

Manual of Petroleum Measurement Standards

Chapter 7—Temperature Determination

FIRST EDITION, JUNE 2001

REAFFIRMED, FEBRUARY 2012



AMERICAN PETROLEUM INSTITUTE

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Measurement Coordination

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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”

This publication is primarily intended for use in the United States and is related to the standards, specifications, and procedures of the National Institute of Standards and Technology (NIST). When the information provided herein is used in other countries, the specifications and procedures of the appropriate national standards organizations may apply. Where appropriate, other test codes and procedures for checking pressure and electrical equipment may be used.

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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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Chapter 7—Temperature Determination

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 tem-

perature 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, Lightning, and Stray Currents*

ASTM¹

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

NFPA²

70	<i>National Electrical Code</i>
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OCIMF³

	<i>International Safety Guide for Oil Tankers and Terminals (ISGOTT)</i>
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IMO⁴

	<i>Safety of Life at Sea (SOLAS)</i>
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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. [$^{\circ}\text{C} = 5/9 (^{\circ}\text{F} - 32)$].

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. [$^{\circ}\text{F} = 9/5^{\circ}\text{C} + 32$].

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).

¹American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, Pennsylvania 19428, USA.

²National Fire Protection Association, 1 Batterymarch Park, Quincy, Massachusetts 02269, USA.

³Oil Companies International Marine Forum, 6th Floor, Portland House, Stag Place, London SW1E 5BH, UK.

⁴International 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:

- The accuracy required.
- The operating conditions which may affect the accuracy (e.g., expected tank temperature stratification).
- The minimum level in the tank at which temperature measurement is required.
- Environmental conditions.
- Number, type and, size of the tanks.
- Requirement for local and remote readout, signal transmission, and cabling.



Documents

Document Sharing Hub

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:

- 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.
- 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).

