Manual of Petroleum Measurement Standards Chapter 7.3

Temperature Determination—Fixed Automatic Tank Temperature Systems

SECOND EDITION, OCTOBER 2011

AMERICAN PETROLEUM INSTITUTE

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Measurement Coordination

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energy API
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Foreword

This foreword is for information and is not part of this standard. This standard discusses equipment, methods and procedures for determining the temperature of hydrocarbon liquids using fixed automatic tank temperature systems.

The below listed sections are removed from API *MPMS* Chapter 7, “Temperature Determination”, 1st edition 2001 and are covered by this publication of API *MPMS* Chapter 7.3 “Temperature Determination-Fixed Automatic Tank Temperature Systems”, 2nd edition, 2011.

— 5.1 Fixed Automatic Tank Thermometers (ATTs)

— 5.5 Thermowells

— 5.6 Data Collection, Data Transmission, and Receiving Equipment

— 6.1 Ambient Temperature

— 6.3 Fixed Automatic Tank Thermometers

— 8.1 Fixed Automatic Tank Thermometers (ATTs)

— 9.1 Fixed Automatic Tank Thermometers

Revision of API *MPMS* Chapter 7-2001 is ongoing. The revision of API *MPMS* Chapter 7 will divide the current standard into four separate standards. It is anticipated that these four standards, including API *MPMS* Chapter 7.3-2011 referenced above, will supersede the sections of API *MPMS* Chapter 7-2001 as follows.

API *MPMS* Chapter 7, “Temperature Determination”, 1st edition 2001, sections:

— 5.3 Glass Thermometers

— 5.5 Thermowells

— 5.6 Data Collection, Data Transmission, and Receiving Equipment

— 6.1 Ambient Temperature

— 6.5 Mercury-in-Glass Thermometers

— 8.3 Glass and Mercury-in-Glass Thermometer Verification

to be covered by API *MPMS* Chapter 7.1, 2nd Edition, 'Liquid-in-Glass Thermometers”.

API *MPMS* Chapter 7, “Temperature Determination”, 1st edition 2001, sections:

— 5.2 Portable Electronic Thermometers (PETs)

— 5.4 Electronic Temperature Devices

— 5.5 Thermowells.

— 5.6 Data Collection, Data Transmission, and Receiving Equipment

— 6.1 Ambient Temperature

— 6.4 Portable Electronic Thermometers

— 8.2 Portable Electronic Thermometers (PETs)

to be covered by API *MPMS* Chapter 7.2, 3rd Edition, “Portable Electronic Thermometers (PETs)”.

API *MPMS* Chapter 7, “Temperature Determination”, 1st edition 2001, sections:

— 5.5 Thermowells.

— 5.6 Data Collection, Data Transmission, and Receiving Equipment

— 7 Dynamic Temperature Measurement

— 8.4 Dynamic Verification and Calibration

— 9.2 Dynamic Temperature Equipment

to be covered by API *MPMS* Chapter 7.4, 2nd Edition, “Dynamic Temperature Measurement”.

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

Should: As used in a standard, “should” denotes a recommendation or that which is advised but not required in order to conform to the specification.

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Suggested revisions are invited and should be submitted to the Standards Department, API, 1220 L Street, NW, Washington, DC 20005, standards@api.org.

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Introduction

The purpose of this standard is to describe methods and practices that can be used to obtain accurate temperature measurements of petroleum and petroleum products in storage tanks, ships and barges under static conditions by the use of an automatic method.

Temperature has a significant effect on the accurate determination of liquid quantities when correcting to standard conditions for custody transfer and inventory control purposes. A temperature of the liquid in the tank is used in these applications, so it is imperative that temperatures be determined accurately and are representative of the tank content.

This standard presents both Metric (SI) and US Customary units, and can 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.

In cases where marine applications have different requirements, they are handled in separate subsections.

Temperature Determination—Fixed Automatic Tank Temperature Systems

1 Scope

This standard describes the methods, equipment, and procedures for determining the temperature of petroleum and petroleum products under static conditions by the use of an automatic method. Automatic temperature measurement is discussed for custody transfer and inventory control for both onshore and marine measurement applications.

Temperatures of hydrocarbon liquids under static conditions can be determined by measuring the temperature of the liquid at specific locations. Examples of where static temperature determination is required include storage tanks, ships and barges.

The application of this standard is restricted to automatic methods for the determination of temperature using fixed automatic tank thermometer (ATT) systems for hydrocarbons having a Reid Vapor Pressure at or below 101.325 kPa (14.696 psia).

Although not included in the scope, requirements in this standard or other Chapter 7 Sections (see the Foreword) can be used for other fluids and other applications including petroleum liquids having Reid vapor pressures in excess of 101.325 kPa (14.696 psia) tanks with inert gas systems and cryogenic liquids. However, such applications can require different performance and installation specifications.

2 Normative References

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

API *MPMS* Chapter 12.1.1, *Calculation of Static Petroleum Quantities,* Part 1—*Upright Cylindrical Tanks and Marine Vessels*

3 Terms, Definitions, and Acronyms

For the purposes of this document, the following definitions apply.

3.1 Terms and Definitions

Terms used in this chapter are defined as follows:

3.1.1
automatic tank thermometer
ATT
An instrument used to continuously generate and transmit a representative measure of the temperature of the contents of any tank, bullet, vessel, or compartment by any means other than by the manual use of a thermometer or Portable Electronic Thermometer (PET). ATTs may include a local temperature display.

3.1.1.1
spot ATT
single-point ATT
A temperature instrument that measures the temperature at a particular point in the tank where the spot temperature sensor is located.

3.1.1.2
multiple-spot ATT
multiple-point ATT
multi-point ATT
A temperature instrument consisting of a number of individual spot temperature sensors (usually three or more) bundled together as a temperature element to measure the temperature at selected liquid levels in the tank.

NOTE The display equipment for a multiple- spot averaging ATT should average the readings from the submerged temperature elements sensors to compute the average temperature of the liquid in the tank, and may also display the temperature profile in the tank.

3.1.1.3
variable-length ATT
An averaging ATT consisting of several temperature sensors of varying length. All sensors extend upwards from a position close to the bottom of the tank. The ATT system selects the longest, completely submerged temperature sensor to determine the average temperature of the liquid in the tank.

3.1.1.4
averaging ATT
An ATT which performs an averaging function, selects one or more temperature sensors submerged within the tank liquid, and determines a representative average temperature based on those sensor reading(s). An averaging ATT may be of the following types:

— **multiple-spot ATT**: A component of the ATT system averages the reading of the submerged temperature sensors to compute the average temperature of the liquid in the tank.

— **variable-length ATT**: The ATT system selects the longest, completely submerged temperature sensor to determine the average temperature of the liquid in the tank.

3.1.2
ATT system
An automatic tank thermometer system includes one or more ATTs and device(s) used to display temperatures, perform calculations, and generate alarms as well as the means to transmit data between the ATT(s) and display device(s).

3.1.3
protecting tube
A tube designed to enclose a temperature sensing device and protect it from the environment and process.

NOTE A protecting tube is not designed for pressure-tight attachment to a vessel.

3.1.4
stilling well
Stilling wells are tubes within a tank that are used for gauging activities including sampling and the determination of level and temperature.

3.1.5
tank
As used in this standard, a tank refers to a storage tank, ship or barge compartment or any other vessel to which this standard is applicable as stated in its scope and introduction.

