API RECOMMENDED PRACTICE 550
THIRD EDITION, 1976

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Manual on Installation of Refinery Instruments and Control Systems

Part I—Process Instrumentation and Control
Section 3—Temperature

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American Petroleum Institute
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Manual on Installation of Refinery Instruments and Control Systems

Part I—Process Instrumentation and Control
Section 3—Temperature

Refining Department

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REG U S PATENT OFFICE

FOREWORD

This recommended practice is based on the accumulated knowledge and experience of engineers in the petroleum industry. Its purpose is to aid in the installation of the more generally used measuring, control, and analytical instruments; transmission systems; and related accessories in order to achieve safe, continuous, accurate, and efficient operation with minimum maintenance. Although the information contained herein has been prepared primarily for petroleum refineries, much of it is applicable without change in chemical plants, gasoline plants, and similar installations.

Successful instrumentation depends upon a workable arrangement that incorporates the simplest system and devices that will satisfy specified requirements. Sufficient schedules, drawings, sketches, and other data should be provided to enable the constructor to install the equipment in the desired manner. The various industry codes and standards, and laws and rulings of regulating bodies should be followed where applicable. The information contained in this publication does not constitute, and should not be construed to be, a code of rules or regulations. Furthermore, it does not grant the right, by implication or otherwise, for manufacture, sale, or use in connection with any method, apparatus, or product covered by letters patent; nor does it ensure anyone against liability for infringement of letters patent.

For maximum plant personnel safety, transmission systems are employed to eliminate the piping of hydrocarbons, acids, and other hazardous or noxious materials to instruments in control rooms. Proper installation is essential in order to utilize the full capabilities which are built into the instrument or transmission system.

In the installation of an instrument, the various components must be accessible for efficient maintenance and certain of these elements must be readable for good operation. Orifices, control valves, transmitters, thermocouples, level gages, and local controllers, as well as analyzer sample points, generally should be readily accessible from grade, permanent platforms, or fixed ladders. In this manual, special consideration is given to the location, accessibility, and readability of the elements.

Users of the various sections of this manual are reminded that in the rapidly advancing field of instrumentation no publication of this type can be complete, nor can any written document be substituted for qualified engineering analysis.

Certain systems are not covered herein because of their very specialized nature and limited use. When one of these systems gains general usage and installation reaches a fair degree of standardization, this section will be revised to incorporate such additional information.

Acknowledgment is made of the work of all the engineers and operating and maintenance personnel who, through years of study, observation, invention, and sometimes trial and error, have contributed to the technology of instrumentation.

Suggested revisions are invited and should be submitted to the Director of the Refining Department, American Petroleum Institute, 2101 L Street, N.W., Washington, D.C. 20037

PREFACE

This section is one of a series which make up RP 550, *Manual on Installation of Refinery Instruments and Control Systems*. RP 550 is composed of four parts:

Part I —Process Instrumentation and Control
Part II —Process Stream Analyzers
Part III—Fired Heaters and Inert Gas Generators
Part IV—Steam Generators

Part I assays the installation of the more commonly used measuring and control instruments, as well as protective devices and related accessories; Part II presents a detailed discussion of process stream analyzers; Part III covers installation requirements for instruments for fired heaters and inert gas generators; and Part IV covers instrument installation requirements for steam generators. These discussions are supported by detailed information and illustrations to facilitate application of the recommendations.

The format of RP 550, Part I has been changed to facilitate continuity of presentation, convenience of reference, and flexibility of revision. Each section is now being published individually as follows:

Section 1—Flow
Section 2—Level
Section 3—Temperature
Section 4—Pressure
Section 5—Automatic Controllers
Section 6—Control Valves and Accessories
Section 7—Transmission Systems
Section 8—Seals, Purges, and Winterizing
Section 9—Air Supply Systems
Section 10—Hydraulic Systems
Section 11—Electrical Power Supply
Section 12—Control Centers
Section 13—Alarms and Protective Devices

In the preparation of these documents, it was necessary to decide on a logical method of presentation: should each point be explained as fully as possible, or should extensive cross-referencing be done between sections?

The final documents contain a combination of these methods of presentation. An attempt has been made to make each section as complete as possible, with cross-referencing done only where very extensive repetition would have been required.

Users of this recommended practice are cautioned to obtain a complete set of sections in order to efficiently accomplish any cross-referencing that is required for a full understanding of the subject matter.

CONTENTS

SECTION 3—TEMPERATURE

PART I—PROCESS INSTRUMENTATION AND CONTROL

SECTION 3—TEMPERATURE

3.1 Scope

This section presents common practices for installation of devices for measuring temperature in refinery process services and for:

1. Displaying the temperature at the point of measurement.

2. Utilizing the temperature for local control of the process variable.

3. Transmitting the temperature to a remote location for indicating, recording, alarming, and/or controlling at that point.

Included in the discussion are the more common types of measuring devices and accessories: thermocouples, resistance-type temperature detectors, filled-system instruments, and dial thermometers. Thermowells are discussed because of their requirements as a part of temperature systems on most applications. Self-acting temperature controllers are also included insofar as the temperature actuation is concerned. The installation of automatic control equipment is discussed in API RP 550, Part I, Section 5. Methods of the transmission of temperature measurements are only briefly mentioned. Transmission systems are discussed in API RP 550, Part I, Section 7.

3.2 Thermowells

3.2.1 GENERAL

It is not usually possible to expose the temperature-sensing device to the process fluid. In spite of the thermal lag introduced, thermowells (see Figures 3-1 through 3-6) are employed in temperature measurement to protect the thermal elements and to permit removal of these elements during plant operation. It is important to maintain good contact between all temperature-sensing elements and their wells.

3.2.2 THERMOWELL INSERTION LENGTH

The insertion length, U (see Figure 3-1), is the distance from the free end of the temperature-sensing element or well to—but not including—the external threads or other means of attachment to a vessel or pipe.

3.2.3 THERMOWELL IMMERSION LENGTH

The immersion length, R (see Figure 3-1), is the distance from the free end of the temperature-sensing element or well to the point of immersion into the medium, the temperature of which is being measured. (Normally,