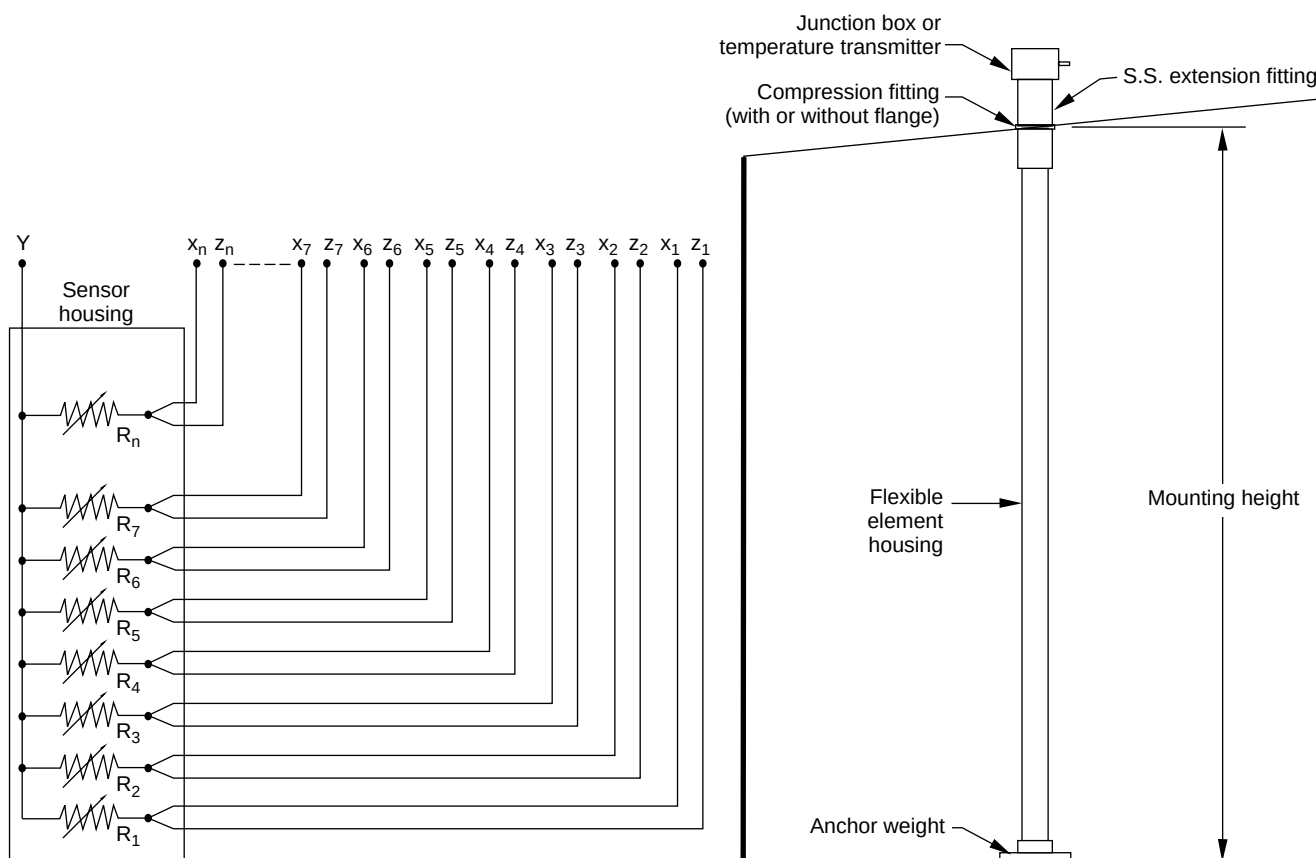


Figure 1—Example of Multiple Spot Temperature Element Installation

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:

