than 8°C (15°F). The stem correction should be considered on a case-by-case basis. Appendix A provides information about the method for stem correction.

5.3.1 Permanent Glass Thermometers

Permanently installed glass thermometers should be securely mounted in a thermowell and protected from breakage by a housing. They should have the same high resolution scale graduation interval and tolerance as glass reference thermometers. These thermometers should be calibrated and checked using reference thermometers as described in 8.3.

5.3.2 Tank Thermometers

Tank thermometers shall be totally immersible and shall be made in accordance with the specifications in ASTM E 1. Each thermometer shall be the mercury-in-glass type with nitrogen or another suitable inert gas filling the space above the mercury column and with graduation marks permanently etched on its glass stem. Angle-stem thermometers shall meet the ASTM E 1 specifications for partial-immersion thermometers with the exceptions that the angle-stem thermometers may exceed the specifications for total length and that they may use a separate graduated scale, as discussed in 5.3.3.3. The thermometers listed in Table 4 shall be used.

5.3.3 Thermometer Assemblies

5.3.3.1 Cup-Case Assembly

The cup-case assembly shown in Figure 5 may be made of either varnished hardwood or non-sparking, corrosion-resistant material. It must have a cup with a capacity of at least 100 milliliters (6.1 cubic inches) and with dimensions such that the side of the bulb will be at least 9.5 millimeters ($^{3}/_{8}$ inch) from the nearest wall and the bottom of the bulb will be 25.4 millimeters ± 5.0 millimeters (1 ± $^{3}/_{16}$ inch) above the bottom of the cup.

5.3.3.2 Armored-Case Assembly

The armored-case assembly shown in Figure 6 shall be made of non-sparking, corrosion-resistant tubing that does not exceed 13 millimeters ($^{1}/_{2}$ inch) in outside diameter.

5.3.3.3 Angle-Stem Thermometer

The angle-stem thermometer in Figure 7 is installed in a standard metal-separable well or socket in a tank. For vertical tanks with capacities greater than 5000 barrels, the glass stem of the thermometer shall be at least 0.9 meters (3 feet) long, excluding the graduated portion, and shall be protected with a light metal tube. For storage tanks with capacities less than 5000 barrels, the stem may be 0.3 meters (1 foot) long, excluding the graduated portion, and also shall be protected with a light, metal tube. The sensitive portion of the thermometer shall not exceed 60 millimeters (2.5 inches), and the stem may have an angle of 90 degrees or greater to conform with the contour of the tank shell.

The assembly shall be attached to the well by a threaded coupling. A thermometer with a separate graduated scale is acceptable as long as the markings on the scale are permanently engraved and temperature lines at approximately 27°C (80°F) intervals are etched on the glass stem of the thermometer to coincide with the corresponding lines on the scale.

In addition to applications discussed in this section, angle-stem thermometers can be used in pipeline metering and prover applications to measure the temperature of the proving medium.

Table 4—Tank Thermometers

Name	ASTM Thermometer	Range	Length (inches)	Graduation	Accuracy
ASTM tank	58F-80	–30°F to +120°F	12	1°F	± 0.5°F
ASTM tank	97F-80	0°F to 120°F	12	1°F	± 0.5°F
ASTM tank	59F-80	0°F to180°F	12	1°F	± 0.5°F
ASTM tank	98F-80	60°F to180°F	12	1°F	± 0.5°F
ASTM tank	60F-80	170°F to 500°F	12	2°F	± 1.0°F
Angle-stem	—	Suitable range	12[a]	1°F	± 1.0°F
Tank thermometer[b]	—	20°F to 220°F	12	1°F	± 0.5°F

Note: Except for the angle-stem thermometer, all of the thermometers listed in this table are the total-immersion type.
[a]Length of the graduated portion.
[b]This thermometer does not have an ASTM designation, but it is commonly used for certain heated materials.

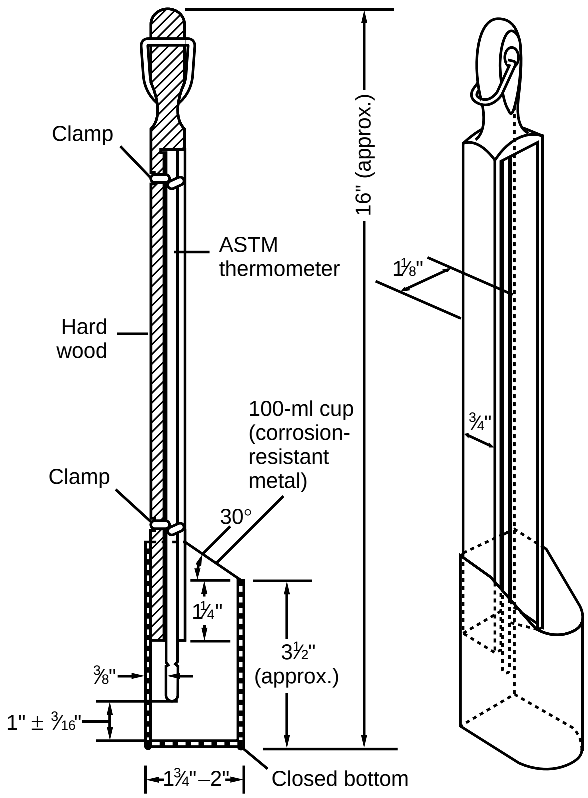


Figure 5—Typical Cup-Case Assembly

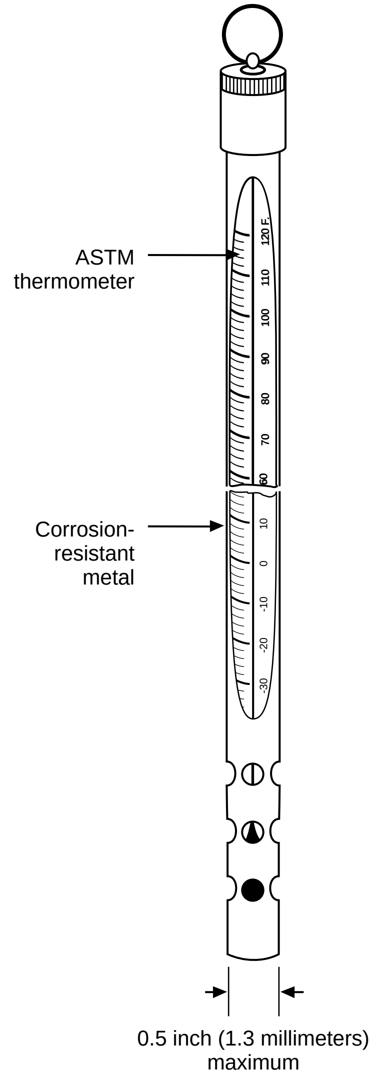
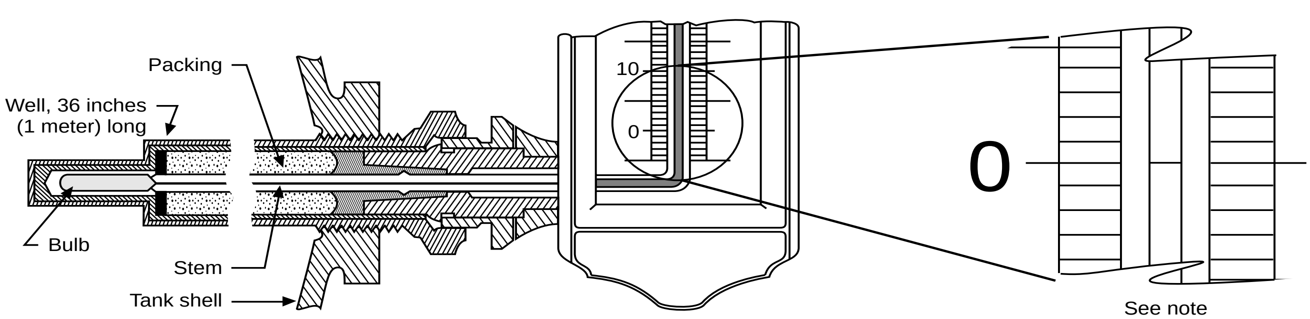


Figure 6—Typical Armored-Case Assembly



Note: The etched reference line on the glass must be aligned with zero on the scale.

Figure 7—Typical Angle-Stem Thermometer

5.3.3.4 Filled Bulb Systems

Filled bulb systems consist of a temperature sensor bulb connected via capillary tubing to a pressure sensitive transducer. Three types of filled systems are in common use: Class I, liquid-expansion; Class II, vapor-pressure; and Class III, gas-pressure. System selection depends on application, maintenance philosophy, and temperature range. Care must be exercised during installation and use to prevent damage (crimping or puncture) to the filled bulb system.

5.4 ELECTRONIC TEMPERATURE DEVICES

Electronic temperature devices for measurement generally use one of the following temperature sensors:

a. Thermistor.

b. Thermocouple.

c. Resistance temperature detector (RTD).

These devices are usually housed in metal probes that mount into thermowells. The probes are generally tip-sensitive. Thus, the probes must be securely seated in the bottom of the thermowell for optimum heat transfer. Spring-loaded or adjustable-length probes are recommended. An appropriate heat-conducting material should be used between the temperature sensor and the thermowell wall. The wiring to the probe is critical because of the low signal levels of the devices. These devices should be installed as recommended by the manufacturer for best accuracy. These transducers require linearization that is typically accomplished within the associated transmitter. Each type of probe requires its own type of circuit.

Safety must also be included in the equipment specifications. The equipment and transducers should be installed in accordance with API RP 500 and RP 551 and with NFPA 70, National Electrical Code (NEC) hazardous area specifications.

All electronic temperature devices should be provided with displays that provide a resolution of 0.1°C or 0.1°F or better.

5.4.1 Thermistors

Thermistors are very small ceramic resistors with high coefficients of resistance. While much more sensitive to small changes in temperature compared with platinum resistance temperature devices, thermistors are not recommended for custody transfer applications without very frequent calibration and verification testing.

They are subject to long-term drift due to aging, their accuracy and ambient temperature compensation are usually less than conventional temperature sensors. They are also less stable and are nonlinear. They are normally used for less precise temperature control and switching in the temperature range from about –100°C to 500°C (–200°F to 900°F).

5.4.2 Thermocouples

Thermocouples are temperature-sensitive devices consisting of a pair of dissimilar metals so arranged that the electromotive force (EMF) produced by the couple depends on the difference in temperature between the hot and reference junctions of the metals. Thermocouple temperature devices, depending on type, measure temperature over a wide range from about –150°C (–300°F) to about 1300°C (2300°F). Electronically compensated single-junction thermocouples shall not be used for custody transfer measurement due to the following: they suffer from drift and corrosion as they age, the millivolt signal is quite low and subject to noise pickup, the length, composition and condition of the thermocouple lead wires affects accuracy. Other thermocouple systems that meet the requirements of Section 8 may be used for custody transfer measurements.