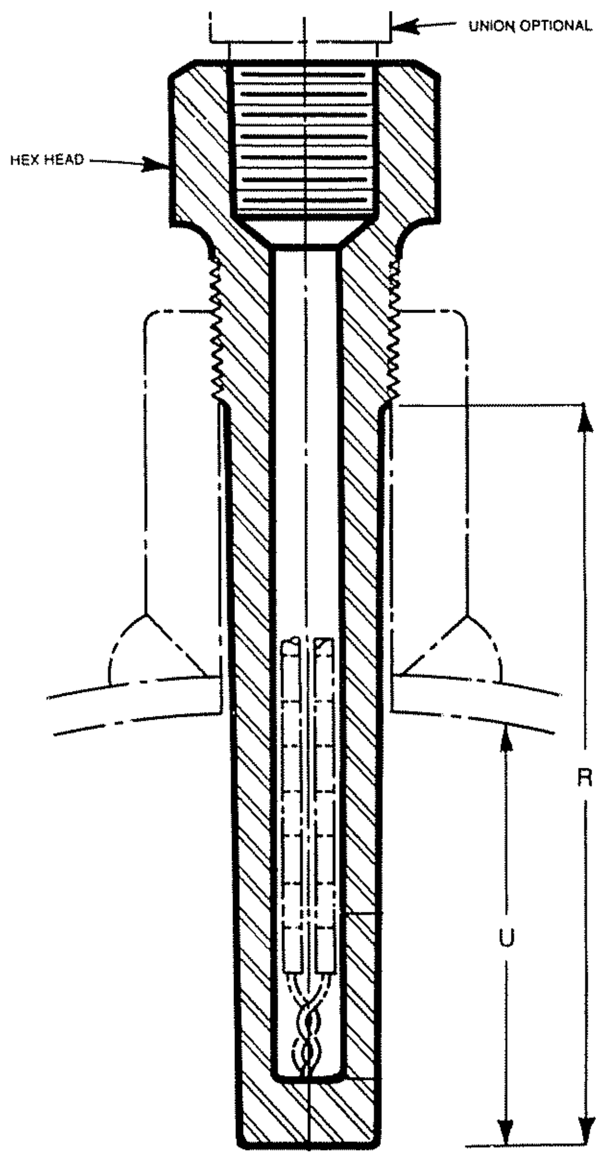


Figure 3-1—Screwed Thermowell

this point would coincide with the inner wall of the vessel or pipe.) The immersion length required to obtain optimum accuracy and response time is a function of such mechanical factors as type of sensing element, available space, well-to-fluid container, mechanical connection design, and well strength requirement. Optimum immersion depth also depends upon heat transfer considerations as determined by the physical properties of the measured fluid, flow velocity, temperature difference between fluid measured and well head, and material and mass distribution of the well and the sensing element. A detailed review of most of these factors is rarely ever justified for petroleum refinery applications.

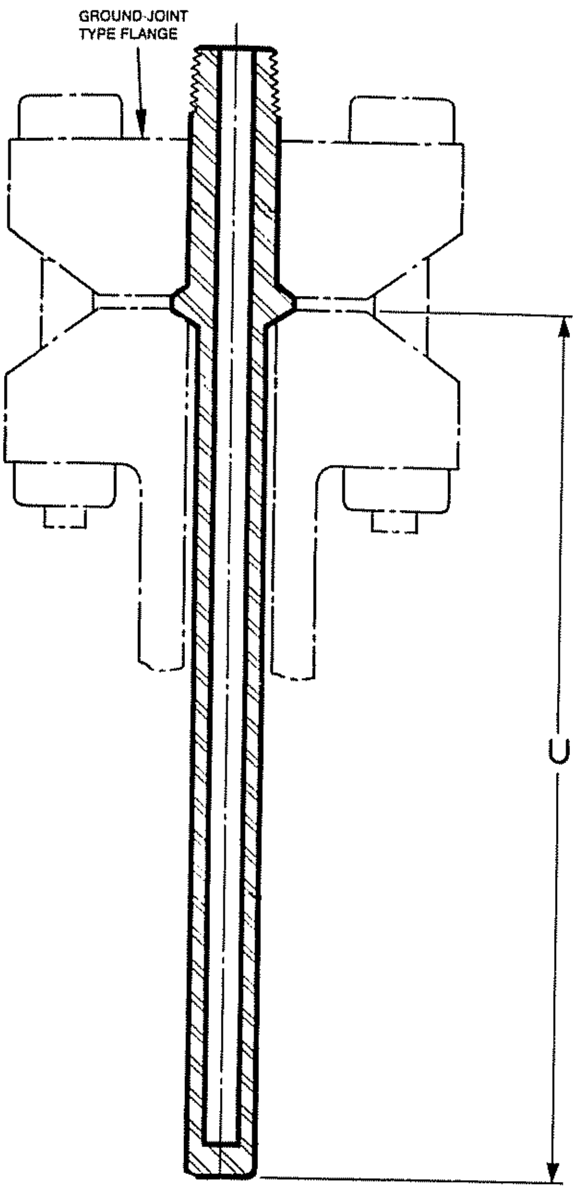


Figure 3-2—Ground-Joint Thermowell

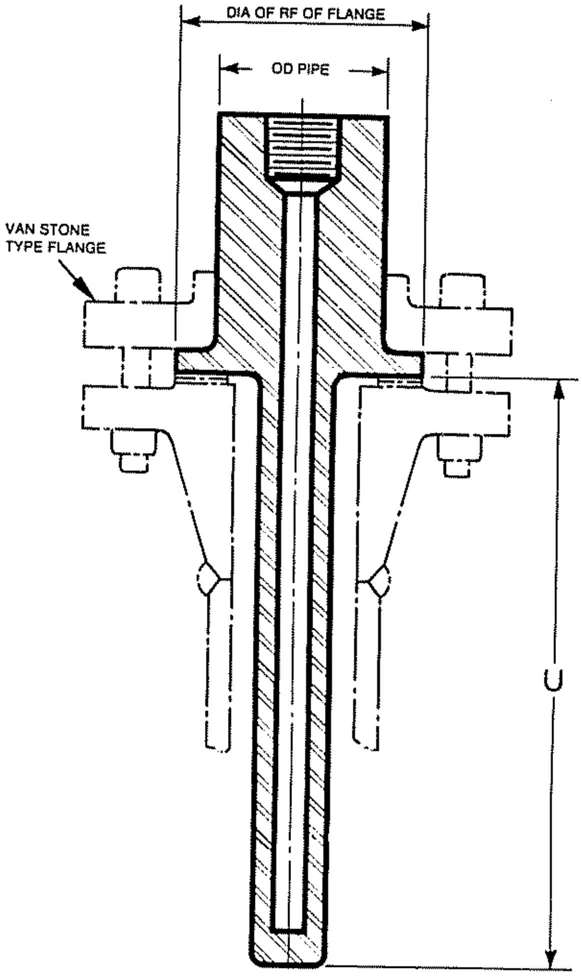


Figure 3-3—Flanged Thermowell—Van Stone

The thermowell should extend sufficiently deep into the medium for the temperature-sensitive portion of the measuring element to be subject to the medium's actual temperature. Insufficient immersion can cause errors due to the conduction of heat to or away from the sensitive end of the thermowell.

When the thermowell is installed perpendicular or at a 45 degree angle to the pipe wall, the tip of the thermowell should be located in the center third of the pipe. If the thermowell is installed at an angle or in an elbow, the tip should point toward the flow in the process line.

Thermowells installed in lines having higher velocities may be subject to vibration which may cause a rupture of the well below the mounting. Tapered stems and U lengths established from a stress analysis are recommended for high velocity lines.*

*J. W. Murdock, "Power Test Code Thermometer Wells," *Journal of Engineering for Power*, 403-16, October 1959.