3.1.6
temperature element
One or more sensors housed in a casing such as a metal probe or protecting tube that makes up a single temperature measuring unit for a thermometer.

3.1.7
temperature sensor
A temperature sensor is one part of a thermometer in which some physical change occurs with temperature and converts this change into a value on a scale, (e.g. the scale on a liquid-in-glass thermometer, a digital device that displays a unit of measure).

3.1.7.1
resistance temperature detector
RTD
A temperature measuring device that operates on the principle of a change in electrical resistance in wire as a function of temperature.

3.1.7.2
thermocouple
A thermocouple is a junction between two different metals that produces a voltage related to a temperature difference.

3.1.8
temperature transmitter
A device that converts the temperature measured by the sensor(s) to electrical or electronic signal, and transmits the signal to a remote or local display.

3.1.9
thermometer
A device that measures temperature using any of a variety of different principles. A thermometer has two important components: a temperature sensor in which some physical change occurs that is dependent on temperature, and some means of indicating and/or transmitting this physical change as a value.

3.1.10
thermowell
Pressure and liquid tight receptacle adapted to receive a temperature sensing element and provided with external threads, flanges or other means for pressure tight attachment to a vessel. A thermowell allows the temperature sensor to be removed and replaced without compromising the process.

3.2 Acronyms and Abbreviations

The following acronyms are used in this publication.

API MPMS	*Manual of Petroleum Measurement Standards*
ATG	automatic tank gauge
ATT	automatic tank temperature
DCS	distributed control system
EMF	electromotive force
FAT	factory acceptance test
IEC	International Electrotechnical Commission
IGS	inert gas system
IMO	International Maritime Organization
ISGOTT	*International Safety Guide for Oil Tankers and Terminals*
ISO	International Organization for Standardization
NEC	*National Electric Code*

NFPA	National Fire Protection Association
NMI	National Metrology Institute
OCIMF	Oil Companies International Marine Forum
PET	portable electronic thermometer
PLC	programmable logic controller
RP	Recommended Practice
RTD	resistance temperature device
SAT	sites acceptance test
SOLAS	*Safety of Life at Sea*
USCG	United States Coast Guard

4 Precautions

4.1 General

Safety considerations shall be included in all equipment specifications, installation and operation. Refer to API 500, API 551 [3], NFPA 70 [9], and API 2003 [4] 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 [1].

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 NFPA 70, *National Electric Code* (NEC) [9].

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.

4.2 Equipment 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.

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. Some integrated ATG/ATT designs may not be suitable for continuous use. For example, float-operated ATGs may need the level/temperature sensor assembly to be raised to a "store" position when it is not being used.

NOTE 3 Certain tank operations such as tank washing on marine vessels, may require removal of the ATT or special precautions be taken to avoid damage.

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 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.

Security—ATT systems should provide security to prevent unauthorized adjustment. ATT systems used in fiscal/custody transfer application should provide facilities to allow sealing for calibration adjustment.

5 Equipment and Design Requirements

5.1 Equipment and Apparatus

5.1.1 Temperature Sensors

ATTs generally use one of the following types of temperature sensors:

— resistance temperature detector (RTD);

— thermocouple.

These devices are usually housed in metal probes that normally mount into thermowells (spot ATTs) or protection tubes (multi-spot or variable length ATTs). For spot ATTs, the probes are generally tip-sensitive. Thus, the probes shall be securely seated in the bottom of the thermowell for optimum heat transfer. Spring-loaded or adjustable-length probes are recommended.

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 sensors require linearization that is typically accomplished within the associated transmitter. Each type of sensor requires its own unique circuit.

The selected sensor shall meet the requirements given in Table 4.

5.1.1.1 Resistance Temperature Detectors

The resistance temperature detector (RTD) is typically made of platinum although other metals such as copper may be used, which is encapsulated in protective material to guarantee long term stability. The sensing element itself should be packaged in an enclosure suitable for the application and installation (typically this is made out of stainless steel). A suitable electronic circuit can be used to measure the transducer resistance by means of a small current (to prevent self heating) and convert the value into a corresponding temperature.

For platinum RTD temperature sensors, standards such as IEC 60751 [8] and ASTM E1137 [7] are available which specify accuracy and performance requirements. These standards cover requirements for various types of testing and define different classes or grades corresponding to different tolerance requirements, as well as mathematical expressions characterizing the temperature-resistance relationship. Sensors produced according to these standards result in the use of either classified or characterized [1] sensors with a stable and well defined relationship between operating temperature and expected tolerances.

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1 In this context, a characterized sensor means that the output of an individual RTD has been compared at several temperatures to equipment traceable to an NMI, resulting in a set of constants to be used in a mathematical expression to characterize the temperature-resistance relationship for the specific RTD in accordance with the standards mentioned.

The use of classified or characterized sensors in compliance with such standards is optional, but for certain applications the added accuracy may be warranted.

RTDs are recommended for custody transfer applications because of their accuracy, responsiveness, long life, and the stability of their output characterization over time. An RTD is less subject to electrical interference and errors caused by changes in the properties of lead-in wires than thermocouples.

When selecting an RTD, consider three or four-wire RTDs as they allow compensation of the (temperature dependent) lead wire resistance. The length of the temperature sensitive portion of a spot ATT sensor should not exceed approximately 100 mm (4 in.).

5.1.1.2 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. There are many different types of thermocouples each with their own measurement range, encompassing temperatures from about –150 °C (–300 °F) to about 1,300 °C (2,300 °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 electrical interference;

— 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.

5.1.1.3 Other Temperature Sensors

Other types of temperature sensors (e.g. thermistors, semiconductors, etc.) are also available and may be suitable for custody transfer purposes provided they meet the performance requirements of Section 8.

5.1.2 Spot ATT

A spot ATT measures the temperature at a particular position in the tank where the spot temperature sensor is located. Because temperature is measured only at one fixed location within the tank, the spot ATT may not be representative of the average tank temperature. The position of the spot temperature measurement relative to the liquid surface will vary depending on tank fill.

5.1.3 Averaging ATT

An ATT which performs an average function selects one or more temperature sensors submerged within the tank liquid, and determines a representative average temperature based on those sensor readings. Averaging ATTs are almost always integral components of an ATG system although ATTs designed to sense the level or receive a level signal could perform the averaging function. Averaging ATTs consist of multiple-spot and variable- length types as described below.

5.1.3.1 Number of Sensors

Position of the sensors within a tank should be such that each sensor represents approximately the same cross sectional tank volume.

To avoid ambient temperature effects placement of sensors within 1 m (3 ft) of the tank shell or tank bottom is not recommended. For additional installation details see Section 6.

The recommended minimum number of sensors is given in Table 1. Additional sensors may be advisable if significant tank temperature stratification exists (see 5.3.2).

Table 1—Minimum Number of Temperature Sensors

Maximum Filling Height	No. of Sensors[a, b]
< 9 m (30 ft)	4
9 m (30 ft) to 15 m (50 ft)	5
15 m (50 ft) to 23 m (75 ft)	6
23 m (75 ft) to 30 m (100 ft)	7

[a] The number of temperature sensors and the locations shown are a suggested minimum.

[b] Refer to 5.1.3.2 and 5.1.3.3 in case of tanks with large temp stratification.