5.4.3 Resistance Temperature Detectors

A resistance temperature detector (RTD) is a sensing element with an electrical resistance that is a function of temperature. The resistance temperature detector is usually a small coil of platinum wire and when used with appropriate circuits will provide temperature signals to readouts and other equipment. RTDs are more accurate than thermocouples and almost all other temperature sensors, and they maintain their accuracy for long periods. The current flow of an RTD is much higher than that of a thermocouple so they are less subject to noise pickup or errors from lead-in wires. RTDs are recommended for highly accurate temperature measurement such as custody transfer service; for narrow span temperature measurement [under 40°C (100°F)]; for temperature difference measurement; and for control and other critical applications.

Note: Three or four wire RTDs are recommended to compensate for lead length resistance.

5.4.4 Temperature Transmitters

A temperature transmitter is a device that converts a signal from a temperature sensor into a form suitable for propagating the temperature data from the site of the measurement to the location where the data will be used. The temperature signal is typically converted into a current or serial digital form. A temperature sensor may or may not be part of the transmitter. Sensor linearization can be typically provided by the transmitter, and the proper linearization option must be selected.

Electronic, digital ("smart") transmitters may have the following benefits over the conventional analog transmitters:

- Wider rangeability
- Calibration procedures
- Improved performance
- Lower drift rate

- Elimination of loop errors (analog drift, analog conversions, etc.)

It is important to read the specifications for a transmitter carefully.

5.5 THERMOWELLS

The use of thermowells may be required in dynamic and static temperature measurement to isolate the liquid material from the temperature sensor.

There are two general classification types of thermowells: *test wells* and *sensor wells*. *Test wells* are thermowells installed for occasional use (temperature checking), and should be capped when not in use. *Test wells* should be installed adjacent to sensor wells. Capping prevents foreign material from accumulating in the well bore. A clogged thermowell may cause measurement errors and may damage thermometers. It is recommended that thermowells be checked periodically for an accumulation of foreign material and cleaned if needed. *Sensor wells* are thermowells installed for use with a permanently installed temperature sensor, and should be matched to the temperature sensor.

Thermowells should be selected based on the application criteria described below. Thermowells should be designed to resist flow-induced vibration.

5.5.1 Pressure Rating

The thermowell selected shall comply with design codes for the operating pressures and temperatures of the system.

5.5.2 Installation

The thermowell should be selected to conform to code and user installation practices. Thermowells are typically threaded, welded, or flange mounted. The immersion length of the thermowell should be sufficient to put the sensor element within the center one-third of the pipe's diameter or provide immersion of 0.3 meter (12 inches) unless limited by fluid velocity considerations. The thermowell should be installed in as near to a vertical position as practical to allow it to be filled with an appropriate heat conducting material.

5.5.3 Material

The thermowell should be constructed of a material that is compatible with the liquid material that the thermowell is exposed to and should provide a degree of corrosion resistance for all surfaces. Usually Type 304 or 316 stainless steel is specified.

5.5.4 Thermal Conductivity

In cases where the temperature sensor does not come into contact with the thermowell walls, the space between the sensor and the thermowell wall should be filled with an appropriate amount of heat-conducting material to improve heat conduction between the wall of the thermowell and the sensor and to improve the temperature sensor's response time. Do not use material that will freeze under normal operating and atmospheric conditions.

Some applications may warrant special design to provide the fastest possible thermal response (for example, truck loading meters).

5.6 DATA COLLECTION, DATA TRANSMISSION, AND RECEIVING EQUIPMENT

The requirements for data collection, transmission, and receiving vary with the type and the make of the temperature determining system. For example, an ATT is often part of an Automatic Tank Gauging (ATG) system. The manufacturer's recommendations should be followed. Additional requirements may be necessary to provide proper security and protection of the measured data. The installation should conform to all applicable codes and regulations.

The remote readout of a temperature device may be used for custody transfer provided that the whole system, including the remote readout, meet the calibration tolerances defined in this standard.

Note: Some readout equipment can be programmed to alarm on high or low temperatures.

The data collection, data transmission and receiving equipment should be designed and installed (refer to API RP 500 and RP 2003) such that data transmission and receiving should:

- not compromise the accuracy of the measurement. The difference between the temperatures displayed by the remote receiving unit and displayed (or measured) by the temperature transmitter should not exceed ± 0.1°C (0.2°F);
- not compromise the resolution of the measurement output signal;
- provide proper security and protection of the measured data to ensure its integrity;
- provide adequate speed to meet the update time required for the receiving unit be electro-magnetically immune.

The same kind of electronic temperature readout equipment and wiring practices used for refinery process unit temperatures can be used for tank temperature readouts. However, in a large tank farm, the cost of direct wiring the elements to the tank farm central control house may be excessive. Normal practice is to transmit temperature information using the wiring network provided for the remote reading ATG level transmitters.

Much of the commonly used ATG equipment provides field converters to convert RTD resistances into data transmission codes of various formats. These field converters permit the ATG field multiplexers or field selectors to transmit both level and temperature information.

The temperature elements, field converters, field multiplexer or selectors, and ATG readout equipment are all proprietary to the ATG systems.

Commonly used modern ATG equipment provides readout equipment to display and log both levels and temperatures. This readout equipment can determine average temperatures either by selecting the appropriate longest, fully submerged variable length RTD or by averaging the appropriate submerged spot elements.

This read-out equipment can usually be programmed to alarm on high or low temperatures. It can also look up the tank capacity table, apply the appropriate expansion coefficients, and calculate the standard volumes.

5.6.1 Data Collection Unit

A data collection unit collects the measured data (e.g., temperature, level, flow) from one or more sources (tanks, pipes, meter runs, etc.). The unit may be in the transmitter, or it may be a microprocessor-based field unit separate from the transmitter or transmitters. Data collected by the unit will be transmitted, preferably in digital format, to a remote receiving unit, which may be a host computer.

5.6.1.1 Electrical Classification

Data collection units should be designed to meet the electrical classification requirements of the area. Since the units are usually located outdoors, weatherproof or rain-tight enclosures (or junction boxes) should be the minimum provided.

5.6.2 Data Transmission

5.6.2.1 Interference from the AC Power Wiring

All AC power wiring should be run with at least 1 meter (3 feet) of separation distance from the signal wiring. Most systems do not require electromagnetic shielding of the power wiring if the current is less than 10 amperes.

5.6.2.2 Radio Frequency Interference

Particular attention should be made to avoid interference from radio frequencies (RF). Cable shielding and cable routing should be designed to minimize RF interference. Filtering may be required at equipment inputs.

5.6.2.3 Signal Wiring

Signals are typically transmitted in pairs of twisted, shielded conductors in an insulated multipair cable installed in conduits or buried. The line impedance should be calculated to stay within the maximum impedance specified by the equipment manufacturer. Digital signals are recommended over analog signals, especially if long distance transmission or high impedance is expected.

Alternatively, signals may be transmitted via other media (for example, fiber optics, or coaxial cables) as recommended by the equipment manufacturer.

5.6.2.4 Grounding

Proper grounding is important to protect equipment from damage due to transients or surges, which can result in loss of measurement data.

Grounding requirements vary by type and make of the equipment. Therefore, the manufacturer's recommendations should be explicitly followed.

In aerial installations, the supporting messenger should be bonded to ground. In buried cable installations, only cable suitable for direct burial should be used. In conduit systems, continuity of ground through conduit joints should be ensured either by proper makeup of joints or by bonding connections around each joint.

5.6.2.5 Wiring Shields

The wiring shields may be copper, aluminum, or steel in accordance with the manufacturer's recommendations. The overall shielding should be bonded together at all junction boxes and properly grounded on only one end either to a power line grounded neutral or to a driven ground rod.

5.6.2.6 Signal-to-Noise Ratio

The requirements covered in 5.6 should be followed to provide immunity to noise pickup.

5.6.3 Receiving Unit

The receiving unit may be an integral part of a temperature system. The unit may be in a local configuration (at the tank(s)), or in a remote configuration (tank farm control house). The remote temperature readout unit should be capable of the following:

a. If an ATG and ATT system, scan all tanks monitored in a manner that meets the data acquisition requirements.

b. Display temperatures on a real-time basis.

c. Perform data validity checks and alert the operator if errors are detected.

d. Display alarms such as high temperature, low temperature, and so forth.

5.6.3.1 Transient and Lightning Protection

Protection against transients should be provided to protect the level and temperature transmitter and to provide secure transmission of the measurement data. The shields and proper grounding described in 5.6.2.4 and 5.6.2.5 often provide adequate protection. However, the manufacturer's recommendations should be followed if they are more restrictive.

In areas where there is a high incidence of lightning and, in particular, where the tanks are spread over a wide area remote from the central readout equipment, additional precautions against lightning should be provided. The lightning protection system should absorb the lightning surge energy in the signal or power lines.

The surge protective level should not interfere with the normal operation of the equipment. Surges that can damage the equipment should not pass through the system. The lightning protection devices should be maintenance free and self-restoring. The selection and installation of protective devices should be based on the recommendations of the equipment manufacturers.

5.6.3.1.1 Installation of Surge Protectors

The lightning surge protectors should be installed at both ends of the signal transmission lines to protect the signal source and its receiving unit from electrical surges propagating in both directions from the induction point.

Alternatively, lightning protection can also be provided by the galvanic separation technique.

5.6.3.1.1.1 Grounding Lighting Surge Protectors

Ground wires for transient and surge protectors should be connected to a good earth ground, such as a metal cold water pipe. If a reliable earth ground is not available, a driven ground rod should be provided. Five ohms is an acceptable ground resistance.

6 Static Temperature Determination

Temperatures of hydrocarbon liquids under static conditions can be determined by measuring the temperature of the liquid at specific locations in vessels. Examples of static vessels are storage tanks, field gathering tanks, ships, barges, tank cars, tank provers, and test measures.

Three basic methods available for determining average static tank temperatures for custody transfer, in order of preference, are:

- Automatic method using fixed electronic temperature sensors.
- Manual method using portable electronic thermometers.
- Manual method using mercury-in-glass thermometers.

The automatic method covers the determination of temperature using fixed automatic tank temperature systems (ATTs) for hydrocarbons having a Reid Vapor Pressure at or below 101 kPa (15 pounds per square inch absolute). ATT systems include precision temperature sensors, field-mounted transmitters for electronic signal transmission, and readout equipment.

The manual methods cover:

- nonpressurized tanks and marine vessels.
- blanketed tanks and marine vessels.
- tanks and marine vessels that have been made inert and are under pressures of less than 21 kPa (3 pounds per square inch gauge).

They do not cover hydrocarbons under pressures in excess of 21 kPa (3 pounds per square inch gauge) or cryogenic temperature measurement unless the tank is equipped with (a) thermowell(s).

Table 5—Minimum Number of Temperature Measurements for Various Depths of Hydrocarbon Liquid in Storage, Lease, Ship and Barge Tanks

Depth of Liquid	Minimum Number of Temperature Measurements	Measurement Level
> 3.0 meters (10 feet)	3	Middle of the Upper, middle, and lower thirds
< 3.0 meters (10 feet)	1	Middle of liquid

Note 1: For tanks with capacities less than 5000 barrels, and no temperature stratification, one temperature measurement at the middle of the liquid can be used. Also, one temperature measurement at the middle of the liquid will suffice in ship or barge tanks containing less than 5000 barrels.