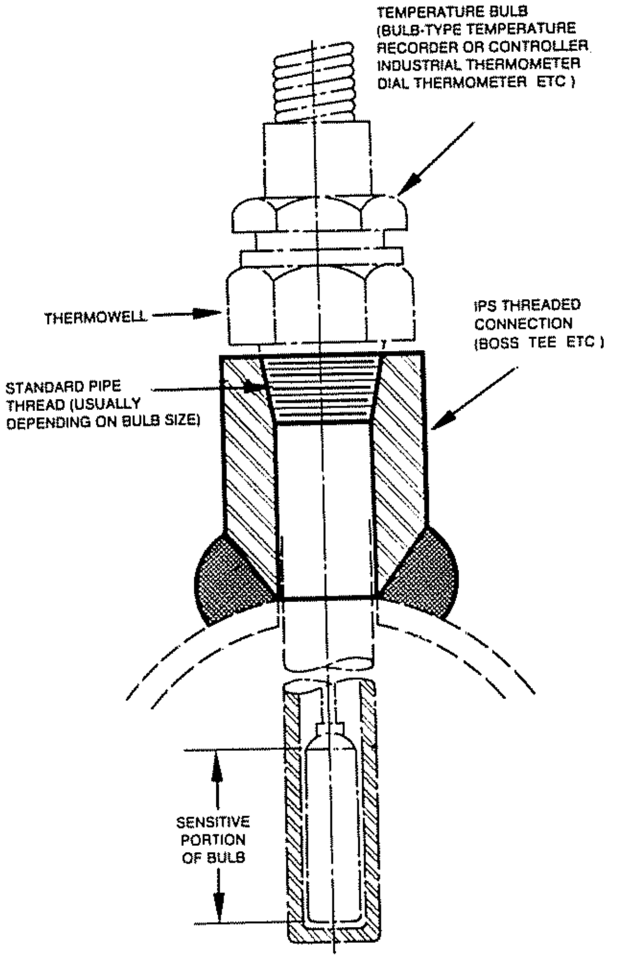


Figure 3-4—Temperature Bulb Installation

3.2.4 THERMOWELL MATERIALS

The materials selected must be suitable for the temperature and corrosion environment encountered. For general services where carbon steel piping is normally used the minimum quality material usually specified is Type 304 or Type 316 stainless steel. Thermowells in certain corrosive services (such as dilute acids, chlorides, and heavy organic acids) require well materials suitable for the specific corrosive media.

3.2.5 THERMOWELL CONSTRUCTION

Typical thermowell construction and installation details are shown in Figures 3-1 through 3-6. Thermowells may be screw mounted as shown in Figures 3-1, 3-4, and 3-5. However, where frequent inspection, special materials (for example, glass coating), or pressure and temperature limitations require it, flange mounted wells (such as shown in Figures 3-2, 3-3, and 3-6) are commonly installed. When experience indicates that rapid temperature response is necessary, thermowells for temperature controller installations should be constructed with wall thicknesses as thin as operating conditions will permit.

CAUTION: *Where atomic hydrogen may permeate the thermowell, it should be vented to the atmosphere.*

3.3 Thermocouple Temperature Instruments

3.3.1 APPLICATIONS

Temperature instruments utilizing thermocouples are now the most generally applied of all temperature-measuring devices. They are applicable for a wide range of temperatures with reasonably good accuracy.

Additional information on application may be found in the American Society for Testing and Materials' *Manual on the Use of Thermocouples in Temperature Measurement*, STP 470A, March 1974.

3.3.2 GENERAL

3.3.2.1 Materials and Ranges

In the petroleum industry the most commonly used thermocouple materials are:

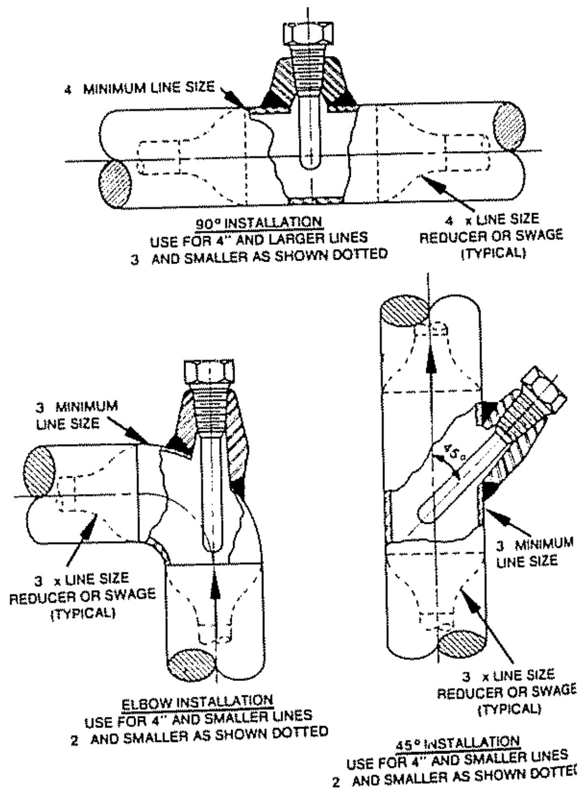
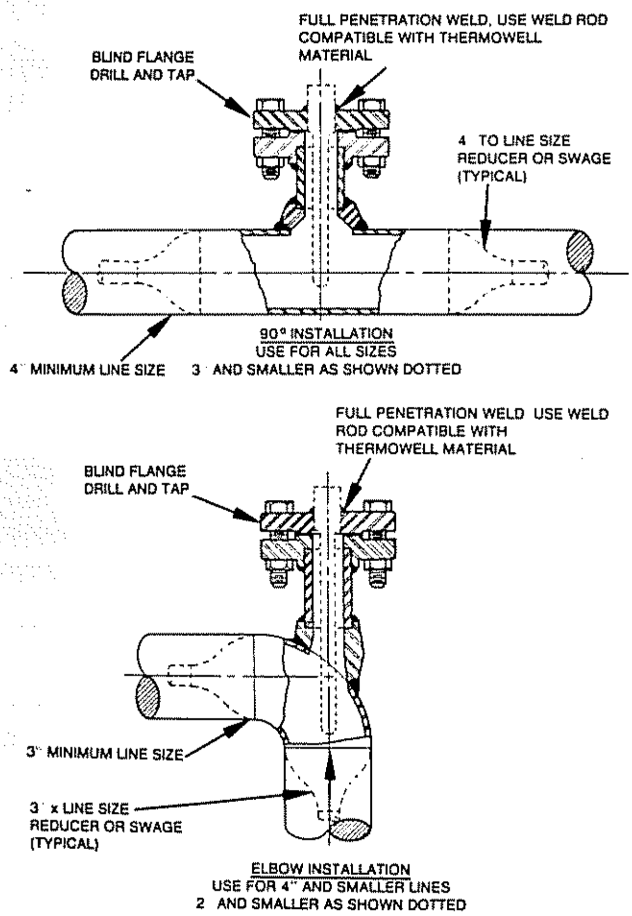


Figure 3-5—Typical Screwed Thermowell Installation

ANSI Symbol	*Thermocouple Materials*	*Normal Temperature Range*
E	Chromel-Constantan	0 to 870°Celsius (32 to 1600°Fahrenheit)
J	Iron-Constantan	−185 to 760°Celsius (−300 to 1400°Fahrenheit)
K	Chromel-Alumel®	0 to 1260°Celsius (32 to 2300°Fahrenheit)
R	Platinum, 13% Rhodium-Platinum	0 to 1480° Celsius (32 to 2700°Fahrenheit)
S	Platinum, 10% Rhodium-Platinum	0 to 1480°Celsius (32 to 2700°Fahrenheit)
T	Copper-Constantan	−185 to 370°Celsius (−300 to 700° Fahrenheit)

Because thermocouples normally are installed in thermowells, the couple usually is selected for the temperature range and well material is selected that is suitable for the measured media. Where thermocouples are installed without protective thermowells, it is common practice to use iron-constantan in reducing atmospheres and Chromel-Alumel in oxidizing atmospheres.