For tank with a regular cross sectional profile equations 1 through 4 may be used to determine sensor elevation. For multiple-spot ATTs the equations determine the height of the spot sensor from tank bottom (3). For variable-length ATTs the equations determine the height of the variable-length sensor (4).

For tanks with irregular cross sectional profile, variable-length ATTs are not generally recommended because they will produce an erroneous average value if tank temperature stratification is present. For multi-spot ATTs follow the ATT manufacturer recommendations.

In SI units:

$$S = \left[\frac{(H-1)}{(N-0.5)}\right] \tag{1}$$

where

S is the spacing between sensors, m;

H is the maximum tank fill height, m;

N is the number of sensors, see Table 1 for suggested minimum.

In US Customary units:

$$S = \left[\frac{(H-3)}{(N-0.5)}\right] \tag{2}$$

where

S is the spacing between sensors, ft;

H is the maximum tank fill height, ft;

N is the number of sensors, see Table 1 for suggested minimum.

Using the spacing determined in equation 1 or 2 the elevation of sensors 1 through N is calculated as follows:

$$En\_spot = B + (n-1) \times S \tag{3}$$

$$En\_variable = n \times S \tag{4}$$

where

En_spot	is the elevation from tank bottom for spot sensor, n (m or ft);
$En\_variable$	is the height of variable-length sensor, n (m or ft);
n	is the sensor number, ranging from 1 to N;
B	is the level of bottom sensor, 1 m (3 ft);
S	is the spacing between sensors (m or ft).

5.1.3.2 Multiple-Spot (Averaging) ATT

Multiple-spot temperature sensors are installed (or encased in a flexible element housing) at approximate 2 m to 3 m (6 ft to 10 ft) intervals with the lowest sensor approximately 1 m (3 ft) from the bottom of the tank. Typically, all temperatures for an ATT element are measured by a single transmitter. The ATT transmitter may be an integral part of an ATG system which has computing ability to provide a tank temperature profile and/or an average temperature (based on the submerged sensors), or in some cases, the averaging function may be performed by the ATT transmitter/system. A typical multiple-spot temperature sensor installation is shown in Figure 1.

Where the tank is operated at a level lower than 1 m (3 ft), an extra temperature sensor can be located at a level as low as practical so as to have a submerged sensor when the tank is operated in this range. This sensor should not be averaged with the other ATT sensors when the tank is operated at or above 1 m (3 ft) to avoid a misrepresentative average caused by ambient ground temperature effects.

5.1.3.3 Variable-Length ATT

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 RTD is typically selected either by a switching device in an ATT or ATG transmitter or by software elsewhere in the system (typically human-machine interface (HMI) computer).

Because of the use of a bottom mounting bracket and/or anchor weight, the sensitive portion of the element begins at some level above tank bottom, typically 0.15 m (6 in.), so that the lowest 0.15 m (0.5 ft) in the tank is not measured. Anchor design should consider typical free water and tank deposits levels. The sensitive portion of the element should provide a representative temperature for the liquid and may have to be positioned 1 m (3 ft) from the tank bottom or above the low point of the tank outlet.

A typical variable-length ATT temperature element installation is shown in Figure 2, and an example of sensor lengths given in Table 2.

5.1.4 Multiple-Spot (Non-averaging) ATT

Multiple-spot ATTs may be provided with individual spot sensors without an averaging function. Otherwise the design and construction is similar to an averaging ATT as described in 5.1.3.2.

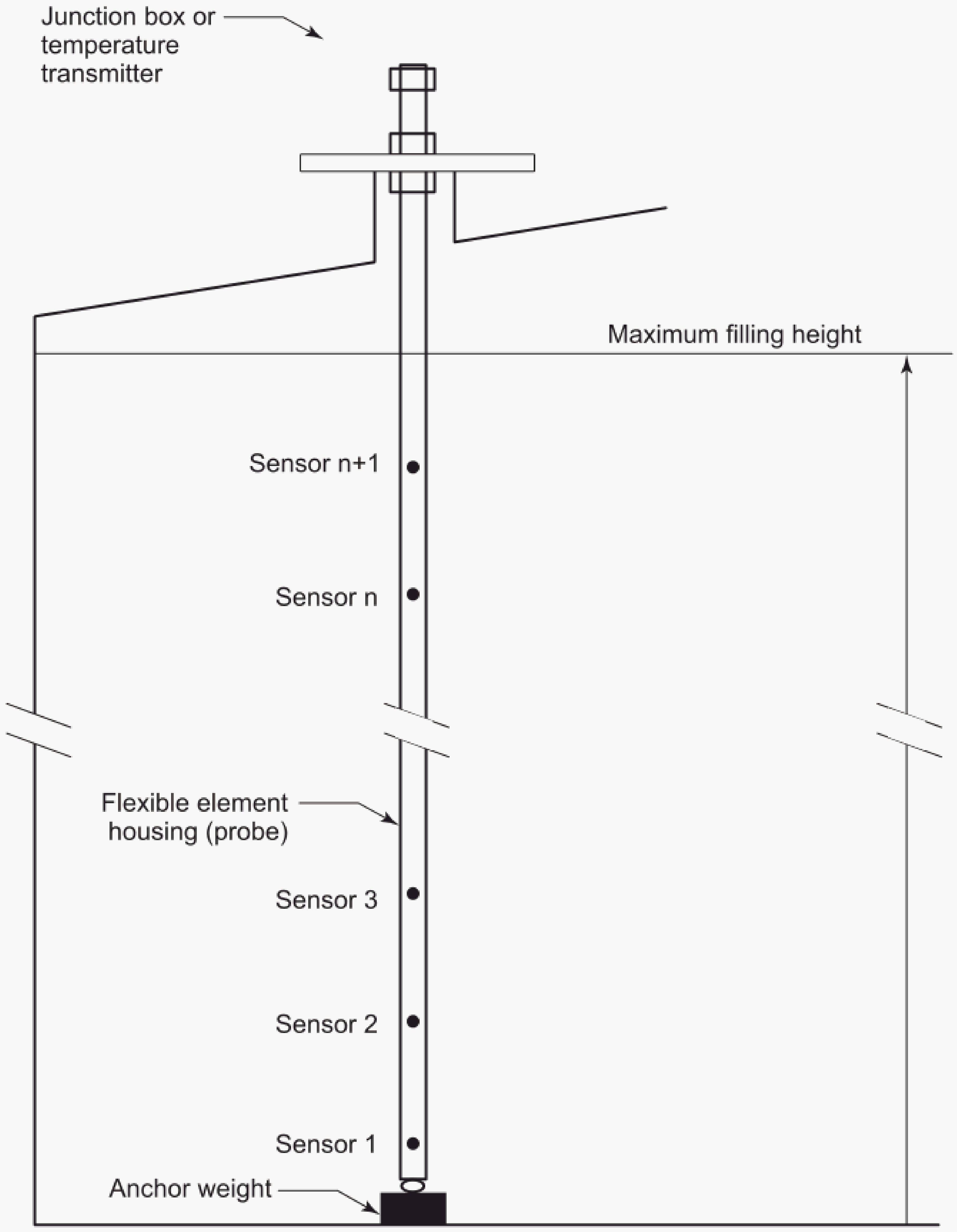

Figure 1—Example of Multiple-Spot Temperature Element Installation

5.1.5 Protecting Tube

A protecting tube is used for some ATTs for mechanical protection and to ensure positional stability of the temperature sensor(s) within the tank. It provides the same functionality for an ATT as an armored case does for a liquid-in-glass thermometer. For multiple-spot and variable-length ATTs, the protecting tube shall have holes or slots to ensure that the product in the protecting tube is representative for the product level and temperature in the tank.