Note 2: The temperature of a liquid in a storage tank or marine vessel can vary throughout its depth: therefore, when temperature differentials greater than 1°C (2°F) are found, an average temperature shall be obtained. This may be accomplished by taking temperatures at different levels that are equally spaced apart, averaging the readings, rounding off the result to the nearest 0.05°C (0.1°F), and reporting the result as the average temperature for the entire volume. In some cases, such as when a tank has a non-uniform cross-sectional area, it may be necessary to calculate a volume weighted average temperature.

Note 3: Additional temperature measurements may be taken for higher precision, if agreed to by all parties.

For static temperature determination in storage, lease, ship and barge tanks, Table 5 shows the *minimum* number of temperature measurements that must be taken to calculate an average temperature.

6.1 AMBIENT TEMPERATURE

Tanks undergo expansion and contraction due to variations in ambient and product temperatures. Such expansion or contraction in tank volume may be computed once the tank shell temperature is determined. Tanks that have been calibrated in accordance with API *MPMS* Chapter 2, "Upright Cylindrical Tanks", have capacity tables based on a specific tank shell temperature. If the observed tank shell temperature differs from the capacity table tank temperature, the volumes extracted from the table will need to be corrected accordingly. To do this the tank shell temperature must be determined.

The tank shell temperature for noninsulated tanks is a function of the liquid temperature and the ambient temperature. Since non-insulated storage tanks cannot readily be sheltered from the elements, ambient air temperature has to be considered, in addition to the liquid temperature, when calculating a correction factor to determine the effect of temperature on the steel shell of a tank as required by API *MPMS* Chapter 12.1.

$$T_s = [(7 \times T_L) + T_a] / 8$$

where

T_s = tank shell temperature.

T_L = liquid temperature,

T_a = ambient temperature,

Ambient Temperature is a representative atmospheric temperature in the vicinity of the tank farm. Ambient air temperature surrounding a storage tank is always an arbitrary, and usually a widely varying parameter. Therefore, it is difficult to determine the best place to measure it. For this reason alone, the uncertainty of this measurement can be ± 2.5°C (5°F). However, the ambient temperature component is only $^1/_8$ of the total tank shell temperature (T_s). Therefore the accuracy required for the measurement of the ambient temperature (T_a) is not as high as that required for the liquid temperature (T_L).

The recommended methods of taking this temperature are:

- A temperature device carried by the gauger into the tank area immediately prior to gauging tanks. Take at least one temperature reading in a shaded area. If more than one temperature is taken, average the readings.
- Shaded external thermometers permanently mounted in the tank farm area.
- Local on-site weather stations.

Temperature readings are to be taken at least 1 meter (3 feet) from any obstructions or the ground. Additionally, allow sufficient time for temperature reading to stabilize.

Thermometers used for this purpose shall have an accuracy (maximum permissible error) of 1°C (2°F) or better, that should be verified every three months.

For reporting purposes, round ambient temperature to the nearest whole degree.

6.2 TIMING OF TEMPERATURE MEASUREMENT

Temperatures shall be measured immediately before or after the liquid level is measured.

6.3 FIXED AUTOMATIC TANK THERMOMETERS

6.3.1 ATTs for Custody Transfer Purpose

Tanks using an automatic method to determine temperature in custody transfer should preferably be fitted with multiple-point ATT except when:

a. The tanks have a capacity less than 1000 m^3 (5000 barrels), or the level is less than 3 meters (10 feet).

b. The maximum vertical temperature variation is less than 1°C (2°F).

c. Manual average temperature measurement is used for custody transfer.

Note: Single-point or spot tank temperature measurement may be used when the temperature of the liquid in the cargo tank is considered to be uniform, or when any temperature stratification in the tank has been shown to be small and acceptable. In all other cases, these types of ATTs are not suitable for custody transfer or fiscal measurement.

6.3.2 Reporting Temperatures

Fixed temperature elements of ATTs should be individually read and recorded to the maximum display resolution (typically 0.1°C or 0.1°F). If the ATT readout equipment does not perform temperature averaging, then average tank temperatures should be calculated from the multiple readings.

6.3.3 Single-Point Tank Temperature Measurement

The single-point or spot tank temperature measurement should only be used when the temperature of the liquid in the tank is considered to be uniform or when the temperature stratification in the tank is considered small and, therefore, acceptable. Small tanks (less than 5000 barrels), tanks storing a uniform temperature material, and tanks with adequate mixing equipment have less temperature stratification. Only in these cases would a single-point temperature measurement be acceptable for custody transfer purposes.

6.3.4 Average Tank Temperature Measurement

Temperatures in large tanks (5000 barrels or larger) are normally stratified unless the tank contents are thoroughly mixed. Vertical temperature differences of as much as 3°C or

5°F are normal, and differences of 5°C or 10°F are common. In the horizontal direction, the temperature differences are typically less than 0.5°C or 1°F for low and medium viscosity petroleum liquids. Somewhat higher differences may be expected in high viscosity petroleum liquids.

For custody transfer measurement, when automatic tank gauges (ATGs) that measure level are used (for example, float-operated ATGs, servo-operated ATGs, or radar ATGs), an average temperature (not a single-point temperature) should be used.

In tanks with vertical temperature stratification, the temperature gradient is rarely linear. An average temperature is needed for custody transfer. The mid-level temperature of the tank contents might not give an accurate average temperature.

When hydrostatic tank gauges (HTGs) are used, which compute standard volume using pressure sensors, a single temperature sensor, located about halfway between the lower pressure sensors, may be adequate.

Note: It is possible to determine the average temperature by a single-point (spot) temperature element located on the outlet of a tank, using the ATG to calculate a volume-weighted average temperature of a parcel being loaded into or discharged out of the tank. Applications of this alternate method include loading of marine vessels from bulk storage tanks.

6.4 PORTABLE ELECTRONIC THERMOMETERS

This section describes the proper use of portable electronic thermometers. Thermometers used for custody transfer shall be calibrated against a reference standard (see 8.2).

6.4.1 Reading and Reporting Temperatures or Average Temperatures

All temperatures should be read and recorded to the nearest 0.1°C or 0.1°F. The temperature (or average of multiple temperatures) shall be reported to the nearest 0.1°C or 0.1°F.

6.4.2 Handling Requirements

Portable electronic thermometers are precise measurement instruments. They should be transported and used carefully.

6.4.3 General Procedure

The following procedure is recommended for measuring temperatures with a portable electronic thermometer:

1. Attach an electrical ground between the thermometer and the tank before opening the hatch. (Check that the ground is securely attached to the thermometer).
2. Verify the condition of the battery before and after each use.
3. Set the temperature range selector as appropriate.
4. Lower the sensing probe to the predetermined level.
5. Raise and lower the probe 0.3 meter (1 foot) above and below the predetermined level to allow rapid stabilization. (See 6.4.3.1).
6. After the temperature has stabilized, read and record the temperature at the depth measured.
7. Repeat steps 4, 5, and 6 at each level if multiple temperatures are required (see 6.4.4).
8. Determine the average temperature.
9. Round off the average temperature and report the temperature to the nearest 0.1°C or 0.1°F.
10. After use, clean all the parts of the thermometer assembly with a suitable solvent and dry it with a cloth to prevent the formation of an insulating film.

6.4.3.1 Immersion Times

Thermometers must be stabilized at the liquid temperature before they are read. To reach stability quickly, all measurements should be accomplished by continuously raising and lowering the probe approximately 0.3 meter (1 foot) above and below the desired temperature measurement depth. Failure to induce movement will substantially increase the required immersion times shown in Table 6. Most currently available electronic thermometers have a bob weight with a high thermal capacity located above the probe. The bob weight is often at a lower temperature than the oil. If the probe is allowed to remain stationary, contact with a convection current of colder oil will cause low readings. However, with a moving probe, the thermometer may be considered to have reached stability if the readout varies by not more than 0.1°C (0.2°F) for 30 seconds.

6.4.4 Storage Tank Temperature Procedures

Liquid temperatures in a storage tank often vary significantly with depth. When custody transfer measurements are being performed, temperatures at multiple levels are required to calculate an average temperature.

When the liquid level is more than 3 meters or 10 feet, the temperatures in the centers of the top third, the middle third, and the bottom third of the liquid height should be measured. If the temperature range exceeds 1°C or 2°F, or when custody transfer measurements at multiple levels are required to calculate an average temperature, temperatures should be taken at intermediate levels and averaged.

All measurements shall be recorded, and then averaged. The average shall be reported to the nearest 0.1 degree.

For liquid levels less than 3 meters (10 feet) or for tanks of less than 5000 barrels, a single measurement at the middle of the liquid may be used with the mutual agreement of all parties.

Table 6—Comparison of Recommended Immersion Times for PETs and Woodback Cup-Case Assemblies

	Recommended Immersion Times (minutes)[a]				
	Electronic Thermometer	Woodback Cup-Case Assembly			
				When Temperature Differential <2.5°C (< 5°F)	
API Gravity At 60°F	In-Motion (see note 1)	In-Motion	Stationary	In-Motion	Stationary
> 50	30 seconds	5 minutes	10 minutes	5 minutes	10 minutes
40 to 49	30 seconds	5 minutes	15 minutes	5 minutes	15 minutes
30 to 39	45 seconds	12 minutes	25 minutes	12 minutes	20 minutes
20 to 29	45 seconds	20 minutes	45 minutes	20 minutes	35 minutes
< 20	75 seconds	45 minutes	80 minutes	35 minutes	60 minutes

[a]These immersion times were established based on the test procedure outlined in Appendix D. Failure to use these recommended times may result in incorrect temperature readings.

Note 1: While measuring the temperature, the sensor probe shall be in motion within the fluid by raising and lowering the thermometer probe 0.3 meter (1 foot) above and below the desired depth.

Note 2: The woodback cup-case assembly can be used in either an in-motion or a stationary mode. In motion is defined as repeatedly raising and lowering the assembly 0.3 meter (1 foot) above and below the desired depth.

Note 3: Cup-case assemblies made of other materials will have different immersion times. Immersion times should be established by testing, and all parties involved should agree on the immersion times (see Appendix D).

Note 4: If additional mass, such as a weight to cause the woodback cup-case assembly to sink, is placed in the liquid near the thermometer, the immersion time of the assembly will be longer than those listed in this table. Immersion times should be established by testing, and all parties involved should agree on the times (see Appendix D).

Note 5: The etched reference line on the glass of the woodback cup-case assembly must be aligned with zero on the scale.

6.4.5 Marine Temperature Procedures

Temperatures should be taken in all tanks or compartments as described in 6.4.1 through 6.4.3.

Upper, middle, and lower temperatures should be taken. By mutual agreement, more than three temperatures may be taken to calculate an average temperature. For barge compartments of less that 5000 barrels, a minimum of two temperature measurements at the middle of the bottom half and at the middle of the top half of the liquid are required.

During the loaded voyage, the marine cargo temperature may change. This may result in non-uniform temperature at discharge, which increases the difficulty of determining the average cargo temperature. Averaging PETs automatically provide the average temperature. For PETs without the averaging feature, the use of the average of upper, middle, and lower temperatures calculated for each tank is the most practical procedure currently available. The total ship volume should be corrected to the standard temperature on tank-by-tank basis, using the average temperature determined for each tank.