NOTE: Material used for thermowell installation should comply with piping specification material and rating.

Figure 3-6—Typical Flanged Thermowell Installation

3.3.2.2 Fabrication

Fabrication details for thermocouples are covered in a publication of the American National Standards Institute, *American Standard for Temperature Measurement Thermocouples*, MC 96.1-1975.

Increased use has been made of metal-sheathed, mineral-insulated thermocouple assemblies. These assemblies are made by insulating the thermocouple conductors with a high purity, densely packed ceramic insulation (usually magnesium oxide) and enclosing the assembly in an outer metal sheath. These thermocouples are available with outside diameters ranging from 1 millimeter to 21 millimeters (.04 inches to .84 inches) and thermocouple wire sizes from No. 36 gage up to No. 8 gage. Outside sheath material is available in a variety of stainless steels, inconel, monel, titanium, tantalum, platinum, or any workable material.

Two types of measuring junctions (see Figure 3-7) are in general use:

1. **A** is the standard construction with grounded tip, welded or silver soldered for fast response.

2. **B** has an ungrounded tip (electrically isolated from the sheath) with slower response.

3.3.2.3 Installation

Thermocouples are generally installed in thermowells as discussed in Paragraph 3.2. To minimize temperature lags (response time), it is essential that the thermocouple be in contact with the bottom of the well. The correct type of extension wires for the particular thermocouple must be used in connecting the thermocouple to the instrument. For information on thermocouple extension wires refer to Paragraph 3.3.5.

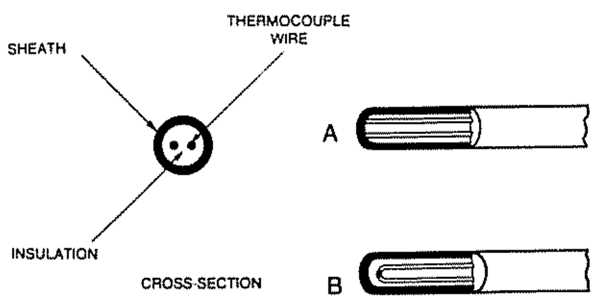
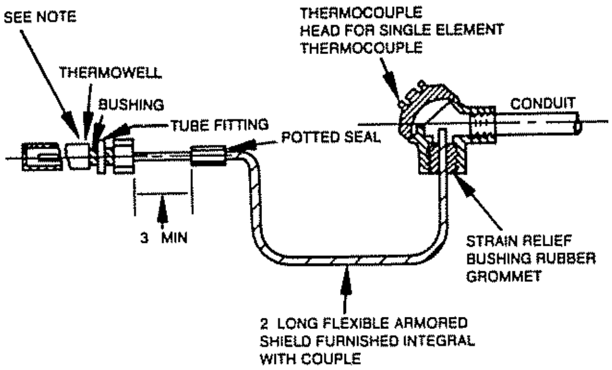


Figure 3-7—Metal-Sheathed, Mineral-Insulated Thermocouple Assemblies

Metal-sheathed, mineral-insulated thermocouples are sometimes installed with the thermocouple head separated from the thermowell. An example of this type of installation is shown in Figure 3-8.



NOTE: Male tubing fitting for thermocouple to pass through. Install ferrule and nut and push couple to bottom of well then tighten tubing nut to secure couple in well.

Figure 3-8—Sheathed-Type Thermocouple and Head Assembly

There are applications where metal-sheathed, mineral-insulated thermocouples are sometimes installed as bare elements without thermowells. Metal-sheathed thermocouples provide longer life and improved long-term accuracy when compared to bare wire thermocouples. An example of this type of installation is shown in Figure 3-9.

For field installation where the thermocouple cannot be directly connected to rigid conduit, flexible conduit may be used as shown in Figure 3-8 or 3-10. It should be noted that both installations incorporate a seal to prevent leakage into the conduit system.

For additional information on installation of thermocouples refer to API RP 550, Part I, Section 7.

3.3.3 TUBE TEMPERATURE MEASUREMENT

A special application of thermocouples is the measurement of skin-point or tube-metal temperature of furnace tubes. Such installations require careful attention to be certain that the thermocouple is properly attached to the tube and is shielded from furnace radiation. Care must be exercised to avoid adding mass at the point of measurement which may assume a temperature different from that of the relatively cool tube wall to which it is attached. Many companies have their own standards for this application. These installations have been costly and complex and not entirely reliable.

One design for attaching this type of thermocouple to heater tubes is shown in Figure 3-11.

3.3.4 FIREBOX TEMPERATURE MEASUREMENT

The application of thermocouples in fireboxes requires some special handling because of the wall construction. For typical installation refer to Figure 3-12 and for further information on this measurement refer to API RP 550, Part III, Section 1.

3.3.5 EXTENSION WIRES

Thermocouple extension wires must have the same electromotive force (emf) temperature characteristics as the thermocouple to which they are connected. This will, in effect, transfer the reference junction to the end away from the thermocouple to a point where the temperature is reasonably stable and where the effect of temperature variations can be compensated. The use of incorrect extension wire will cause errors in the tem-

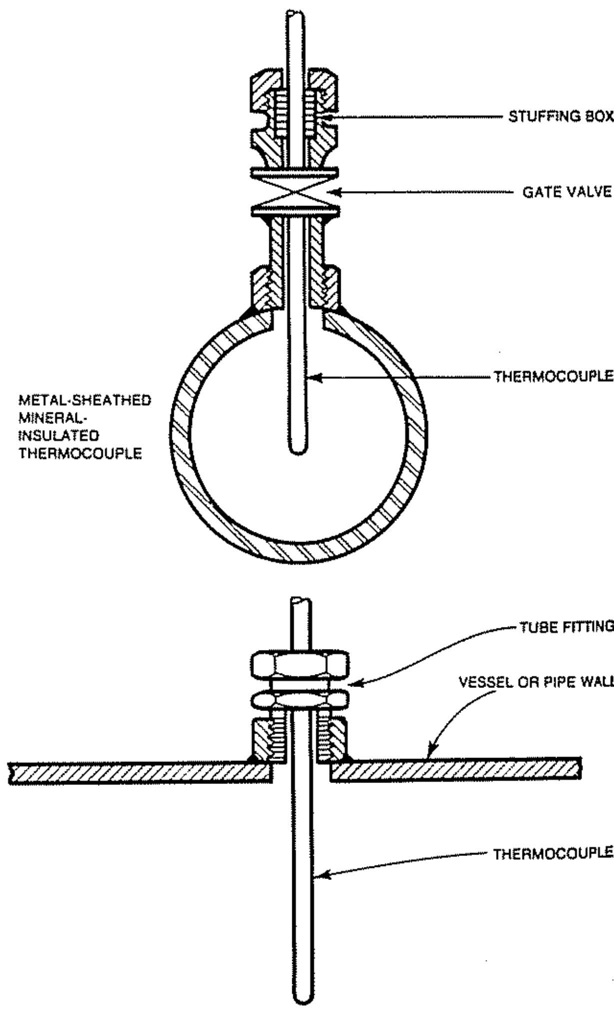
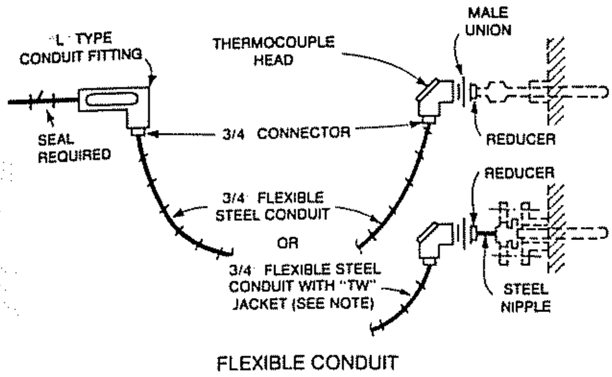