Various designs of vertical protecting tubes are available to support multiple-spot or variable-length ATT temperature sensors in floating-roof or fixed-roof tanks.

5.1.6 Thermowells

The use of thermowells may be required to isolate the liquid material from the temperature sensor or to provide mechanical protection. They may be inserted through the tank wall, horizontally or at an angle, or through the tank

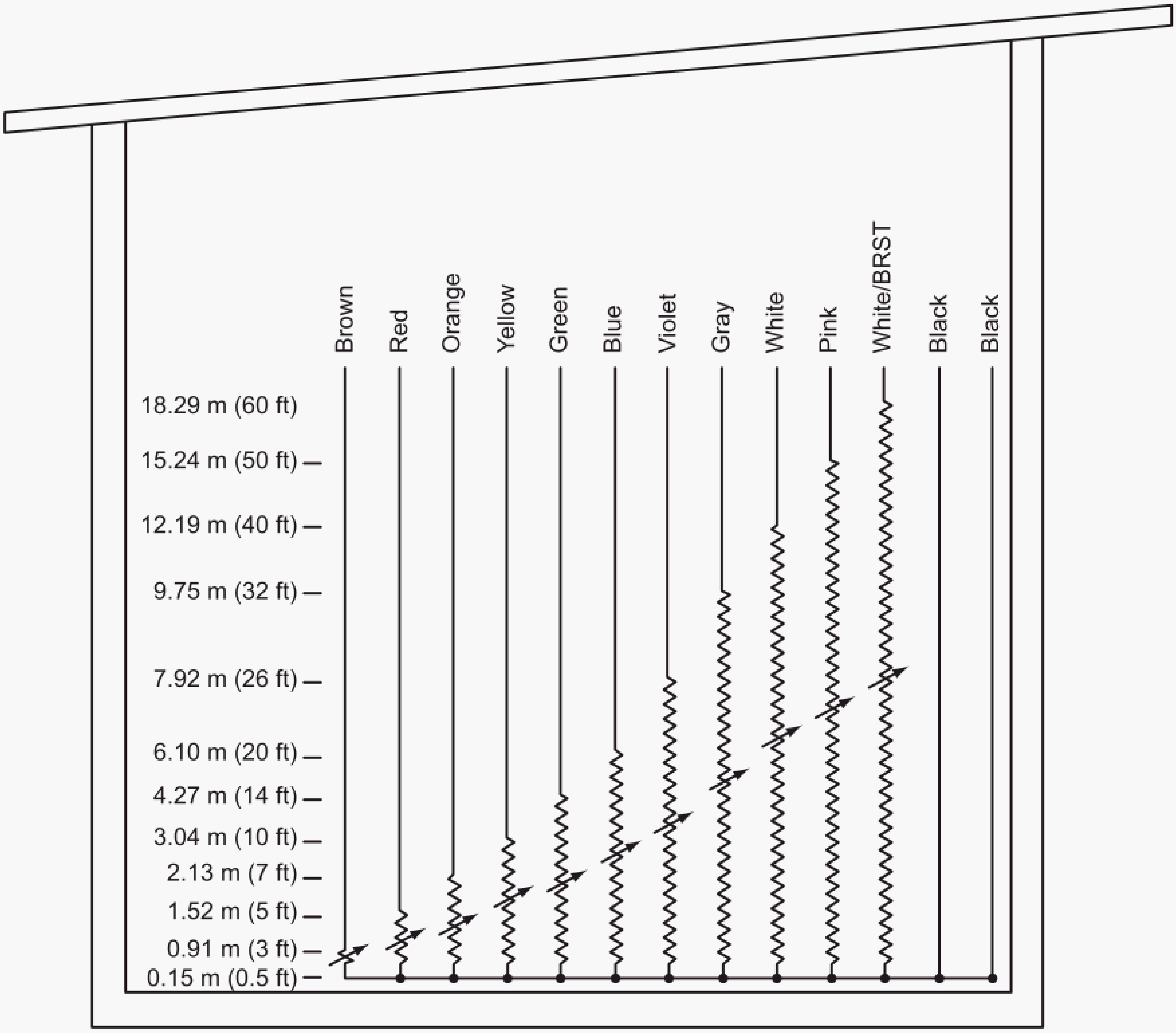

Figure 2—Example of Variable-Length ATT Temperature Element Installation

Table 2—Example of Sensor Lengths for a Variable Length ATT

Sensor Lengths
0 to 0.91 m (3 ft)
0 to 1.52 m (5 ft)
0 to 2.13 m (7 ft)
0 to 3.04 m (10 ft)
0 to 4.27 m (14 ft)
0 to 6.1 m (20 ft)
0 to 7.92 m (26 ft)
0 to 9.75 m (32 ft)
0 to 12.19 m (40 ft)
0 to 15.24 m (50 ft)

roof vertically. Thermowells may be filled with a heat transfer medium to ensure the temperature sensor accurately reflects the tank temperature. Pastes or fluids may be used depending on the orientation of the thermowell. Thermowell design should allow for thermal expansion of the medium.

Adequate clearance should be provided between the ATT sensor assembly and the thermowell for ease of insertion. The clearance, however, should be kept as small as practical to reduce the time lag for heat transfer.

Thermowells used to allow the insertion of a reference thermometer for the purposes of verifying the accuracy of the ATT are referred to as test thermowells. Test thermowells should be capped when not in use to prevent foreign material from accumulating in the bore. A clogged thermowell may cause measurement errors and may damage thermometers.

5.1.7 Temperature Transmitters

The temperature signal is typically converted into serial digital form. Sensor linearization can be typically provided by the transmitter, and the proper linearization option shall be selected depending on sensor type and wiring configuration (3 wire/4 wire).

Temperatures within an ATT system can vary from a simple device to a specially designed device to handle multiple sensors and perform other specialized functions.

Within the ATT system, a temperature transmitter is used to transmit one or more temperature signals to data collection units and/or the ATT HMI computer. They may provide additional functionality such as:

— ability to transmit spot temperatures and average temperatures to local or remote displays;

— averaging functions;

— sensor characterization;

— sensor switching;

— alarming.

The transmitter may be designed such that the temperature element is integral to the transmitter or the element and sensors may be remotely located with interconnecting wires.

Each type of temperature sensor has a similar characteristic relationship between temperature and its electrical output. Frequently an industry accepted characterization curve is used to interpret the sensor signal. For added accuracy, a characterization curve, specific to each sensor may be part of the functionality of the ATT transmitter.

Transmitters may be equipped with a local display of temperature or other configuration parameters and in some cases may provide communication to a remote display (such as those that may be located at ground level beside a tank).

Different forms of output signals are available. An analogue signal, usually 4 mA to 20 mA, may be provided, particularly for spot ATTs. Digital signal transmission using industry standard or proprietary protocols are more frequently used for ATTs with multiple sensors as they can more easily transmit multiple signals.

ATTs are often closely integrated with an ATG system. Many of the commonly used ATG systems provide the functionality within the ATG transmitter to receive and convert sensor signals into data suitable for transmission. These devices may include the functionality described above for an ATT transmitter.