If there is insufficient on-board quantity (OBQ) or remaining-on-board (ROB) to permit temperature measurement, the material may be assumed to be at standard temperature. The temperature of any substantial quantity of OBQ or ROB (for example slops) should be taken at the midlevel of the oil or oily layer.

6.4.6 Tank Car Temperature Procedures

Temperatures should be taken on every tank car at the middle of the liquid. However, by mutual agreement, when loading multiple tank cars with non-heated oil from one source, temperatures may be determined on the contents of at least 10% (a minimum of three tank cars) of the number of cars, selected at random. This assumes that all of the tank cars are of the same nominal size and that all of them are either insulated or all uninsulated. When a car is to be heated to facilitate discharge in cold weather, the temperature of the contents of each car should be taken at the same time the car is gauged.

6.5 MERCURY-IN-GLASS THERMOMETERS

For a non-pressure tank, a temperature can be obtained by lowering an ASTM or IP tank thermometer of appropriate range, and with an appropriate sampling apparatus (e.g., cup-case) through the gauge hatch to the specified liquid level. Keep the thermometer immersed for a predetermined time period, and then quickly withdraw and read the thermometer. This procedure is also used for a low-pressure tank equipped with a gauge hatch or perforated standpipe. It cannot be used for pressurized or inerted tanks fitted with vapor control valves.

For a tank equipped with a thermowell, a temperature is obtained by reading a thermometer placed in the well with its bulb at the desired liquid level.

Table 7—Thermometer Assemblies and Temperature Levels for Tanks and Cargo Carriers

Tanks	Typical Temperature Measurement Facilities	Thermometer Assemblies	Measurement Levels
		Stationary Tanks	
Fixed-roof	Roof hatch	Cup-case	See note
Floating-roof	Gauge hatch	Cup-case	See note
Variable vapor space	Gauge hatch	Cup-case	See note
	Vertical thermowells	Armored	See note
	Pressure lock	Cup-case	See note
	Horizontal separable wells	Angle Stem	Three for tank heights less than 10 meters (30 feet); four for tank heights greater than 10 meters (30 feet)
Horizontal-cylindrical			
Nonpressure	Gauge hatch	Cup-case	See note
Pressure	Vertical thermowells	Armored	See note
	Horizontal separable wells	Angle-stem	Two, one at middle of tank and one 0.3 meter (1 foot), above bottom
		Tank Cars and Tank Trucks	
Nonpressure	Dome hatch	Cup-case	Middle of liquid[a]
Pressure	Vertical thermowells	Armored	Middle of liquid[a]
		Ships and Barges	
Nonpressure	Deck hatch	Cup-case	See note
Pressure	Vertical thermowells	Armored	Middle of liquid[a]

Note: See Table 5 for the minimum number of measurement levels.
[a] In special cases, it may be desirable to obtain temperatures at more than one level and calculate a weighted average temperature. See Table 5, Note 2, for the correct method of averaging multiple temperatures.

In all cases where more than one temperature is determined, the average temperature of the liquid is calculated from all observed temperatures.

6.5.1 Thermometer

A thermometer of suitable range for the temperature to be measured shall be selected from Table 4, and the appropriate assembly for the various types of tanks and cargo carriers (see Table 7) shall be used. After the thermometer with its appropriate assembly has been selected and verified according to the procedure provided in 8.3, then the procedure outlined in 6.5.2 through 6.5.6.1 shall be followed.

6.5.2 Cup-Case Assembly

To obtain a temperature reading of a tank of less than 5000 barrels for custody transfer with the cup-case assembly, it shall be lowered through the gauge hatch or pressure lock to the required level and moved gently through a range of ± 0.3 meters (1 foot) of the required level for the time specified in Table 6, which give the recommended immersion times for the woodback cup-case assembly. For immersion times not covered by Table 6, Appendix D provides a procedure for determining them for mercury-in-glass thermometers. As noted in Table 6, the required immersion time for the cup-case assembly may be minimized by continuously raising and lowering the assembly. To take a reading, the assembly shall be withdrawn, and the thermometer shall be read with the cup sheltered below the edge of the hatch to minimize the possibility of a change in the reading due to wind or atmospheric temperature. The cup must be kept full at all times while the thermometer is being read, and the temperature shall be recorded immediately. For operational expediency and the ability to determine and verify temperature stratification in tanks of 5000 barrels or more, a portable electronic thermometer will provide significant improvements in response time.

6.5.3 Armored-Case Assembly

The armored-case assembly is used in pressurized tanks equipped with vertical thermowells that are filled with a suitable heat transfer medium. For small pressure tanks, the thermometer assembly shall be lowered into the well to the middle of the liquid in the tank. For large pressure tanks, the thermometer shall be lowered to the level indicated in Table 5. Usually a minimum of 5 minutes is required for the thermometer to reach a stabilized temperature; however, tests should be conducted on each given application to determine the required immersion time.

To read the temperature, the assembly shall be withdrawn, but the perforated end shall remain in the well to minimize the possibility of a change in the thermometer indication. The thermometer shall be read, and the temperature shall be recorded immediately. Failure to withdraw quickly and read the thermometer can result in erroneous readings due to temperature gradients within the tank and ambient temperature.

6.5.4 Angle-Stem Thermometer

Angle-stem thermometers are permanently installed in separable sockets or thermowells and are removed only for replacement or calibration. Other items to remember concerning angle-stem thermometers are:

a. Ensure that angle-stem thermometers are installed in the same orientation that they were in when they were calibrated.

b. If a separate graduation scale is used, verify that the etched reference line on the angle-stem thermometer is aligned with the zero on the scale.

6.5.5 Non or Low Pressure Tanks and Cargo Carriers

6.5.5.1 Bulk Storage Tanks

The average temperature in a tank of liquid for custody transfer is required to calculate its volume at a standard temperature, so temperatures must be determined accurately. For inventory control follow company procedures. During the gauging operation, temperatures should be taken at the correct measurement level (see Table 5), but before the temperature readings are taken, the thermometer assembly must be allowed the time necessary (see Table 6) for stabilizing at the temperature of the liquid at the measurement level. Temperatures in tanks greater than 5000 barrels should be read and recorded to the nearest 0.5°C (1.0°F), but they may be reported to less than 0.5°C (1.0°F) if all parties involved agree and if this does not conflict with legal requirements. Averages of multiple temperature readings shall be reported as explained in Note 2 of Table 5.

The cylindrical core of any storage tank will provide the most representative temperature measurement because it is the area least affected by external factors which may influence the shell of the tank.

Large storage tanks with external floating roofs normally have several gauge hatches around the perimeter of the tank and may have a hatch in the center of the roof area as well. Large fixed roof tanks or tanks with internal floating roofs usually have one or more gauge hatches located around the outer perimeter of the roof. When more accuracy than the conventional method for determining custody transfer or fiscal quality temperature (Top, Middle, Bottom temperatures from the gauge well or roof hatch close to gauge well) is desired, then the temperatures can be taken in all of the hatches and averaged. Of course, with immersion time requirements for cup-case thermometers, this would require a considerable amount of time, therefore it should be used in extraordinary circumstances only. At a minimum, temperatures must be taken as close as possible to the gauge hatch.

Smaller lease tanks usually only have one gauge hatch located near the shell of the tank. When obtaining temperature measurements through a hatch located near the shell, on small or large tanks, the thermometer assembly must be suspended at least 300 millimeters (12 inches) from the shell of the tank or as far as the hatch will allow. See Tables 5 and 6 for recommended location, depths and immersion times for taking temperatures in lease or storage tanks.

6.5.5.2 Tank Cars

During gauging, temperatures should be taken at the middle of the liquid on every tank car. However, when loading multiple tank cars with unheated liquids from one source, temperatures may be determined from the measurement of the contents of a minimum of 10% of the cars loaded (a minimum of three cars is required), selected at random if all parties involved agree, and all of the tank cars have the same conditions, i.e., are the same nominal size, all are insulated or all are uninsulated, and all are exposed to the same atmospheric conditions. When tank cars are heated to facilitate discharge (e.g., in cold weather), the temperatures for each car must be taken at the same time each car is gauged. In all cases, thermometer immersion times must be in accordance with those specified in Table 6.

6.5.5.3 Marine Vessels

On marine vessels, temperatures should be taken in all tanks or compartments, and these temperatures should be measured using the measurement information and recommended immersion times provided in Tables 5 and 6. For both ships and barges, the average temperature should be determined for each tank.

For marine vessels required to operate with closed or restricted systems, mercury-in-glass thermometers are not suitable for use. In these circumstances, the vessel will be fitted with vapor control valves, and measurements can only be taken with a suitable portable electronic tank thermometer (PET).

If there is insufficient [less than 100 millimeters (4 inches)] on-board quantity (OBQ) or remaining onboard (ROB) volume to permit temperature measurement or if this material is below its pour point, it may be assumed to be at the standard temperature of 15°C (60°F). The temperature of any substantial on-board quantity or remaining-on-board volume should be taken at the mid-level of the hydrocarbon.

6.5.6 Pressure Tanks and Cargo Carriers

Temperatures of liquids in pressure tanks and cargo carriers normally cannot be obtained through open hatches. The preferred temperature measurement in these circumstances is use of automatic tank thermometers (ATTs) (or a PET through a vapor control valve if pressure limitations permit). If thermometers are used, they should be in suitably located thermowells or separable sockets or through pressure locks. Levels at which temperatures are to be taken are outlined in Tables 5 and 7. If thermowells are used, the thermowells should be filled with a suitable heat transfer medium. Thermowells installed in the vertical wall of a tank or in the curved wall of a cylindrical tank shall be inclined slightly to retain the heat transfer medium.

6.5.6.1 Pressure Locks

A pressure sampling and gauge lock is a vapor-tight assembly mounted on the top of a tank which can be used for obtaining temperatures. The lock shall have a vapor-tight window and shall enclose a bob and tape on a reel which can be operated by a handle. A shut-off valve is required between the lock and the tank to prevent vapors from escaping while the lock is open.

When taking temperatures through a pressure lock, a cup-case assembly should be used. It may also be possible to use an armored case thermometer with other sampling apparatus. To obtain the temperatures, the following sequence shall be used:

a. Wind the tape on the reel until the bob is above the shut-off valve, lock the reel, and close the valve to prevent vapors from escaping from the tank.

b. Open the window, remove the bob, and attach the cup-case assembly to the tape.

c. After attaching the cup-case assembly, close the window, open the valve, and lower the cup-case assembly to the prescribed level with the reel.

d. After the proper immersion time has elapsed, withdraw the cup-case assembly from the tank into the pressure lock and immediately read the thermometer through the window. If the thermometer cannot be read through the window, close the valve and open the window to take the reading.

e. After all of the required temperatures have been obtained, remove the thermometer assembly and replace the bob.

Where pressure limitations permit, the preferred method is to use a closed or restricted system PET through a vapor lock valve.