Figure 3-9—Installation of Thermocouples Without Wells



NOTE: Where "TW" jacketed flexible steel conduit is used, it should be vented to relieve the pressure in case of thermocouple well failure.

Figure 3-10—Thermocouple-to-Conduit Connections

perature readings by creating spurious thermocouples at the thermocouple terminal block or in the instrument.

Thermocouple extension wires (available either in pairs or bundles with multiple pairs) should be installed as described in API RP 550, Part I, Section 7. Materials for thermocouple extension wires may be selected as follows:

ANSI Symbol	*Thermocouple Materials*	*Extension Wire Materials*
EX	Chromel-Constantan	Chromel-Constantan
JX	Iron-Constantan	Iron-Constantan
KX	Chromel-Alumel	Chromel-Alumel
SX	Platinum 10% or 13% Rhodium-Platinum	Copper-Copper Nickel Alloy
TX	Copper-Constantan	Copper-Constantan

The wire sizes normally used for extension wire either singly or in pairs are 14, 16, and 20 American Wire Gage (AWG), with 16 gage being the most common size used. When bundled and reinforced to provide strength for pulling, 20 gage and smaller may be used.

3.3.6 TEMPERATURE INSTRUMENTS

Measurement data can be collected and displayed in two basic forms, analog or digital, from single or multi-loop systems. In all systems, however, measurements are made by the use of a bridge circuit and amplifier.

3.3.6.1 Input Circuit

Since the system deals with a low millivolt input from the thermocouple, the bridge and amplifier must be carefully designed to meet system requirements. The following points must be considered when designing a system.

1. Differential or isolated input is necessary for use with grounded thermocouples.
2. Parallel systems should be avoided where possible by the use of dual thermocouples or a separate thermowell and thermocouple. Input impedance must be high to reduce interaction with other parallel devices. Impedances of 100,000 ohms or more are generally considered to be high impedances.
3. Various feedback systems to linearize the amplifiers may be used including a DC voltage feedback to the bridge circuit and a balancing motor that moves a slide wire in the bridge circuit. The latter circuit is satisfactory only in slow readout systems; and since this circuit is unbalanced for a long time, the input impedance is lowered for a proportionately longer time.
4. Thermocouple burnout protection can be provided, but this protection lowers input impedance and is not compatible with parallel instrument applications.
5. The amplifier should have a high common-mode rejection to prevent conversion of common mode to normal mode voltage. This point is extremely important in high-speed measuring circuits and should not be neglected in slow-speed circuits since the normal mode AC voltage could possibly be rectified by a nonlinear component in the measuring circuit with a resulting millivolt error.

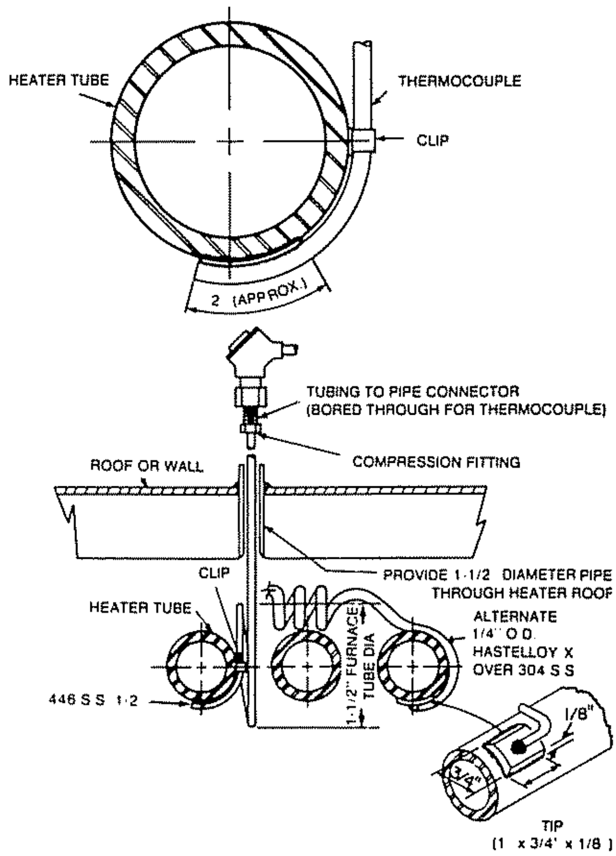
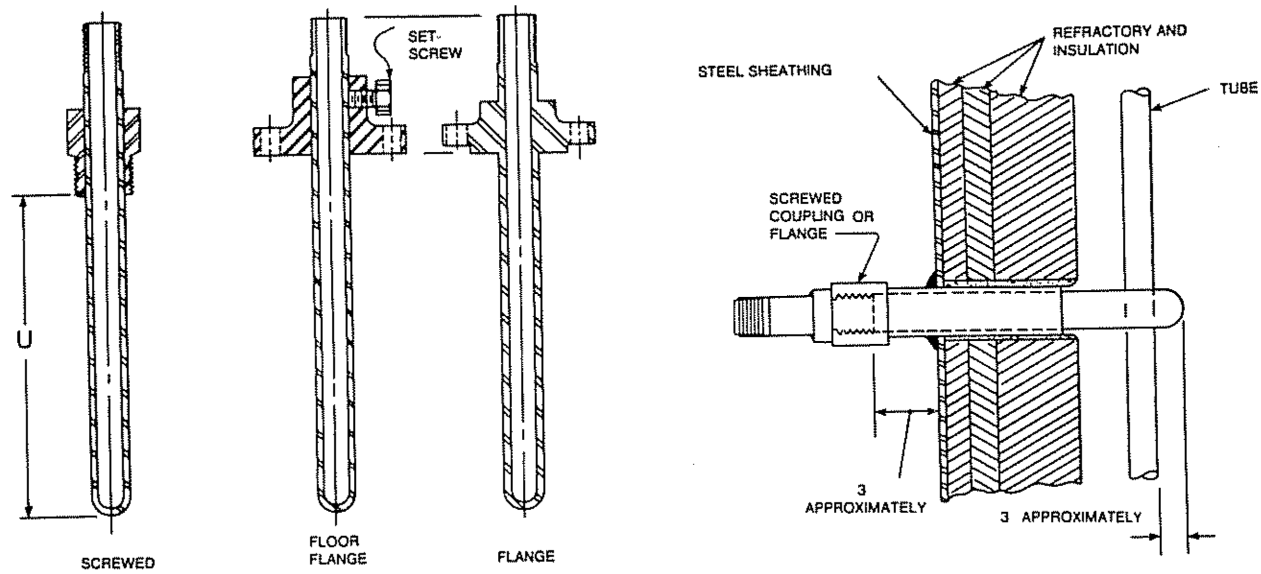
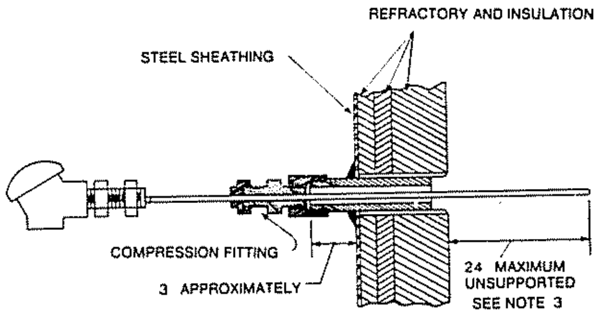