Digital ("smart") transmitters may have the following benefits over analogue transmitters:

— wider rangeability;

— easier calibration procedures;

— improved performance;

— lower drift rate;

— elimination of loop errors (analogue drift, analogue conversions, etc.);

— software linearization;

— digital communication;

— fault and error detection.

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

5.1.8 Data Acquisition

Measured data (e.g. temperature, level) from an ATT or integrated ATG/ATT system is collected from one or more tanks, or transmitters for display and processing at a centralized location. In some systems data transmission is performed by the transmitters themselves and in others, a data collection unit or other device is used. Data collected will be transmitted, preferably in digital format, to a receiving unit, which may be a specialized device, supervisory computer, or process control system.

The data transmission system 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.

Since the data transmission systems are usually located outdoors, the enclosures should be appropriate for the application.

5.1.9 Displays

Temperature displays, whether local or remote, should provide a resolution of 0.1 °C or 0.1 °F or better.

Temperature displays may be used for custody transfer provided that the whole system, including the display, meets the requirements defined in this standard. Some displays have additional functionalities, such as alarming on high or low temperatures.

5.1.10 Supervisory Equipment

At some centralized location, typically a control room, supervisory equipment receive signals from the temperature devices. The supervisory equipment may include:

— ATG supervisory computer;

— ATT supervisory computer;

— programmable logic controller (PLC);

— distributed control systems (DCS).

Supervisory equipment should be capable of the following functionalities:

a) 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.

The supervisory equipment used in an ATG system typically displays and logs both levels and temperatures and may include temperature averaging. These computers or control systems may perform display and calculation functions.

5.2 System Description

ATT systems can range from a simple transmitter providing a temperature signal to a control system to a multi-tank system designed as part of a tank farm inventory measurement and control system. Typically one ATT is installed for each tank. Signals, alarms and diagnostic information may be transmitted by wire, fibre optic or wireless transmission systems to a computing system that manages and displays the signals.

Because temperature measurement is normally a crucial part of an ATG system, the ATT system and ATG system are often combined with a single set of supervisory equipment and display. Figure 3 shows only an example of an ATT system as referred to in this standard and is not intended to cover all possible configurations.

5.3 Selection of an ATT System

5.3.1 General

The selection of a suitable ATT should be made based on recommendations in Table 3 and the following criteria:

— application (custody transfer, inventory);

— the accuracy required;

— tank size and height;

— fluid properties;

— tank operating parameters (e.g. temperature range);

— the minimum level in the tank at which temperature measurement is required;

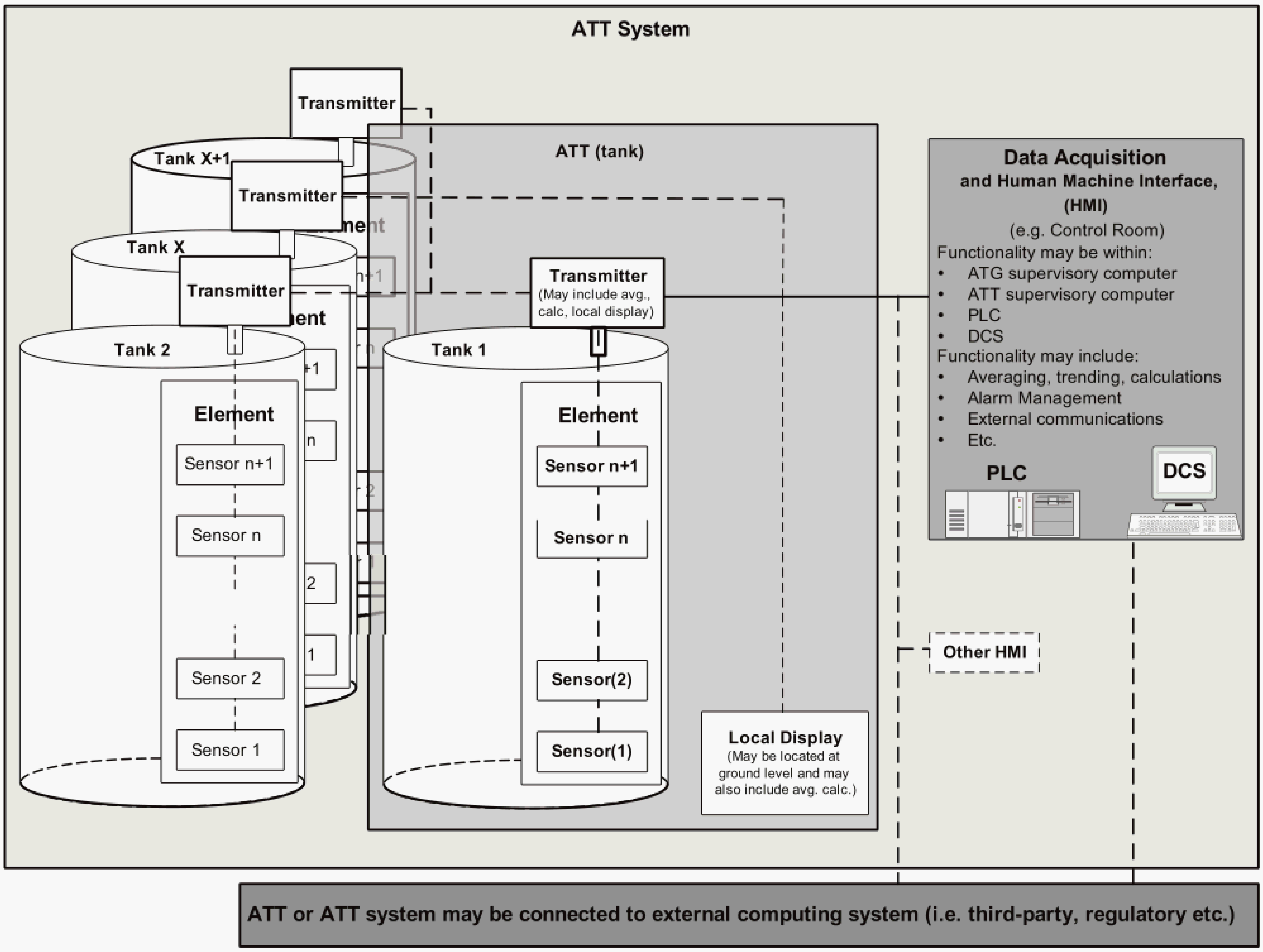

Figure 3—Example of Automatic Tank Temperature System Diagram

— environmental conditions;

— data communication requirements;

— system computing, display, archiving and alarming requirements.

5.3.2 Tank Temperature Stratification

Temperature stratification can be present in both the vertical and horizontal direction in a tank. Temperatures in large tanks, 795 m^3 (5,000 bbl) or larger, are normally stratified unless the tank contents are thoroughly mixed.

Tank temperature stratification can be reduced by tank fill, empty and transfer procedures, the use of circulating pumps and by in-tank mixers.

In the vertical direction, temperature differences of as much as 3 °C (5 °F) are normal, and differences of 5 °C (9 °F) or more may occur.

Table 3—Recommendations for the Use of ATTs

ATT	Custody Transfer	Inventory	Comment
Spot	No	Yes	See Note 1
Multiple-spot (non-averaging)	No	Yes	See Note 2
Multiple-spot, averaging	Yes	Yes	
Variable-length, averaging	Yes	Yes	

NOTE 1 Spot tank temperature measurement may be used for custody transfer or fiscal applications if either of the following conditions is met.

a) The tanks have a capacity less than 795 m^3 (5,000 bbl), or the level is less than 3 m (10 ft).