6.5.6.2 Pressure Storage Tanks

A horizontal-cylindrical tank should be equipped either with a vertical thermowell that extends through its center to about 150 millimeters (6 inches) from its bottom or with two horizontal separable wells: one in the middle of the tank and one 300 millimeters (12 inches) above the bottom of the tank.

A spherical- or spheroidal-type tank may be equipped with either horizontal separable wells or pressure locks which can be used for temperature determinations. If horizontal separable wells or sockets are used, three are sufficient for a tank less than 9 meters (30 feet) high: one about 0.6 meter (2 feet) above the lower capacity mark and one for each additional 3 meters (10 feet) of maximum liquid height. At least four thermowells are necessary for a tank more than 9 meters (30 feet) high: one about 0.6 meter (2 feet) above the lower capacity mark, one about 1.2 meters (4 feet) below the upper capacity mark, and two at about equal intervals between the top and bottom wells.

6.5.6.3 Pressure Tank Cars and Tank Trucks

Each pressure tank car and tank truck should be equipped with a vertical thermowell that extends through the shell of the tank to the middle of the liquid.

6.5.6.4 Pressure Marine Vessels

Each ship and barge compartment pressurized to greater than 20.7 kPa (3 psig) should be equipped with an individual vertical thermowell that extends from a point 150 millimeters (6 inches) above the deck to at least the center of the tank.

6.5.7 Field Standard Test Measures

Total-immersion thermometers are frequently used to determine the temperature of water in field standard test measures. Section 7.1.3.1 discusses this further.

7 Dynamic Temperature Determination

Dynamic temperature determination includes the measurement of liquids flowing through a pipe, as well as the determination of temperature in equipment used for calibrating, or proving the measurement of the quantity of liquid moving through a pipe. The temperature devices used for this purpose are generally glass reference thermometers including complete-immersion thermometers, partial-immersion thermometers, and total-immersion thermometers (see Figure 4) that conform to ASTM E 1 specifications for thermometers or to NIST specifications, or electronic temperature sensors such as resistance temperature detectors (RTDs).

7.1 TEMPERATURE SENSOR PLACEMENT

A temperature sensor (see Section 5) is a device that provides a usable output in response to a measurand: in this case the temperature of flowing hydrocarbon liquid. The placement of the sensor is a critical component of accurate temperature measurement.

7.1.1 Meters

The objective when determining the temperature of metered liquid, for use in correcting for the thermal effects on the liquid, is to obtain an accurate liquid temperature inside the meter body. Some meters make provision for the installation of a temperature sensor in the meter body; however, with many meters this type of installation is impractical as a result of meter construction or the type of temperature sensor selected for use.

Where it is impractical to mount the temperature sensor within the meter body, the sensor should be installed either immediately downstream or upstream of the meter consistent with flow conditioning requirements. Downstream is the preferred location. Caution should be exercised if placing the temperature sensor upstream in a turbine meter run so as not to disturb the flow profile. Where several meters are manifolded in parallel, one temperature sensor located in the total liquid stream is acceptable, provided the temperature at each meter and at the temperature sensor location agree within the discrimination limits listed in API *MPMS* Chapter 12. Test thermowells should be provided in each meter run to verify that the individual meter run temperatures compare with that of the total liquid stream. This verification should be done as frequently as necessary to satisfy all parties involved.

In all cases, the temperature sensor must be positioned within the flowing liquid stream to ensure fast response and accuracy. (Refer to API *MPMS* Chapters 5 and 6.)

7.1.2 Pipe Provers

When determining the temperature of a liquid flowing through a prover for use in correcting for the thermal effects on the liquid and prover, the liquid temperature shall be measured as close to the prover inlet and outlet as is practical. When two measurements are taken, they shall be averaged to arrive at the prover temperature.

In many cases, the inlet and outlet liquid temperatures are the same (for example, on provers with high flow rates or on well-insulated provers). Under these conditions, one temperature sensor is acceptable if temperature measurements are performed periodically on the opposite end of the prover to verify that the two temperatures agree.

7.1.3 Prover Tanks

When determining the temperature of a liquid contained in a tank prover, for use in correcting for the thermal effects on the liquid and tank material, the following *minimum* numbers of temperature sensors are required for both insulated and non-insulated tanks:

a. Tanks with less than 380 liters (less than 100 gallons): 1 sensor.

b. Tanks with 380 to 1900 liters (100 to 500 gallons): 2 sensors.

c. Tanks with greater than 1900 liters (greater than 500 gallons): 3 sensors.

If one temperature sensor is used, it should be placed in the center of the tank vertical height. If two temperature sensors are used, one should be located in the upper one-third of the vertical height, and the other in the lower one-third. If three temperature sensors are used, one should be located in the upper one-third of the tank vertical height, one in the center, and one in the lower one-third of the tank vertical height. When two or more temperature sensors are used, they should be equally spaced around the tank's circumference.

Where a tank prover is insulated and/or its cycle is rapid, two temperature sensors may be sufficient in tanks over 1900 liters (500 gallons) capacity.

The temperature sensor element shall be positioned a minimum of 0.3 meter (1 foot) from the tank shell. (Refer to API *MPMS* Chapter 4.)

7.1.3.1 Field Standard Test Measures

When using field standard test measures (primarily for water draw calibrations) ranging in size up to 38 liters (10 gallons), immerse the temperature sensor into the center of the test measure through its neck. A total-immersion glass thermometer or a portable electronic thermometer may be used (see Sections 5 and 6). Volume readings should be taken immediately prior to immersion of a temperature sensor into the field standard test measure. Caution should be exercised to ensure that volume readings are not taken on the test measures while the temperature sensor is immersed in the water.

With larger field standard test measures, the temperature sensor is commonly held in the water stream during drainage of the field standard immediately after recording the volume reading. However, alternative methods of determining the water temperature in the field standard test measure may be required as a result of the unique characteristics of the temperature sensor or of the operating conditions.

On some large field-standard test measures, thermowells may be installed to house temperature sensors (Refer to API *MPMS* Chapter 4).

7.1.3.2 Test Facilities

A test thermowell should be provided close to temperature sensors that are permanently mounted in piping systems, such as in meter runs or meter prover systems. Caution should be exercised to be sure the thermowell is installed to a depth which will allow the reference thermometer to be inserted to approximately the same depth as the permanently installed temperature sensor. The test thermowell is used to make on-stream comparisons between the sensor and a thermometer certified by the National Institute of Standards and Technology (NIST) or a precision thermometer traceable to a NIST-certified reference thermometer (see 8.4).

7.2 TEMPERATURE DISCRIMINATION

A temperature sensor should be selected to meet the temperature discrimination requirements of API *MPMS* Chapter 12.2.

7.2.1 Prover Calibration

Prover calibration procedures require temperature discrimination to 0.05°C (0.1°F). Thermometers graduated to 0.1°C (0.2°F) and read to 0.05°C (0.1°F) are normally used to assure reliability and accuracy. All temperature devices, regardless of type, should be inspected and checked for accuracy prior to their use.

Pipe prover calibration calculations require prover temperature and withdrawal (water in test measure) temperatures be read to the nearest 0.05°C (0.1°F).

Tank prover calibration by water draw requires prover temperatures and the withdrawal temperatures (water in test measures) to be read to the nearest 0.05°C (0.1°F).

Master meter calibration of a pipe prover requires that the master meter be proved against a master prover. If a master tank prover is used, the temperatures taken are to be read to the nearest 0.05°C (0.1°F). If a master pipe prover is used, the prover liquid temperature is read to the nearest 0.05°C (0.1°F). In either case, the liquid temperature at the master meter is to be read to the nearest 0.05°C (0.1°F). The subsequent calibration of the pipe prover requires prover and master meter liquid temperatures be read to the nearest 0.05°C (0.1°F).

7.2.2 Meter Proving

The temperature sensor should be positioned in the flowing liquid and allowed to remain there, until the temperature of the liquid and the sensor have stabilized.

Meter proving procedures require that all temperatures be read to a minimum discrimination level of the nearest 0.25°C (0.5°F), and to higher levels of discrimination (for example, 0.1°F) if practical. For example, if thermometers used in meter proving have a graduation interval of 0.2°C or 0.2°F), then the temperature should be read and reported to the nearest 0.1°. For example, if a "smart" temperature transmitter is used that reads to the nearest 0.01°, then the temperature should be reported to the nearest 0.01°. Tank prover techniques require that temperatures taken be read to 0.25°C (0.5°F), while pipe prover techniques require prover and meter temperatures read to 0.25°C (0.5°F).

The above readings, or the average of a series of these readings, are rounded to a minimum discrimination level of the nearest 0.25°C (0.5°F), and to higher levels of discrimination (for example, 0.1°F) if practical before being used in calculations discussed in API *MPMS* Chapter 12.2.

7.2.3 Measurement Tickets

Measurement ticket temperature requirements are for temperature discrimination to the nearest 0.5°C (1.0°F). Various methods of applying temperature compensation are available to meet the requirements of API *MPMS* Chapter 12. The statement regarding reporting to a higher level of discrimination in 7.2.2 above also applies to measurement tickets.

8 Calibration Verification, and Inspection

All temperature measurement devices used for custody transfer *must* be calibrated and periodically verified against reference standards.

Just as flow meters are proved against a reference standard, temperature devices must be verified frequently as part of normal operations to assure proper performance. Facilities should be provided for frequently and routinely verifying the operational unit. Two or more operational devices can be compared as a check, but a thermometer certified by a nationally recognized laboratory such as NIST, or a thermometer traceable to a NIST-certified reference thermometer, should be used to verify the operational unit. Differences in the readings may indicate the need for calibration or replacement of the device.

Temperature devices may require checks or calibrations based on the use of a temperature-controlled source as reference. The use of such a source is often impractical in a field environment and is better accomplished in a controlled laboratory environment, or a shop or test facility in accordance with manufacturer's recommendations (refer to ASTM E 77).

Calibration of an existing or new temperature device should consist of temperature comparisons, at a minimum of three temperatures on uniform intervals over the operating range of the device.

The calibration can be accomplished similar to the verification procedure, except that a temperature-controlled source will facilitate the three-point test. The certification calibration corrections must be applied to the reference thermometer readings. The certified reference thermometer shall be graduated with scale marks at intervals not greater than twice the discrimination requirement of the temperature-measuring instrument. In the case of instruments having a discrimination requirement larger than 0.05°C (0.1°F), the reference thermometer should preferably have scale marks at intervals of, or less than, the discrimination, though not necessarily less than 0.1°C (0.2°F).

Calibration of electronic temperature devices should be performed in accordance with the recommended procedure provided by the manufacturer.

For additional information, refer to API *MPMS* Chapter 21.2.

8.1 FIXED AUTOMATIC TANK THERMOMETERS (ATTs)

ATTs to be used for custody transfer applications can be calibrated/verified either as a system, or by components. If verified as a system, the temperature reading of the ATT readout should agree with the bath temperature within ± 0.25°C (0.5°F) at a minimum of three test temperatures spanning the anticipated working range of the ATT. If the ATT is verified by components:

1. The temperature equivalent of the measured resistance should agree with the bath temperature within 0.20°C (0.40°F) at each temperature; and

2. The temperature transmitter/converter and the ATT readout should be checked using precision resistors or a recently calibrated thermal calibrator. The ATT readout should agree with the temperature equivalent of the resistors or calibrator within 0.15°C (0.3°F) at each temperature.