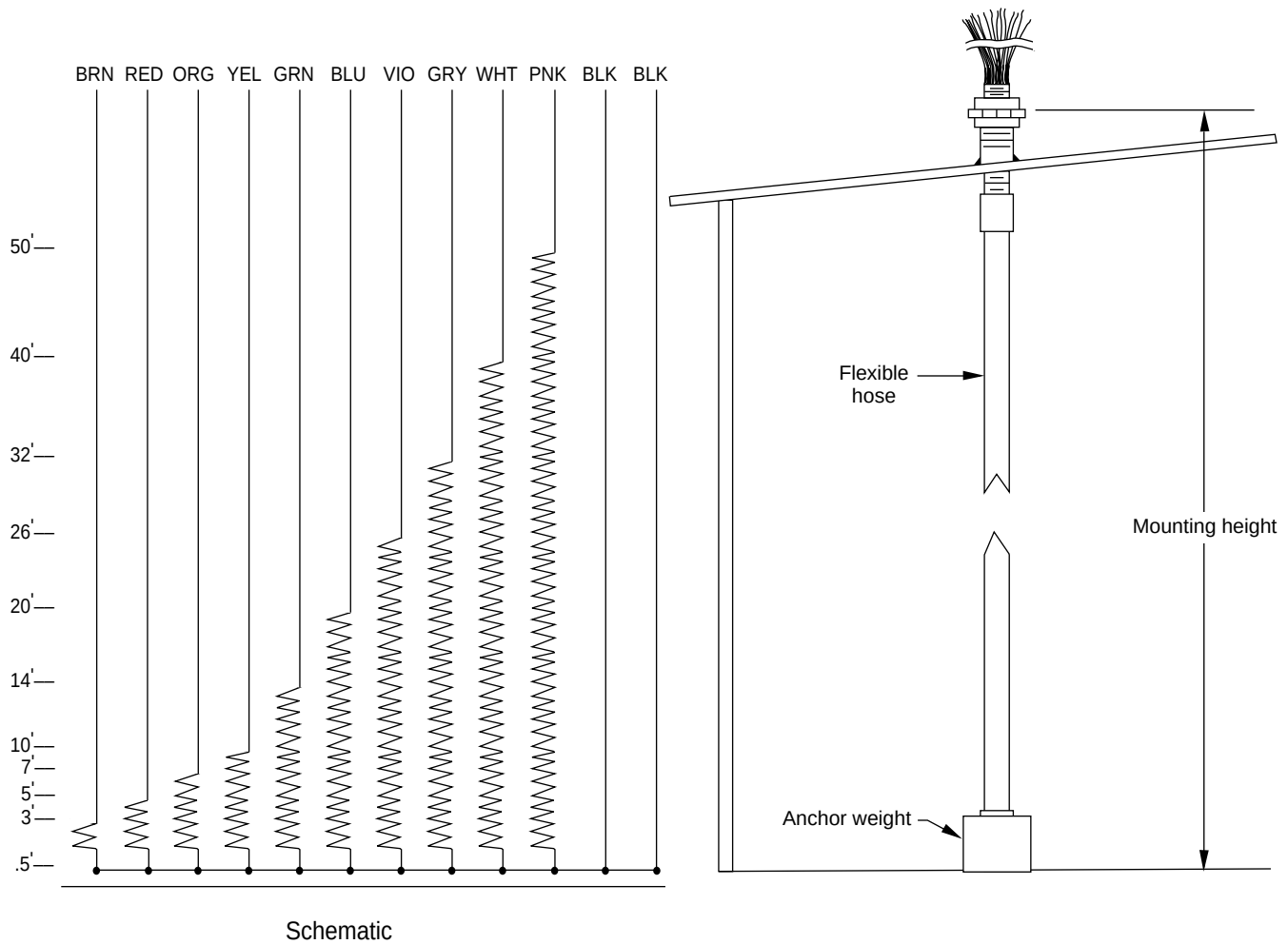


Figure 2—Example of Variable Length ATT Temperature Element Installation

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 stand-pipe 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

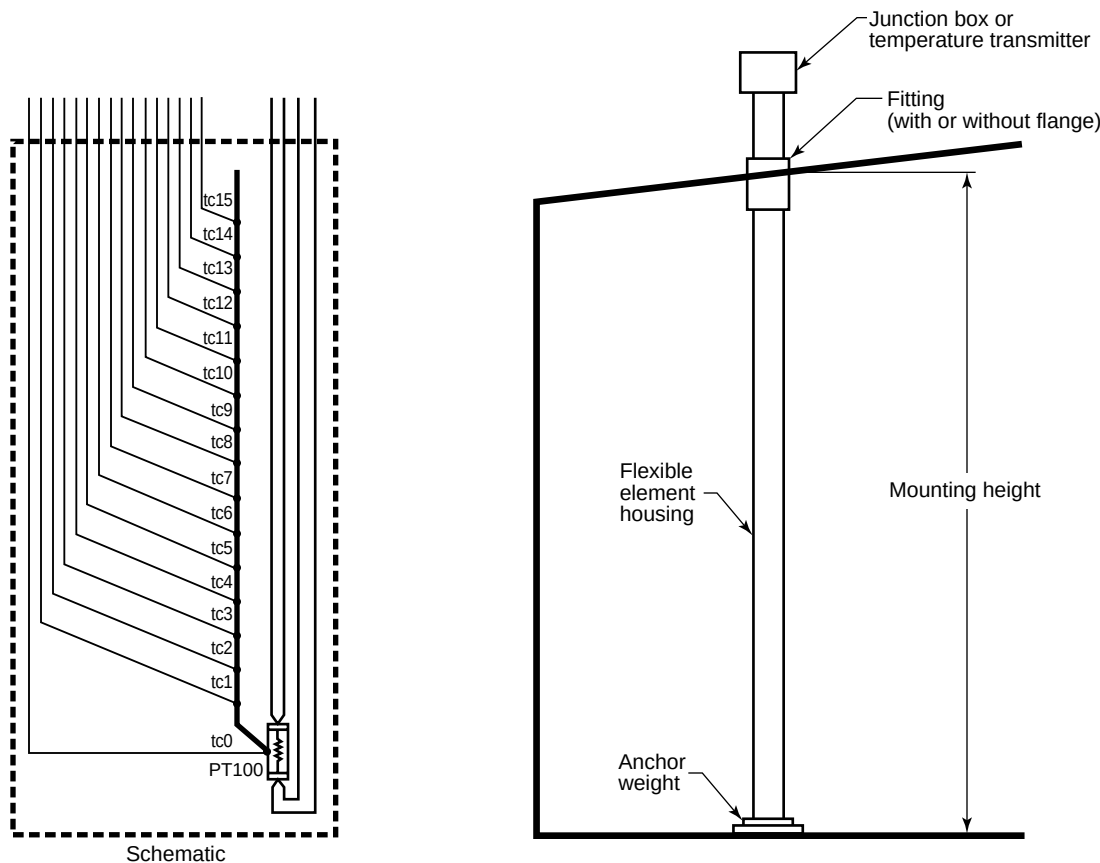


Figure 3—Example of Thermocouple System Installation

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.