Figure 3-11—Heater Tube Skin Thermocouple Installation



NOTES:
1. See RP 550, Part III, Table 1-1 for materials.
2. Material external of firebox may be other than specified in Table 1-1



NOTES:

1. Thermocouple should be .500-inch O.D. by .120-inch wall MgO insulated 14-gage chromel-alumel thermocouple wire with 446 stainless sheath, or material listed in RP 550, Part III, Table 1-1.

2. The head end of the thermocouple should have 2 inches of exposed wire. The mineral insulation shall be removed to a depth of at least ¼ inch and potted with compound

3. The 24-inch maximum immersion does not apply to top entering installations.

Figure 3-12—Typical Firebox Thermocouple Installations

3.3.6.2 Output Devices

The readout from the amplifier circuit may be analog or digital. The balancing motor (Paragraph 3.3.6.1, 3) may be used to drive a pointer or pen in a simple system; or the feedback current to the bridge may be used to drive a milliamp indicator, recorder, or other device. For a single-loop digital output, the amplifier must drive a characterizing circuit to introduce the thermocouple curve characteristic before feeding a type of digital volt meter.

3.3.6.3 Thermocouple Transmitters

To avoid the use of thermocouple extension wire, the bridge and amplifier can be located in the field. When installing this type of transmitter, the ambient temperature limitations must be considered. The manufacturer's literature should be consulted to determine the specific limitation. The amplifier output milliamps is then transmitted over standard copper wire to the remote receiver (See output devices, Paragraph 3.3.6.2.)

3.3.6.4 Multiple Input Systems

Instruments can be obtained to select one of several thermocouple inputs ahead of the input circuit (Paragraph 3.3.6.1.) This switching device should always break both leads of the thermocouple. It can take any one of the several following forms depending on system requirements:

1. Toggle or push-button switches
2. Drum switches

3. Relays of various forms
4. Solid state switches

The following forms are examples of how the output temperature data collected by these multiple input systems can be presented.

1. A multipoint indicator or recorder can give analog values. These devices can be made to scan points sequentially and sound an alarm if a measurement exceeds a desired value.
2. For digital output, the information can be presented on digital indicators. Scanning for alarm conditions can be specified.
3. Additional options on digital output can be achieved by the use of a temperature instrument with an integral minicomputer to drive typewriters or other devices. The computer can be utilized to provide calculation for the temperature electromotive force (emf) curve and to enable random selection or scanning for alarm or logging purposes.

3.3.7 AVERAGING THERMOCOUPLES

To measure average temperature, thermocouples are connected in parallel. For accurate measurement, the resistances of all thermocouples, including extension wires, should be the same. To prevent the flow of current through a ground loop, the thermocouples should not be grounded. All thermocouples must be of the same type and must be connected by the correct extension wires.

A suggested method of wiring is to use an external connection box placed in a convenient location. To obtain equal resistances, all extension wires between the thermocouples and connection box should be made the same length with the excess leads coiled up to the nearer couples. An alternative method is to incorporate a noninductive, low temperature coefficient, nominal 1500 ohm resistor in series with the thermocouple, so that minor differences in resistance of the thermocouple extension wires have negligible effect. In the connection box all terminals of each polarity should be connected in common, and a common pair of extension wires run to the instrument terminal panel. The suggested methods are schematically shown in Figure 3-13.

3.3.8 TEMPERATURE DIFFERENCE

Two thermocouples may be used for measurement of differential temperatures between two points. Two similar thermocouples are connected together with extension wire of the same materials as those used in the thermocouples. The connections are made in such a way that the electromotive forces developed oppose each other. Thus, if the temperatures of both thermocouples are equal, regardless of the magnitude, the net emf will be zero. When different temperatures exist, the voltage generated will correspond to this temperature difference and the actual difference may be determined from the proper calibration curve. An instrument—either calibrated for zero millivolts at midscale or zero millivolts at the end of the scale, depending upon whether thermocouples are operated at high or low temperatures with respect to each other—can be furnished and used to read temperature differences.

Copper leads may be used to connect the instrument and a connection box to which the thermocouple or extension wires are brought. The instrument should not have the reference junction compensation that is normally furnished when measuring temperatures with thermocouples. As in the case of parallel thermocouple connections, the thermocouples should not be grounded and the resistance of both thermocouple circuits should be the same. A suggested method is shown schematically in Figure 3-14.