The overall accuracy of the system components shall not exceed 0.25°C (0.5°F).

For multiple-point ATTs, the required accuracy for each spot temperature sensor is as stated above, depending on how they are calibrated (i.e., as a complete thermometer system, or as components).

For variable length ATTs, the required accuracy for each temperature element should be as described above depending on the method used to calibrate them (i.e., as a complete thermometer system, or as components).

For inventory control and accounting temperature measurements, less stringent calibration procedures and tolerances may be used depending upon the requirements of the user or the regulations.

The remote readout of an acceptable ATT system may be used for custody transfer provided the whole system, including the remote readout, complies with the required calibration tolerances.

To prevent unauthorized adjustment or tampering, ATT systems used for custody transfer should provide facilities to allow sealing the calibration adjustment and should provide for data security.

The precision electronic temperature elements and field transmitters used for fixed automatic tank temperature measurement are factory calibrated. The transmitters normally do not provide field calibration adjustments.

The purpose of the following calibration procedures is to verify the adequacy of the factory calibration and the accuracy of the ATT system (including the temperature elements, the transmitter, and the local or remote readout equipment) as installed.

The accuracy of each component in an ATT system (that is, the temperature elements, the transmitters, and the remote readout equipment) is normally better than the accuracy of the calibration device or test equipment used for field verification. The calibration tolerances set forth in this standard reflect the accuracy limitations of this field verification equipment.

The calibration reference for an ATT system should be certified by or traceable to the National Institute of Standards and Technology (NIST). The uncertainty of the reference should not exceed ± 0.05°C (± 0.10°F).

8.1.1 Single-Point or Mid-Level Temperature Element ATT Systems

8.1.1.1 Factory Calibration

Single-point or mid-level ATT systems should be calibrated in one of the following ways:

a. The ATT system (including the temperature sensors, the temperature transmitter-converter, and the readout) as a whole is calibrated with constant temperature baths, at three or more temperatures covering the operating range. The temperature measured by the ATT system and the bath temperature that is measured by reference thermometers should be calibrated to within ± 0.25°C or 0.5°F at each temperature.

b. Alternately, the components of the ATT system are separately calibrated. Measure the resistance of the temperature element in the bath. The bath temperature and the temperature equivalent to the resistance should be within ± 0.15°C or 0.25°F at each temperature. Separately, use precision resistors or a thermal calibrator (recently calibrated against a reference traceable to NIST) to simulate temperature input to the temperature transmitter-converter and to the readout of the ATT system. The temperature measured and displayed by the ATT system and the temperature input should be calibrated to within ± 0.15°C or 0.25°F at each temperature.

8.1.1.2 Initial Field Verification

8.1.1.2.1 By Components

Separate calibration checks of the temperature element and the temperature transmitter are performed as follows:

a. Temperature element: Use a recently calibrated electronic digital thermometer to verify the measurement from the ATT temperature element. Lower the thermometer to the depth at which the element is located. The temperature measured by the thermometer and by the element should be within ± 0.5°C or 1°F.

b. Temperature transmitter: The ATT system, excluding the temperature element, can be verified by using a temperature calibrator (for example, precision resistors or a thermal calibrator) to simulate temperature input at three or more temperatures covering the expected tank operating temperatures. The ATT output or display should agree with the calibrator within ± 0.25°C or 0.5°F at each temperature. The temperature calibrator and precision resistors should be previously calibrated against a reference certified by NIST.

8.1.1.2.2 As a System

As an alternate to separate calibration checks of the temperature element and the transmitter, a portable electronic digital thermometer, calibrated immediately before verification, may be used to verify the entire ATT system. Because it may not be possible to position the thermometer close to the temperature element and because slight horizontal temperature stratification may exist, the measurement by the thermometer may not agree completely. In general, for ambient storage tanks, if the sensing element of the portable electronic thermometer can be placed within 1 meter (3 feet) of the fixed temperature element, calibration by a portable electronic thermometer is acceptable. If the temperature measured by the thermometer and by the fixed temperature element is within ± 0.5°C or 1°F, the ATT system is considered within calibration.

This method should not be used in heated tanks where uneven heating by heating coils is often encountered.

8.1.2 Calibration of Upper, Middle, and Lower or Multiple-Point ATT Systems

8.1.2.1 Factory Calibration

Refer to the factory calibration procedure for single-point or mid-level ATT systems. Each point (that is, temperature element) of the ATT system should be checked following the factory calibration procedure described in 8.1.1.1.

8.1.2.2 Initial Field Verification

8.1.2.2.1 By Components

Separate calibration checks of each temperature element and the temperature transmitter are performed as follows:

a. Temperature element: Use a recently calibrated electronic digital thermometer to verify the measurement from each ATT temperature element. Lower the thermometer to the depths at which the RTDs are located. For each temperature element, the temperature measured by the reference thermometer and by the ATT element should be within ± 0.5°C or 1°F.

b. Temperature transmitter: Refer to 8.1.1.1, item (b), for the field verification procedures for the temperature transmitter.

8.1.2.2.2 As a System

As an alternate to separate calibration checks of the temperature element and the transmitter, a portable electronic digital thermometer, calibrated immediately before verification, may be used to verify the entire ATT system.

The tank should preferably be nearly full, with all temperature elements submerged. Take ten temperature readings evenly spaced, or every 0.7 meters (2 feet), covering the entire liquid level. The manual average temperature by the portable thermometer is the average of the readings. The average temperature by the ATT system is the average temperature of all temperature elements submerged in the liquid. If the difference between these two average temperatures is within ± 0.5°C or 1°F, the ATT system is considered within calibration.

Note: An "Upper-Middle-Lower" ATT system, which automatically adjusts according to the liquid level, does not require the tank to be full.

8.1.3 Calibration of Variable Length ATT Systems

8.1.3.1 Factory Calibration

Refer to the factory calibration procedure for single-point or mid-level ATT systems. The average temperature read by each element (consisting of multiple RTDs) of the ATT system should be checked following the factory calibration procedure.

8.1.3.2 Initial Field Verification with a Portable Electronic Thermometer

This procedure is used to verify the variable length averaging ATT systems that automatically select the longest, fully submerged element to determine the average tank temperature. A portable electronic digital thermometer, calibrated immediately before verification, should be used to verify the entire ATT system.

The tank should preferably be nearly full, with all temperature elements submerged. Take ten temperature readings evenly spaced, or every 0.7 meters (2 feet), covering the entire liquid level. Manually select each temperature element (either by a software or a hardware switch). Compare the average temperature calculated from the appropriate portable thermometer readings against the average temperature measured by the temperature element selected and displayed by the ATT readout. For each temperature element, if the difference between the average temperature calculated from the portable thermometer and the average temperature read by the ATT system is within ± 0.5°C or 1°F, the ATT system is considered within calibration.

For small tanks (that is, the tank height is 10 feet or lower) with no temperature stratification, three temperature readings (at upper, middle, and lower levels) may be used to calculate the average temperature.

8.1.4 Marine ATTs

Marine ATTs must meet the same calibration and verification tolerances as shore tank ATTs. They can also be calibrated as a system or by component. They should similarly be factory calibrated before installation.

Note: The precision electronic temperature elements and onboard transmitters/converter used for fixed, automatic tank temperature measurement are calibrated before installation. The transmitters normally do not provide onboard calibration adjustments.

8.1.4.1 Onboard Verification of Marine ATTs

When an ATT is checked or calibrated by manual temperature measurement, the manual temperature measurement shall be performed in accordance with this standard. The uncertainty of the field calibration reference should not exceed ± 0.1°C (0.2°F), with any necessary calibration corrections applied.

8.1.4.2 Single-Point Temperature Element ATTs

8.1.4.2.1 Initial Verification at Shipyard or During Sea Trial

Initial verification and adjustment procedures at the shipyard or during sea trial should be performed in accordance with the ATT manufacturer's instructions. In addition, one of the following two procedures should be used if practical.

8.1.4.2.1.1 Verification by Components

a. Temperature Element. Use a recently calibrated, portable electronic thermometer (PET) to verify the measurement by the temperature element. With the cargo tank filled, lower the thermometer to the depth at which the element is located and move the PET up and down over a range of approximately 0.3 meters (1 foot) until the temperature is stable. The temperature by the RTD temperature sensor should agree with the temperature measured by the calibrated, portable electronic thermometer within 0.75°C (1.5°F).

Note: The tolerance is larger than that for shore tank based ATT systems because the location of taking manual temperature measurements with a portable electronic thermometer (through a vapor lock valve or other suitable gauging access point) is often not close to the location of the ATT temperature elements, and there are other additional factors which can result in marine cargo temperature measurement being less precise (refer to Appendix C).

b. Temperature Transmitter. The ATT, excluding the temperature element, can be verified by using a temperature calibrator (e.g., precision resistors, or a thermal calibrator) to simulate temperature input at three or more temperatures covering the expected tank operating temperatures. The readout for each temperature element of a multiple-point ATT should agree with the temperature equivalent of the resistors within ± 0.25°C (0.5°F) at each temperature.

8.1.4.2.1.2 Verification as a System

As an alternate to separate calibration checks of the temperature element and the transmitter, a portable electronic thermometer (PET), calibrated immediately prior to verification, may be used to verify the entire ATT, preferably with the cargo tanks nearly full and all temperature elements submerged. Because it may not be possible to position the PET close to the temperature element, and because slight horizontal temperature stratification may exist, the measurement by the thermometer may not agree completely.

The temperature readout from the ATT system (temperature sensor, temperature transmitter/converter, and readout) should agree with the temperature measured by a recently calibrated, portable electronic thermometer within ± 1°C (2°F).

Note: The tolerance is larger than that for shore tank based ATT systems because the location of taking manual temperature measurements with the PET (through a vapor lock valve or other suitable gauging access point) is often not close to the location of the ATT temperature elements, and there are other additional factors which can result in marine cargo temperature measurement being less precise (refer to Appendix C).

8.1.4.3 Multiple-Point ATTs

8.1.4.3.1 Initial Onboard Verification at Shipyard or During Sea Trial

Initial verification and adjustment procedures at the shipyard or during sea trial should be performed in accordance with the ATT manufacturer's instructions. In addition, one of the two procedures below should be followed if practical.

8.1.4.3.1.1 Verification by Components

a. Temperature Element. Use a recently calibrated portable electronic thermometer to verify the measurement by the temperature element. With the cargo tank near full, lower the thermometer to the depths at which the RTDs are located and move the thermometer up and down over a range of approximately 0.3 meters (1 foot) until the temperature is stable. Each temperature sensor (of a multiple-point ATTs) should agree with the temperature measured by the calibrated portable electronic thermometer within ± 0.75°C (1.5°F).

b. Temperature Transmitter. The ATT, excluding the temperature element, can be verified by using a temperature calibrator (e.g., precision resistors, or a thermal calibrator) to simulate temperature input at three or more temperatures covering the expected tank operating temperatures. The ATT readout should agree with the temperature equivalent of the resistors within ± 0.25°C (0.5°F) at each temperature.