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

In all other cases, spot ATTs are not suitable for custody transfer or fiscal measurement.

NOTE 2 Can be used for custody transfer provided that the averaging principles apply, see 5.1.3 (averaging ATT).

In the horizontal direction, the temperature differences are typically less than 0.5 °C (1 °F) for low and medium viscosity petroleum liquids. Somewhat higher differences may be expected in high viscosity petroleum liquids and very large diameter tanks.

For horizontal stratification where temperature differences in excess of 0.5 °C (1 °F) are anticipated, an increased number of elements may be appropriate.

5.3.3 ATT Systems for Custody Transfer Applications

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. For custody transfer measurements, an averaging ATT should preferably be fitted as shown in Table 3 and described under 5.3.1.

The design of an ATT system shall consider the number, type and placement of sensors within the tank as described in 5.1.3.1. Where temperature differences between 1 °C to 3 °C (2 °F to 5 °F), due to vertical stratification are likely to occur, the use of averaging ATTs with a design in accordance with 5.1.3.1 are recommended. For temperature differences in excess of 3 °C (5 °F), an increased number of sensors per element may be appropriate as suggested in 5.1.3.2 and 5.1.3.3.

Select a sensor type described above with suitable accuracy, longevity and stability for the application which meets the accuracy requirements in Table 4.

For increased reliability a redundant ATT element or secondary ATT device may be used.

Other ATT designs than those described herein may be in use and may be suitable for custody transfer applications provided Table 3, note 1 or note 2 applies.

5.3.4 ATT Systems for Inventory Control Applications

The performance requirements of an ATT system for inventory control applications may not be as stringent as for custody transfer as shown in Table 3. The ATT system should be selected and designed based on defined business needs to provide a temperature sufficiently representative of the overall fluid temperature.

5.4 Ambient Temperature

An ATT provides a tank liquid temperature (T_L) as part of a tank volume calculation according to API *MPMS* Chapter 12.1.1. In addition to T_L an ambient temperature T_L may be required if a tank shell correction ($CTSh$) is necessary. ATT system design should consider:

— If $CTSh$ is necessary;

— If ambient temperature will be live or manually input;

— If ambient air temperature will be transmitted as part of the ATT system.

Ambient temperature is a representative atmospheric temperature in the tank farm. The ambient air temperature surrounding a storage tank may vary widely, 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 (TSh) so a reduced accuracy as compared to that required for the liquid temperature (T_L) may be acceptable.

See 7.3 about how and where to measure ambient temperature.

5.5 ATT Systems for Marine Applications

An ATT system on board marine vessels or floating storage vessels carrying crude oil and refined products may be used for custody transfer temperature measurement provided it meets the accuracy requirements given in Section 8.

6 Installation Requirements

The installation of the ATT system should conform to all applicable codes and regulations as referred to in Section 4 of this document and be in accordance with the ATT manufacturers' instructions where applicable.

6.1 Location Requirements for ATTs in Custody Transfer Applications

6.1.1 General

The design of temperature element or sensor placement should ensure the following.

— **There is no interference with tank operations**—Consider gauging operations, tank fill/empty, the ability to safely access and maintain equipment, interference with mixing or other rotating equipment, and floating roof movements.

— **Temperatures are as representative as possible**—To ensure measured temperatures are representative of the overall tank liquid temperature, avoid proximity to inlets, outlets, tank floors and walls, mixers, heaters, sludge deposits or water bottoms etc.

— **The possibility of damage by liquid movement is minimized**—Make use of thermowells and protecting tubes and be aware of roof movement, jetted streams such as for cleaning as well as inlets and outlets.

Proximity of temperature sensors to various types of internal tank equipment or activities may result in nonrepresentative temperatures or failure of the device.

6.1.2 Top Entry

Top entry installation is normally used for multiple-spot or variable-length ATTs. Recommendations on the number of sensors and their elevation are given in 5.1.3.1.

The element should be positioned at least 1 m (3 ft) from the tank shell, inlets and outlets.

To facilitate maintenance, verification and calibration of the sensor(s), sensors should be installed close, preferably within 1 m (3 ft), to a gauging hatch, vapor lock valve, or other suitable access point to facilitate verification and calibration of the sensor(s). For access, sensors should be located near a ladder or stairway or accessible from a gauging platform.

A protecting tube is recommended to ensure positional stability of the ATT (see 5.1.5), and necessary means shall be taken to ensure the ATT sensor is fully extended at all times (i.e. to get stable sensor positions relative to the tank shell and liquid level).

If the ATT is free hanging in the air the positional stability of the ATT shall be secured by other means to ensure the sensor positions will not change. This can be done by the use of an anchor weight or by other means.

ATTs are commonly constructed such that the addition of further mechanical protection may not be required and the element may be placed directly in the fluid. However, in some applications, additional mechanical protection of the ATT may be required. This may be provided by placement of the temperature element within a protecting tube, thermowell or a stilling well.

If the temperature sensor (ATT) is mounted in a stilling well, the stilling well shall have holes or slots along its entire length to ensure the stilling well fluid is representative of the level and temperature in the tank.

6.1.3 Side Entry

Side entry installation is normally used for spot ATTs and will normally require a thermowell as described in 5.1.6. Spot ATTs are not generally recommended for custody transfer, guidance is given in 5.3.3. Where used, more than one spot ATT should be installed at different levels on the tank.

The lowest sensor is to be positioned 1 m (3 ft) or more from the tank floor. Where the tank is operated at a level lower than 1 m, a temperature sensor can be located at a level as low as practical but it should only be used for determining average tank temperatures when the tank is at this level of fill.

The sensor should extend at least 1 m (3 ft) from the tank shell (shorter insertion lengths may be suitable for insulated tanks) and at least 1 m (3 ft) from inlets and outlets.

Test thermowells should be installed adjacent to ATT thermowells for ease of verification and calibration.

6.2 Location Requirements for ATTs in Inventory Applications

With reference to company policies and procedures, less stringent requirements may apply for inventory applications compared to custody transfer applications, see further 5.3.4 for requirement on ATTs for inventory applications.

Lesser minimum heights above tank floor for thermowell installations may be appropriate for inventory applications with a recommended minimum height of 0.3 m (12 in.).

For tanks with internal floating roofs with side entry installation, the maximum height of the thermowell and test thermowell shall be 0.15 m (6 in.) below any roof appurtenance which could cause damage to the thermowell based on the low leg setting. Otherwise, they should be located about 0.15 m (6 in.) below the minimum operating level. Minimum operating level is often based on defined spacing criteria for the tank level with respect to the center or top of the tank outlet pipe.

6.3 Other Mechanical Installation Arrangements

The following other installation arrangements may be of use.

— **Mid-level**—A spot ATT is installed through a top entry such that the spot temperature is continuously positioned approximately half-way between the liquid surface and the bottom of the tank.

— **Upper, middle and lower**—Three spot ATTs (a multiple-spot ATT) are installed through a top entry such that the temperature is continuously measured at the upper, middle, and lower part of the liquid at all levels. The three spots are either electrically combined or their readings averaged to give the average temperature.

6.4 ATT Systems for Marine 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, verified and replaced without de-pressurizing the IGS.