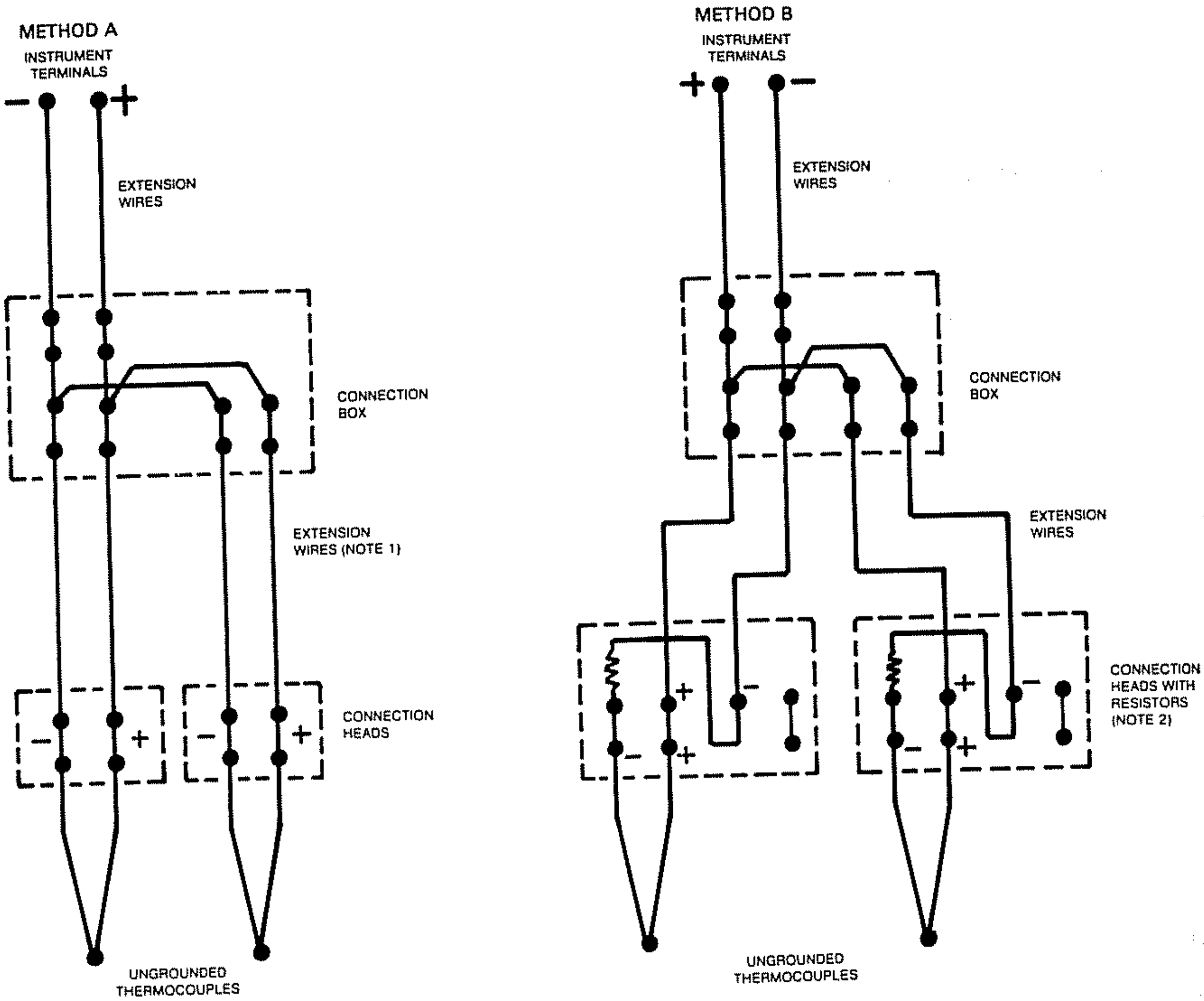
3.3.9 REFERENCE JUNCTIONS

The reference junction, sometimes called the cold junction, is usually located in the instrument. In some instances where especially accurate temperature measurements are required, or where the temperature instrument is subjected to varying temperatures the reference junction is external. Also, when a number of very long leads are required, a noncompensating cable is used and a reference junction compensation device is located at the termination point of the conventional extension wire. Such external reference junctions may be installed in an enclosure where the temperature is thermostatically controlled. In any event, it should be noted that the accuracy of temperature measurements is no better than the constancy of the reference junction temperature or its compensation in the instrument.

3.4 Resistance-Type Temperature Measurement

3.4.1 APPLICATION

Resistance-type temperature measurement can provide more accurate measurement of temperature than is possible with thermocouple installations. Accordingly, resistance units are used in many installations where their greater accuracy is warranted, such as in the case of low-differential temperature measurement. In order to obtain the greater accuracy and sensitivity inherent in a resistance system and to minimize thermal lag, it is important that optimum thermowell dimensions (for the particular resistance element) be employed in order to maintain good contact between the resistance bulb and the well. For this reason, wells for resistance bulbs frequently are provided with the resistance bulbs as matched units.



NOTES:
1. Duplex extension wires to be of equal resistance—same lengths.
2. Connection head with 1500-ohm resistor—permits use of different lengths of extension wires.

Figure 3-13—Average Temperature Measurement With Thermocouples

Resistance-type temperature measurement can be used in the range of −185 to 800 degrees Celsius (−300 to 1500 degrees Fahrenheit) with spans as small as 2 degrees Celsius (5 degrees Fahrenheit).

3.4.2 RESISTANCE ELEMENTS

Resistance elements operate on the principle of change in electrical resistance of the wire as a function of temperature. Two types of wire are most generally used in resistance elements, nickel for ranges up to 315 degrees Celsius (600 degrees Fahrenheit) and platinum for ranges up to 800 degrees Celsius (1500 degrees Fahrenheit). A third type, copper, is used in large motor windings up to 150 degrees Celsius (300 degrees Fahrenheit).

Resistance elements are available in many configurations with the most common type being a tip-sensitive construction. Even though most resistance elements used in the petroleum industry are mounted in a thermowell, the elements are designed to be used bare when very fast (5–6 seconds) response times are required.

3.4.3 EXTENSION WIRES

Individual extension wires (usually three) from the resistance element may (a) terminate in a connection head, (b) quick disconnect, or (c) extend directly to the measuring unit. Generally, a connection head is employed and the wires are frequently run in a three-wire cable to the board-mounted resistance temperature

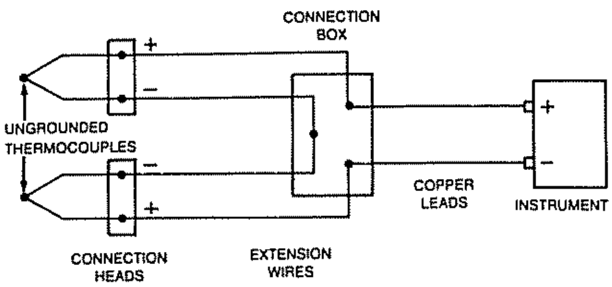


Figure 3-14—Temperature Difference Measurement With Thermocouples

measuring instrument. The wire normally used is 18 AWG stranded copper.

Where multiple installations of resistance elements are used, the wires can be run to a field terminal strip. A multiconductor cable is then used to bring the signals into the control panel. The wire in the multiconductor cable may be 20 or 22 AWG; however, for long distances a check should be made with the manufacturer on allowable wire resistance. Generally, no problem exists up to 1.6 kilometers (5000 feet).

Installation practices as outlined in API RP 550, Part I, Section 7 should be followed.

3.4.4 RESISTANCE CONVERTERS

The use of converters with resistance bulbs has become more common both for pneumatic and electronic systems. Such converters allow the use of standard transmission signals and offer more flexibility in the use of receiver equipment.

3.5 Thermometers for Local Temperature Measurement

3.5.1 GENERAL

Because local temperature-measuring devices are exposed to accidental contact and possible damage, they must be reasonably rugged and must provide the necessary accuracy.

3.5.2 DIAL THERMOMETERS

Dial thermometers are the most common thermometers in industrial use. They are frequently of the bimetallic type with circular dials and are available in a wide range of temperature scales and styles. Dial-type thermometers, which use filled systems are also available (see Paragraph 3.6). The most common type has a fixed orientation. Care should be taken on installation of the fixed-orientation type to assure readability of the dial from a convenient location. Some manufacturers offer a type that can be adjusted to various angles. For low-temperature applications below −30 degrees Celsius (−22 degrees Fahrenheit), it may be desirable to use a filled thermal system type (See Table 3-1 for limitations.)

3.6 Filled-System Temperature Instruments

3.6.1 GENERAL

A thermal system is a closed system containing a fluid fill (the temperature sensitive medium) and comprised of a bulb, an expansible device (Bourdon tube, diaphragm, capsule, bellows, and so forth), and a capillary tube operatively connecting the two.

The use of filled-system devices is limited by the capillary tubing which may be employed and by the maximum temperature to which the bulb may be exposed. Systems which have compensation are built to self-adjust for changes in temperature either on the case or on the capillary and the case. This self-adjustment assures accurate measurement of the temperature where the bulb is located. The classes of thermal systems which are in general use are shown in Table 3-2.