8.1.4.3.2 Verification as a System

As an alternate to separate calibration checks of the temperature element and the transmitter, a portable electronic thermometer (PET), calibrated immediately before the verification, may be used to verify the entire ATT. The tank should preferably be nearly full, with all temperature elements submerged. Take temperature measurements at the depths of the temperature elements. At each measurement location, move the PET up and down (over a range of approximately 0.3 meters/1 foot) until the temperature is stable. The manual average temperature by the PET is the average of the readings. The average temperature by the ATT is the average temperature of all temperature elements submerged in the liquid. The average temperature read by the ATT system should agree with the average of the temperatures read by the calibrated PET within ± 1°C (2°F).

Note: The tolerance is larger than that for shore tank-based ATT systems because the location of taking manual temperature with the

PET (through a vapor lock valve or other suitable gauging access point) is often not close to the location of the ATT temperature elements, and there are other additional factors which can result in marine cargo temperature measurement being less precise (refer to Appendix C).

8.1.5 Subsequent Verification of ATT System Accuracy

8.1.5.1 Frequency of Subsequent Verification

A regular verification program should be established for fiscal, custody transfer and inventory control ATT systems. All essential components of the ATT system installation should be checked as recommended by the manufacturer's instructions. Every 3 months, each ATT system should be inspected and its calibration verified using the same procedures described in the initial field calibration paragraphs in this standard. Longer intervals may be acceptable when agreed by all parties.

8.1.6 Record Keeping

Full records shall be kept of the initial calibration and the periodic verifications of each ATT system, whether it is used for custody transfer or inventory control. Records shall be maintained for a minimum of 2 years, or in the case of marine vessels, a minimum of 20 voyages.

8.2 PORTABLE ELECTRONIC THERMOMETERS (PETs)

Before initial use, and at least once a year thereafter, each portable electronic thermometer (PET) shall be re-standardized in a laboratory or other qualified calibration facility. The PET shall be compared at three or more temperature points, near the midpoint and ends of the range, with either a National Institute of Technology (NIST) certified reference thermometer or an equivalent thermometer with accuracy traceable to the NIST. The PET shall be calibrated in accordance with the manufacturer's instructions. These standardization checks will ensure that accuracy is maintained within the limits given in Table 3.

8.2.1 Field Verification

Before each use, or once per day (whichever is less frequent), PETs should be spot checked by comparing the ambient reading against an ASTM glass stem thermometer in liquid. If the reading differs by more than ± 0.25°C (0.5°F), the portable electronic thermometer should be re-standardized before it is used for custody transfer.

8.2.2 Monthly Verification And Inspection

On a monthly schedule, the portable electronic thermometer should be checked at two or more temperatures near the ends of its range against a NIST-certified reference thermometer or an equivalent thermometer with accuracy traceable to the NIST. Make this check by either:

1. Placing the two thermometers side-by-side in a circulating bath and leaving them undisturbed for at least 10 minutes before making the comparative readings, or
2. Placing the thermometer in a metal block temperature generator that has been verified against a NIST-certified reference thermometer.

Alternatively, the ice point and boiling point of fresh water may be used for the accuracy check. The boiling point of fresh water must be corrected for altitude. If the thermometer readings differ by more than the tolerance listed in Table 3, the thermometer should be restandardized (see 8.2).

In addition the following physical checks should be made:

1. The junction between the cable and the probe should be checked for mechanical damage.
2. The cable insulation should be checked for cuts, breaks, or abrasion.
3. Grounding cable should be checked for damage.
4. Case body should be checked for cracks or damage.

If any of the damage above is noted, the PET shall be removed from service until repaired.

8.3 GLASS AND MERCURY-IN-GLASS THERMOMETER VERIFICATION

8.3.1 Bench Inspection

Before each thermometer's initial use and at least once a year after its initial use, each thermometer shall be compared to a thermometer certified by the National Institute of Standards and Technology (NIST) or an equivalent thermometer of traceable accuracy. The comparison shall be made at three or more temperatures to ensure that the thermometer is accurate within the limits given in Table 8. Typically, the checkpoints should be at 10%, 50%, and 90% of the temperature range in which the thermometer is expected to be used.

8.3.2 Field Inspection

A thermometer is a precision instrument; therefore, it must be handled with care and examined before each use for breakage and separation of the mercury column. Some other items to remember while field inspecting a thermometer are as follows:

a. After use in heavy or high-pour-point oils, all parts of the thermometer assembly shall be cleaned to avoid the formation of an insulating film of oil.

b. An armored-case thermometer is particularly susceptible to the formation of an insulating film, so the glass thermometer should be removed frequently from the metal assembly and cleaned.

c. A thermometer which has lost a substantial amount of pigment from its engraved scale should not be used in light colored products and condensates because it is difficult to read the graduation increments and numbers.

d. A thermometer with a separated mercury column shall never be used. If the mercury has been completely rejoined, the thermometer may be used provided it is found by bench inspection (as described in 8.3.1) to be accurate within the limits of Table 8.

8.4 DYNAMIC VERIFICATION AND CALIBRATION

Temperature devices that be verified periodically against a NIST-certified reference thermometer or a thermometer traceable to a NIST-certified reference thermometer to ensure accuracy. Verification confirms whether or not the temperature device is operating within acceptable parameters, or requires calibration, repair or replacement.

Temperature devices that are used for intermittent service, such as prover calibration, must be verified before each use against a NIST-certified reference thermometer or a thermometer traceable to a NIST-certified reference thermometer.

Temperature devices that are in continuous service shall be verified periodically, while on line, against temperature devices in the system and against a NIST traceable test. The frequency of verification or calibration will vary depending on system volume, attended or unattended operation, and other operational or regulatory factors. Quarterly verification of accuracy should be a minimum requirement (i.e., the maximum length of time between verification). More frequent checks are recommended (e.g., during every meter proving). Temperature devices installed in systems that are in periodic service should be checked on a frequency consistent with these continuous service guidelines.

The recommended maximum deviation limits between the operating device and the certified reference thermometer are shown in Table 8. A deviation greater than those limits indicate that corrective action is required in the form of calibration or replacement of the inaccurate device. These limits may be subject to other guidelines existing in agreements, contracts, regulations, or company policy. Table 8 is provided as a reference for limits considered acceptable for dynamic temperature determinations in custody transfer measurement of petroleum and petroleum products.

Inspect all thermometers to ensure that the medium columns are continuous (no separations) and that the thermometer is clean and free of insulating coatings. If the scale graduations are not legible, replace the device.

Table 8—Maximum Deviation Limits: Temperature Device Versus Reference Thermometer

Service	°C	°F
Meter Prover Calibration	0.05	0.1
Meter Proving	0.10	0.2

8.4.1 Verification Procedures

The verification procedure shall consist of at least one comparison at a temperature within the operating range, between the temperature device and the reference thermometer. If the deviation limits of Table 8 are exceeded, then the temperature device shall be re-calibrated or replaced.

The verification is accomplished by placing the operational temperature device and the reference thermometer into a source of uniform temperature. Using a temperature-controlled source (e.g., temperature bath) may do this. However, it should preferably be performed in the operating pipe or vessel, providing that suitable facilities exist for the simultaneous registration of temperature by the operational device and the calibration instrument. The verification point positions should be adjacent to one another and the temperature must be allowed to stabilize before recording the comparative readings.

Precision glass thermometers have scale graduation intervals of 0.1°C to 0.2°C (0.2°F to 0.5°F) and should be supplied with a calibration certificate that details corrections which are to be applied to observed readings. They may be of the partial- or complete-immersion type. Partial-immersion thermometers should be immersed to the proper level as marked on the thermometer. Usage at different immersion depths or at significantly different ambient temperatures from which the thermometer was certified may require that stem corrections be made. Complete-immersion thermometers are typically used partially immersed into a thermowell. The portion of the stem that is outside the thermowell will respond to the ambient temperature, and may cause a significant error in the reading, depending on the difference between the temperature being measured and the ambient temperature and the amount of active stem that is exposed to the ambient condition. Corrections should be made where necessary, in accordance with the procedure detailed in Appendix D.

When a verification test is performed, the "as found" reading should be recorded and compared to the reference thermometer. Should the "as found" reading fail to agree with the reference thermometer, within the required control limit, a calibration of that device will be required. The reference thermometer should have a minimum resolution of 0.1°C (0.2°F). If the device being verified is to supply data for use during meter proving, it should agree within 0.1°C (0.2°F) of the reference thermometer.

Where portable electronic thermometers are used for dynamic temperature measurements, their calibration verification tests should be in accordance with Section 8.2.

9 Factors that Affect Temperature Measurement Uncertainty

9.1 FIXED AUTOMATIC TANK THERMOMETERS

The accuracy of petroleum temperatures taken by the ATT system should be consistent with the accuracy of the levels taken by the automatic tank gauging (ATG) system so that the overall accuracy of the standard volume measurement is not degraded.

The accuracy of an ATT system depends on the following conditions:

a. The tank temperature stratification and the location of the temperature sensing elements.

b. The resistance or temperature characteristics of the resistance temperature detectors (RTD).

c. The accuracy of the ATT system readout equipment.

9.1.1 Intrinsic Error of ATTs

The temperature measurement accuracy of all ATTs will be affected by the intrinsic error of the ATT; i.e., the accuracy of the ATTs when tested under controlled conditions as specified by the manufacturer. The calibration reference should be traceable to appropriate international standards. The temperature elements and field transmitters used for fixed ATT measurement are calibrated before installation, and the transmitters normally do not provide field calibration adjustments.

9.1.2 Error Caused by Installation and Operating Conditions

The total error of the ATT for custody transfer service can be affected by the installation and by variations in the operating conditions.

The accuracy of an ATT depends on the following:

- The number of temperature sensing elements
- The location of the temperature sensing elements

The tank content's temperature may be subject to stratification which varies with:

- Cargo heating method and/or location of heating coils
- Multiple sources of supply
- Viscosity of the liquid in the tanks
- Tank insulation
- Adjacent tank temperatures
- Seawater temperature for tanks in contact with the ship hull and bottom.

Temperatures in large tanks are often vertically stratified unless the contents are thoroughly mixed. Larger stratification may be expected in high viscosity petroleum liquids. Temperatures in wing tanks can also be horizontally stratified due to effect of the sea temperature.

9.2 DYNAMIC TEMPERATURE EQUIPMENT

API *MPMS* Chapter 12 provides requirements for minimum acceptable discrimination for dynamic temperature measurements and calculations in custody transfer measurement of petroleum and petroleum products. Table 8 provides maximum acceptable deviation limits for agreement between two temperatures.

9.2.1 Transmitter Accuracy

All transmitter accuracies should be stated as ± temperature values. The stated accuracy of a transmitter can be expressed as 1) a percentage of the upper range value (URV), or 2) a percentage of the calibrated span. For example, a transmitter has a URV of 250°F. It has been calibrated over a span of 0°F – 180°F. Assume flowing temperature to be 100°F. Therefore, if the transmitter accuracy is stated as:

- ± 0.25% of URV, then the accuracy is ± 0.625°F
- ± 0.25% of calibrated span, then the accuracy is ± 0.45°F

It is critical to understand what the manufacturer's specifications mean with respect to accuracy, before choosing the equipment for your application.