The spot and/or multiple-spot ATT 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 vertical protecting tube through the deck (tank roof). This protecting tube should allow for one or more (usually three) temperature sensors to be mounted from the deck, suspended by their individual metal cabling, down to various depths in the tank. When three temperature sensors 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).

The location of a protecting tube in a ship tank will be restricted to "close to bulkhead" due to the requirements for mechanical supports to withstand ship's vibration.

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

c) Single spot ATTs on marine vessels, barges etc. have usually one to three sensors installed appropriately in relation to the tank height; e.g., in the upper, middle and lower sections of the tank.

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

6.5 Data Acquisition, Data Transmission, and Receiving Equipment

The data acquisition, data transmission and receiving equipment should be designed and installed in accordance with the requirements in 5.3.3.

Normal practice is to transmit temperature information using the wiring network provided for the remote reading ATG level transmitters.

Additional aspects to consider when constructing the data acquisition and transmission system are:

— signal path length between ATT and remote display;

— interference from AC power wiring;

— radio frequency interference;

— signal wiring;

— grounding;

— shielding;

— transient and lightning protection (in areas with high incidence of lightning and, in particular, where the tanks are spread over a wide area remote from the central display equipment, additional precautions against lightning should be provided).

6.6 Configuration

Once the ATT is mechanically and electrically installed, software configuration of the ATT may be required. If the ATT includes temperature average calculation, the following shall be considered (to be found either in tank drawings or ATT documentation):

— the associated level gauge (ATG);

— the sensor positions relative to the tank references (datum plate);

— ensure that the sensors included in the average calculation are submerged;

— specific configuration recommended by the ATT manufacturer.

7 Procedures for Temperature Determination

7.1 Timing of Temperature Measurement

Temperatures shall be measured and recorded simultaneously or as close as practical, to the liquid level measurement and the same procedures should be used to measure a tank temperature before the product transfer (opening gauge) and after the product transfer (closing gauge).

7.2 Reporting of 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 display equipment does not perform temperature averaging, then average tank temperatures should be calculated from the multiple readings according to the averaging principles as described in 5.1.2.

7.3 Ambient Temperature

The recommended methods of taking this temperature are as follows.

a) 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.

b) Shaded external thermometers permanently mounted in the tank farm area.

c) Local on-site weather stations.

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

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

NOTE Measurement of ambient temperature is not applicable for temperature measurements on a marine vessel.

8 Accuracy Requirements

8.1 Requirements for ATTs

The ATT shall be calibrated and verified to demonstrate that it meets the accuracy of the intended service. Table 4 summarizes the maximum tolerances to be met by the ATT for various verification activities taking into account the uncertainty contributions from the sensor itself as well as the conversion electronics.

The accuracies specified in Table 4 are for temperature range –40 °C to +70 °C (–40 °F to +160 °F).

Table 4—ATT Tolerances at Different Verification Stages

Application	Resolution	Activity	Verification tolerances		
			By component		As a System
			Sensor	Transmitter (conversion electronics)	
Custody transfer	0.1 °C (0.1 °F)	Factory calibration (FAT)	±0.2 °C (±0.4 °F)	±0.15 °C (±0.3 °F)	±0.25 °C (±0.5 °F)
		Initial Field Verification (SAT)	±0.4 °C See note 1	±0.25 °C See note 1	±0.5 °C (±1 °F)
		Subsequent Verification	±0.4 °C See note 1	±0.25 °C See note 1	± 0.5 °C (±1 °F)
Inventory See note 2	0.1 °C (0.1 °F)	Factory calibration (FAT)	±0.2 °C (±0.4 °F)	±0.15 °C (±0.3 °F)	±0.25 °C (±0.5 °F)
		Initial Field Verification (SAT)	±0.4 °C See note 1	±0.25 °C See note 1	±0.5 °C (±1 °F)
		Subsequent Verification	±0.8 °C See note 1	±0.5 °C See note 1	±1.0 °C (±2 °F)

NOTE 1 Verification by component is not practical for multiple-spot or variable-length ATTs because of the difficulty of verifying the sensor in the field.Verification in field is normally done as a system. Verification of the transmitter component may be performed if system verification fails.

NOTE 2 For inventory application these tolerances are considered recommendations. Business or Regulatory requirements may impose or require different criteria.

8.2 Requirements for Test Equipment

Reference or measurement standards used for calibration and verification shall be traceable to a national metrology institute (NMI) such as NIST by means of a valid calibration certificate. Test equipment should be verified daily or prior to use to ensure proper function, whichever is less frequent. See API *MPMS* Chapter 7-2001, Section 5.2, or when published, API *MPMS* Chapter 7.2 (see the Foreword) for PET requirements. Table 5 indicates requirements for test equipment.

Table 5—Requirements for Test Equipment

Test Equipment	Resolution	Accuracy Requirements [1]	Frequency of Calibration
Reference Standard Thermometer (liquid-in-glass)	0.1	3 times better than the device being tested See note 2	Yearly
Ambient air temperature Thermometer	1	±1 °C (±2 °F)	Yearly
Portable Electronic Thermometer (PET)	0.1	±0.3 °C (±0.5 °F) See note 3	Yearly
RTD Simulator	N/A	3 times better than the device being tested	Yearly
Thermal Blocks and Baths	N/A	3 times better than the device being tested	Yearly

NOTE 1 Test equipment accuracy expectations do not normally differ for custody transfer or inventory applications. For inventory applications, lesser accuracies may be appropriate.

NOTE 2 Requirements given in API *MPMS* Chapter 7-2001, Section 5.3, or when published, API *MPMS* Ch. 7.1 (see the Foreword), if different, should be taken as the requirement.

NOTE 3 Requirements given in API *MPMS* Chapter 7-2001, Section 5.2, or when published, API *MPMS* Ch. 7.2 (see the Foreword), if different, should be taken as the requirement.

9 Inspection, Verification, and Calibration Requirements

9.1 General

All ATTs shall be inspected, verified and if needed calibrated periodically to assure proper performance. The verification and calibration should be performed against reference standards.

9.2 Verification

The term "verification" refers to the process of comparing the ATT in service against a measurement or reference standard. Often this is a certified reference standard thermometer. Verification confirms whether or not the ATT is operating within the tolerances given by Table 4, or requires calibration, repair or replacement.

Verification of the ATT is performed in different stages prior to being put in service as well as during operation; these are:

— factory acceptance test (FAT),

— site acceptance test (SAT),

— subsequent field verification.

Verification of an ATT system may be done as a complete system, or by component. In the field the former technique is normally used. Test equipment meeting the requirements of 8.2 shall be used.

Before being put into service, temperature sensors shall be verified by one or more measurements, preferably at several points throughout the range of the device.

The complete system as a whole shall be verified either at the FAT, SAT, or both before being put into service.

9.2.1 Factory Acceptance Test (FAT)

A FAT includes the following checks:

— Verify accuracy (see 9.2.1.1 or 9.2.1.2) throughout the operating range of the device, which is critical because of the difficulty in varying temperature in an operating tank.

— Verify ATT type, model and design to ensure the intended use as well as conformity documentation such as test delivery certificates (see also Section 5 and Section 6).

— Verification of the ATT system as a whole (typically this can be to connect a small part of the ATT system and read the temperature measurements on the local and remote displays to be within a reasonable span).

9.2.1.1 As a System

The ATT system (see Figure 3) is verified by placing the temperature element(s) in constant temperature baths, at three or more temperatures covering the operating range. The difference between the temperature measured by the ATT system and the bath temperature as measured by one or more reference thermometers should not exceed the tolerance given in Table 4. Each sensor (or each average sensor if a variable-length ATT) in the ATT should be checked following this procedure.

9.2.1.2 By Component

Alternately, the components of the ATT are separately verified.

9.2.1.2.1 Sensor

Measure the output of the temperature sensor in the bath at three or more temperatures covering the operating range. The difference between the bath temperature and the temperature equivalent to the sensor output should not exceed the tolerance given in Table 4.

Alternately, the ATT system may make use of sensors constructed in accordance with industry standards that specify accuracies and testing methods. The use of such sensors may not require additional test during the FAT (see 5.1.1.1 for example).

9.2.1.2.2 Transmitter

Use reference standard test equipment such as precision resistors or a thermal calibrator traceable to a NMI to simulate temperature inputs to the transmitter. The difference between the temperature corresponding to the simulated input and the ATT transmitter temperature output should not exceed the tolerance given in Table 4.

9.2.1.2.3 Other Components

Where other ATT system components are used to convert signals or for data acquisition between the ATT transmitter and the human-machine interface (HMI) those components should also be tested. It may be necessary to test data acquisition system components at the SAT if not supplied as part of the ATT system. The combined tolerance for the ATT transmitter and any conversion/data acquisition components should not exceed that given in Table 4 for the transmitter. It is expected that digitally transmitted signals will be faithfully reproduced at the HMI.

9.2.2 Site Acceptance Test (SAT)

Prior to putting the ATT in service, the following should be checked:

— ensure no damage occurred during transport;

— verify ATT type and model to ensure the intended use (see also Section 5 and Section 6);

— mechanical installation (correct sensor length, properly mounted etc.);

— electrical installation (grounding, wire connections in junction boxes etc.);

— configuration (see 6.6);

— temperature values can be read on local and/or remote displays;

— verify accuracy (see 9.2.2.1, 9.2.2.2, or 9.2.2.3 depending on ATT type).

9.2.2.1 Spot ATTs

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 fluid temperatures close to ambient, if the sensor of the PET can be placed within 1 m (3 ft) of the spot ATT sensor, calibration by a PET is acceptable.

Lower the PET to the same level where one of the fully submerged spot sensors of the ATT is located and wait until a temperature reading from the PET stabilizes. The temperature measured and displayed by the ATT for the particular spot sensor should be compared to the temperature measured by the PET and verified to within the tolerance for initial field verification as given in Table 4 for the intended use. Each ATT spot sensor should be verified following this procedure.

For heated tanks, where uneven heating by heating coils is often encountered, it is recommended that the heating process be stopped temporarily prior to verification.

9.2.2.2 Multiple-spot (averaging) ATTs

Take ten temperature readings evenly spaced, or every 0.7 m (2 ft) for tank levels less than 7.7 m (22 ft) covering the entire liquid level. The average of the temperature readings using the PET is compared to the average temperature of all ATT temperature sensors submerged in the liquid. The difference of these two average temperatures shall be within the tolerance given in Table 4.

NOTE An “Upper-Middle-Lower” ATT system, which automatically adjusts according to the liquid level, does not require the tank to be full.

9.2.2.3 Variable-length ATTs

This procedure is used to verify the variable-length averaging ATT systems that automatically select the longest, fully submerged sensor to determine the average tank temperature. A PET shall be used to verify the ATT.

The tank should preferably be nearly full, with all temperature sensors submerged. Take ten temperature readings evenly spaced, or every 0.7 m (2 ft), for tank levels less than 7.7 m (22 ft) covering the entire liquid level. Manually select each temperature sensor (either by a software or hardware switch). Compare the average temperature calculated from the appropriate PET readings against the average temperature measured by the temperature sensor selected and displayed by the ATT display. Each of these should be verified to within the tolerance for initial field verification as given in Table 4 for the intended use.

9.2.3 Subsequent Field 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. Each ATT system should be inspected and its calibration verified using the same procedures described in 9.2.2 to ensure the ATT instruments are working within the tolerances given in Table 4.

To ensure that the automated selection of sensors and their accuracy reflects the tank temperature at all levels of fill, the ATT should be periodically verified at randomly chosen fill levels within the normal opening and closing gauge readings of the tank.

Manual comparisons should also be made frequently during the initial months of operation, or as long thereafter as required to establish that temperature readings by the system, before instrument adjustment, are within the specified tolerance given in Table 4.

Table 6 provides recommendations for the frequency of calibration and verification activities. Regulatory or contractual requirements may differ. Longer intervals may be acceptable when agreed by all parties and should be based on definitive data, reliability studies on actual verification, and calibration performance.

Table 6—Calibration and Verification Frequency

Application	Frequency
ATT Custody Transfer	Monthly
ATT Inventory	Annual
Ambient Temperature	Annual

9.2.4 ATT Systems with Malfunctioning Sensor(s)

If an ATT is verified outside the tolerance as given in Table 4, it should be repaired or replaced.

During the time until an existing multiple-spot ATT has been repaired or replaced, it may still be used although not fulfilling the requirements of 5.1.3, provided that:

— not more than one of the sensors are broken if the system was designed with the minimum number of sensors per Table 1;

— for systems designed with additional sensors in excess of those required by Table 1:

  — if the remaining number of sensors meet Table 1;

  — if there is at least one sensor in each of the upper, middle and lower third of the tank with more than 15 ft (5 m) liquid;

— the broken sensor is excluded in the average calculation;

— the stratification in the vertical direction can be considered;

— normal, as defined in 5.3.2;

— the remaining spot sensors (or one fully-submerged variable length sensor can be substituted) used to determine the average temperature, for both opening and closing gauge, can still be verified within the tolerances given in Table 4.

After replacement of an ATT, it should be verified (within the tolerances as given in Table 4) prior to being put in service.

9.2.5 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 3 years, or in the case of marine vessels, a minimum of 20 voyages or 3 years whichever is greater.

Records of these verifications/calibrations shall be on file and available for review. The records should contain the as-found and as-left temperatures and a record of required maintenance.

9.2.6 ATT Systems for Marine Applications

Marine ATTs shall meet the same verification tolerances as shore tank ATTs. They can also be verified as a system or by component. They should similarly be factory verified before installation and the same verification methods apply (at shipyard or during sea trial).

However, for onboard re-verification the tolerance might be 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 Annex A).

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.

9.3 Calibration

For the purpose of this standard, the term “calibration” refers to the process of verifying and then adjusting if necessary.

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, a shop, or test facility in accordance with manufacturer’s recommendations (refer to ASTM E77 [5]), and in accordance with 9.2.1.

9.4 Certification

In a few countries, national regulations may require the ATT or ATT system to be pattern approved and certified by an NMI, to be used in custody transfer applications.

9.5 Inspection and Maintenance

Inspection is normally performed in connection with a SAT or at subsequent verifications. See 9.2.1.2.3 and 9.2.3 respectively.

Requirements for other regular maintenance are limited and the need for maintenance will normally be established through a failed verification. Consult the manufacturer's documentation for any other expectations.

Annex A
(normative)

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.

a) Change of the cargo temperature due to loading temperature.

b) 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.

c) Change of the cargo temperature due to seawater temperature.

d) 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.

e) Change of the cargo temperature due to adjacent cargo tank temperature.

f) Change of the cargo temperature due to cargo heating.

g) 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 temperature systems.

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