While most temperature transmitters have a manufacturer's stated accuracy, the accuracy of "as installed" transmitters can be affected by:

- Ambient temperature effects
- Vibration effects
- Power supply effects
- Mounting position effects

It is important to evaluate the effects of these conditions, and calculate their effect to determine the "as installed" accuracy of the temperature transmitter.

APPENDIX A—EMERGENT-STEM CORRECTION FOR LIQUID-IN-GLASS THERMOMETERS

Precision thermometers are typically calibrated with the entire stem immersed in the bath, which determines the temperature of the thermometer bulb. However, it is common practice when using a thermometer to permit its stem to extend out from the thermowell or liquid. Under these conditions, both the stem and the mercury in the exposed stem are at a temperature different from the bulb. This introduces an error into the observed temperature. Since the coefficient of thermal expansion of glass is less than that of mercury, the observed temperature will be less than the true temperature if the bulb is hotter than the stem and greater than the true temperature if the thermal gradient is reversed. For exact work, the magnitude of this error can only be determined by experiment. However for most purposes, and where specific manufacturer's information is lacking, it is sufficiently accurate to apply the following equation which takes into account the difference of the thermal expansion of glass and mercury.

$$T_c = T + kn(T - t)$$

where

T_c = corrected temperature,

T = observed temperature,

k = mercury-glass-correction factor; for degrees Fahrenheit use 0.00009; for degrees Celsius use 0.00016,

n = the number of degrees emergent above the surface of whose temperature is being determined,

t = average temperature of exposed stem.

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APPENDIX B—LOCAL DIRECT-READING THERMOMETERS

B.1 General

Most aboveground bulk storage tanks are equipped with at least one local direct-reading thermometer mounted in a fixed thermowell. This local thermometer is *not* recommended for custody transfer temperature determination because it is usually inaccurate and it does not provide an average tank temperature unless the tank contents are at a uniform temperature. Rather, it provides a rough check on the custody transfer temperature measurement.

Table B-1 describes thermowells and location for tank temperature measurement.

B.2 Thermowells for Local Reading Thermometers

The thermowell for the fixed direct-reading thermometer should extend through the tank shell for at least 0.3 meters (1 foot). A longer immersion depth (0.6 to 0.9 meters or 2 to 3 feet) will reduce errors caused by the effect of the ambient air temperature on the liquid immediately adjacent to the tank shell. The thermowell material should be compatible with the liquid. Usually Type 304 or 316 stainless steel is specified.

The thermowell and the thermometer should be located for convenient reading near the stairway, ladder, or ATG. The thermowell should be located approximately 0.9 to 1.2 meters (3 to 4 feet) above grade for ease of reading and to lessen bottom effects. However, the thermowell must be low enough to clear the landed roof of a floating-roof or pan-roof tank.

A thermowell fill fluid will reduce the thermometer's response time to react to temperature changes. Fill fluids should have a low volatility and freeze point. If the thermowell is sloped down from the horizontal, it will retain the fill fluid better; however, thermowells designed for the angle-stem, industrial-type glass thermometers should be horizontal.

B.3 Local Direct-Reading Thermometers

B.3.1 ANGLE-STEM, INDUSTRIAL-TYPE GLASS THERMOMETERS

Angle-stem, industrial-type glass thermometers are installed in standard metal separable thermowells in the tank. The glass stem of the thermometer must be at least 0.3 meters (1 foot) long and must be protected with a light, metal tube. The sensitive portion of the thermometer should not exceed 60 millimeters (2.5 inches). The assembly should be attached to the well by a threaded coupling. A thermometer with a separate graduated scale is acceptable provided that the markings on the scale are permanently engraved and the markings are etched on the glass stem of the thermometer, near the ends of the range, to coincide with the corresponding lines on the scale.

B.3.2 BIMETAL-ACTUATED DIAL THERMOMETERS

Bimetal-actuated dial thermometers are installed in standard metal separable thermowells sloping downward into the tank. The stem of the thermometer should be at least 0.3 meters (1 foot) long, and the sensitive portion of the thermometer should not exceed 60 millimeters (2.5 inches). The assembly should be attached to the well by a threaded coupling.

B.3.3 MERCURY-ACTUATED DIAL THERMOMETERS

Mercury-actuated dial thermometers are installed in standard metal separable thermowells sloping downward into the tank. The stem of the thermometer should be at least 0.3 meters (1 foot) long. The assembly should be attached to the well by a threaded coupling.

Table B-1—Tank Appurtenances for Temperature Measurement

Tank Type	Fixed Temperature Measurement	Portable Temperature Measurement
Fixed-roof tanks	Thermowell for local thermometer	Roof hatch
	Thermowell for remote readout	
	Thermowells or vertical temperature well for average temperature assemblies	
Floating-roof or internal floating-roof tanks	Thermowell for local thermometer	Gauging hatch and slotted gauging well
	Thermometer for remote readout	
	Vertical temperature well for average temperature assemblies	

APPENDIX C—ACCURACY LIMITATIONS OF TANK TEMPERATURE MEASUREMENTS ONBOARD MARINE VESSELS

Tank temperature measurements using marine ATTs are limited by the following inherent limitations, regardless of the ATTs used:

1. Change of the cargo temperature due to loading temperature.

   Shortly after loading, cargo holds in contact with ballast tanks or sea water (nowadays a rare case due to SOLAS regulations for cargo segregation), a sharp temperature step gradient in the vertical direction may develop, under the influence of a very different rate of heat exchange of the cargo above and below the water line, assuming that the cargo temperature is above the water temperature. Below the waterline a strong convection circulation is set in motion by the heat exchange between cargo and ballast/sea water through vertical parts of the ship's hull. In the horizontal direction the temperature differences in a cargo are only very small, due to the equalizing effects of the convection circulation. A marked temperature difference may, however, exist initially between wing and center tanks because the center tanks mainly exchange heat with the seawater via the wing tanks forming a barrier.

2. Change of the cargo temperature due to seawater temperature.

   Temperature differences may exist because the tank bulkheads may be in contact with the ocean (nowadays a rare case due to SOLAS regulations for cargo segregation), making it difficult to determine an accurate average cargo temperature.

3. Change of the cargo temperature due to adjacent cargo tank temperature.

4. Change of the cargo temperature due to cargo heating.

5. Thermal offsets and time delays due to thermowell design and properties.

The limitations listed above may have significant impact on the overall accuracy of temperature measurement by all types of marine automatic tank thermometers.

APPENDIX D—TEST PROCEDURE FOR DETERMINING IMMERSION TIMES OF MERCURY-IN-GLASS TANK THERMOMETERS AND THEIR ASSEMBLIES

D.1 Equipment

The following equipment is needed to conduct the test procedure described in this appendix:

a. One insulated, temperature-controlled bath with a capacity of approximately 100 liters (30 gallons).

b. One NIST-certified glass thermometer or an equivalent of traceable accuracy.

c. One portable electronic thermometer.

d. Two mercury-in-glass tank thermometers and their assemblies (for example, woodback cup-case assembly).

D.2 Test Temperatures

All tests start with the glass thermometers in their assemblies stabilized at ice point. Suggested bath temperatures at which immersion times should be measured are provided in Table D-1.

D.3 Before the Tests

D.3.1 Glass thermometers shall be removed from their assemblies and verified against a NIST-certified reference thermometer or an equivalent of traceable accuracy. Verifications should be made at the approximate average test-bath temperature and at temperatures that are approximately ± 30% of the average. Only thermometers that agree within ± 0.3°C (0.5°F) of each test point can be used. Two thermometers are needed to obtain duplicate readings at each test-bath temperature.

D.3.2 If a portable electronic thermometer is used to determine test-bath temperatures, it is to be verified according to D.3.1.

D.4 Test Procedure

D.4.1 Determine the test-bath temperature by measuring it with a portable electronic thermometer, a certified glass-stem thermometer, or a glass-stem thermometer of known accuracy. This thermometer is to be suspended at all times in the bath at the same level as the test assembly.

D.4.2 Stabilize the test bath at the lowest temperature as determined by Table D-1. The bath is not to be stirred, circulated, or heated while data is being taken. For gravities greater than or equal to 25° API, the bath temperature should be within ± 0.3°C (0.5°F) of the desired test temperature at the start of the test. For gravities less than 25° API, the bath temperature should be within ± 5% of the selected test temperature at the start of the test. Stabilize the tank thermometers in their assemblies at ice point.

Table D-1—Suggested Bath Temperatures

°API Gravity at 60°F	Test Bath Temperatures[a]
≥ 25	7°C, 16°C, 27°C, 38°C, 49°C (45°F, 60°F, 80°F, 100°F, 120°F)
< 25	Average handling temperature ± 15°C (25°F) for a total of three test points[b]

[a]Take care not to approach or exceed the flash point of the test medium.
[b]The temperature ± 15°C (25°F) may need to be adjusted to accommodate the pour and flash points. It shall be adjusted to obtain the maximum differential for obtaining three test temperatures.

D.4.3 Take care during the test runs not to have direct air movement across the bath from open windows or air conditioning ducts

D.4.4 Totally submerge the tank thermometers and their assemblies in the test bath using a string. At the intervals specified in Table D-2, raise and read the thermometers one at a time. The maximum time allowed for reading a thermometer is not to exceed 15 seconds in a test medium greater than or equal to 25°API and 30 seconds in a test medium less than 25°API. Readings are to be taken until three consecutive readings that agree within ± 0.3°C (0.5°F) of the bath temperature as determined with the certified or verified glass thermometers or portable electronic thermometer are obtained with each thermometer. All readings should be recorded to the nearest 0.5°C (1.0°F).

Table D-2—Time Intervals for Reading Thermometers

°API Gravity at 60°F	Assembly	Reading Interval (minutes)
≥ 25	In-motion	2
	Stationary	2
20 to 24	In-motion	2
	Stationary	5
12 to 19	In-motion	2
	Stationary	10
< 12	In-motion	a
	Stationary	a

[a]Tests should be conducted to determine acceptable intervals.
Note: Reading intervals are inclusive of reading times which are a maximum of 15 seconds in mediums greater than or equal to 25°API and 30 seconds in mediums less than 25°API.

D.4.5 In the stationary assembly test, create as little disturbance in the test bath as possible when withdrawing and reading the thermometers. For the in-motion assembly test, move the assembly up and down a minimum distance of 150.0 millimeters (6 inches), ten times per minute. Readings for both the stationary and the in-motion assembly tests shall be taken with the assembly completely withdrawn from the test medium.

D.4.6 Repeat D.4.1 through D.4.5 for each of the next higher test-bath temperatures as determined by Table D-1 until results are available for all test temperatures. Note that for each higher temperature, the thermometer assemblies are to be stabilized at ice point before the test run is commenced.

D.4.7 The time taken for each tank thermometer assembly to reach thermal equilibrium with the test bath shall be recorded for each successive test-bath temperature/API gravity combination, and the necessary time interval to be used in actual practice shall be established.

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