3.6.2 APPLICATIONS

Application comparison of various filled thermal systems is summarized in Table 3-1. This information is an approximate guide only. Dimensional, functional, and physical data vary depending on the manufacturer. See Figure 3-4 for installation.

3.6.3 SELF-ACTING TEMPERATURE CONTROLLERS

Where precise control is not essential, self-acting temperature controllers are frequently used. These devices utilize thermal expansion systems and direct-operated valves. In operation, an increase in temperature expands the liquid in the system and thereby operates the valve. Because of the many different fluids being used, bulb sizes and filling fluids vary with the temperature range. As with other temperature-sensing instruments, bulbs should be protected by thermowells.

Valve operators are in bellows form. The bellows may operate either a valve (directly) or a pilot valve which controls line fluid for actuating power to operate the main valve. Temperature indication in the form of a dial mounted on the top of the valve and operated by the same thermal system is available from some manufacturers. Some form of temperature indication is always desirable with these self-contained devices.

As with all capillary types of thermal systems, the bulb and capillary should be protected from any damage which may cause fluid leaks or impede the flow of fluid. Also, the installation should be made so that the valve can be removed for inspection or service without damage to the capillary.

Table 3-1—Application Data for Filled Measurement Systems

SYSTEM TYPES (SAMA[a] Class)	SYSTEM SPECIFICATIONS: Temperature Limits (degrees)		Minimum Span (degrees)		Maximum Span (degrees)		Limits Of Overrange (degrees)		Maximum Tubing Length[b]		Bulb Size (inches)		63% Time Constant[c]
	Celsius	Fahrenheit	Celsius	Fahrenheit	Celsius	Fahrenheit	Celsius	Fahrenheit	Meters	Feet	Maximum	Minimum	(seconds)
Vapor Pressure (II-A, B, C, D)	−225 to 315	−425 to 600	40[d]	70[d]	220	400	II-A, C, D: (above top scale temperature) 28 II-B: 50 or 100	50 120 or 212	45	150	6x5/8	2x3/8	
Gas Pressure (III-B)	−270 to 760	−450 to 1400	110	200[e]	550	1000	760	1400[f]	30	100	10x7/8	6x5/8	2-8[g]
Mercury Expansion (V-A, V-B)	−38 to 650	−38 to 1200	55	100[e]	V-A: 550 V-B: 315	1000 600	200% of span		V-A: 30 V-B: 15	100 50	6x5/8	3x1/2[g]	2-6[g]
Expansion Liquid (I-A, I-B)	−185 to 315	−300 to 600	22	40	315	600	100% of span		I-A: 30 I-B: 6	100 20	6x3/8	3x1/4	6

[a] Scientific Apparatus Manufacturers' Association.
[b] Longer lengths possible, but unwieldy bulb sizes or poor ambient temperature compensation usually result.
[c] Time for temperature to reach 63 percent recovery constant of a step change for bulbs immersed in well-agitated liquid baths. Short tubing lengths and minimum bulb diameters are required to obtain these minimum figures.
[d] Standard spans as narrow as 10 C (20 F) are possible under certain application conditions, particularly very low temperatures. Minimum temperature of −225 C (−425 F) is possible with special construction.
[e] Minimum gas and mercury system span for force balance pneumatic transmitters is 50 C (90 F).
[f] Reduce to 122 C (250 F) for narrowest spans.
[g] Lowest value generally attainable only with force balance pneumatic transmitters. These instruments have bulbs as small as 6 x 3/8 inches (gas systems) and 3 x 3/8 inches (mercury systems).

NOTES:
1. Relative costs for vapor pressure, gas pressure, mercury expansion, and expansion liquid are—respectively—low, medium-low, medium-high, and high.
2. Scale for vapor pressure is nonuniform. The other three systems are uniform. Uniform motion or output with temperature may be accomplished for certain vapor pressure ranges by mechanical means.

3.6.4 TEMPERATURE TRANSMITTERS

Temperature transmitters may utilize any one of several types of filled systems, together with pneumatic or electronic transmitting and amplifying devices, to convert the measured temperature into an air or electrical signal. Besides covering a wide range of temperatures, some instruments can be obtained with the additional features described in Paragraphs 3.6.4.1 and 3.6.4.2.

3.6.4.1 Suppressed Range

A very accurate measurement of temperature can be obtained by selecting a transmitter with full range of signal output over only a portion of the operating temperature limits of the instrument.

3.6.4.2 Thermal Lag Compensation

In some instruments it is possible to obtain a pneumatic device (derivative action directly applied in the measuring system) which, when properly adjusted, will compensate for thermal lag with a resultant high speed of response. Some companies use this compensation for transmitters associated with controllers but not for transmitters for recording instruments alone.

3.6.5 PRECAUTIONS

In all installations of filled-system temperature instruments, it is necessary to protect the bulb and capillary tubing from mechanical damage. It is usually desirable to use armored capillary tubing and to support the tubing run between the bulb and controller or transmitter in such a manner as to protect it from accidental damage. It is essential that the capillary tubing not be cut or opened in any manner.

Table 3-2—Classes of Thermal Systems in General Use

CLASS	*DESCRIPTION*
Class I-A	Liquid filled; uniform scale; fully compensated.
Class I-B	Liquid filled; uniform scale; case compensated only.
Class II-A	Vapor pressure; increasing scale; with measured temperature above case and tubing temperature.
Class II-B	Vapor pressure; increasing scale; with measured temperature below case and tubing temperature.
Class II-C	Vapor pressure; increasing scale; with measured temperature above and below case and tubing temperature.
Class II-D	Vapor pressure; increasing scale above, at, and below case and tubing temperature
Class III-A	Gas filled; uniform scale; fully compensated
Class III-B	Gas filled; uniform scale; case compensated only.
Class V-A	Mercury filled; uniform scale; fully compensated.
Class V-B	Mercury filled; uniform scale; case compensated only.

3.7 Radiation-Type Pyrometers

The radiation-type pyrometer measures the temperature of an object without requiring physical contact. The ability to accomplish this is based on the fact that every object emits radiant energy and the intensity of this radiation is a function of its temperature.

Most applications use infrared radiation as the measurement source; however, ultraviolet is also used in some instances.

If the radiation pyrometer is to measure absolute temperature, the effective emissivity of the target must be determined The effective emissivity is the emissivity of the target material in the spectral range of the radiation pyrometer. This emissivity can be determined indirectly by applying the radiation laws of physics or experimentally by characterizing the material at a known temperature. Such target nonuniformities as significant temperature changes in the material, the nonhomogeneous nature of some materials, or a basic product change, all represent cases which exhibit an absolute change in effective emissivity.

In industrial temperature measurement using a properly designed industrial instrument, background radiation effects are not a detrimental factor as long as the infrared field of view is aimed exclusively on the target area to be measured. The reflection from the background area should be minimized to reduce spurious effects of radiant energy from sources other than the target Infrared instruments are designed to minimize these background conditions, but energy overlays in the electromagnetic spectrum cannot be completely eliminated without impairing the accuracy and performance of the instrument.

Most radiation-type pyrometers that are used in refinery applications are in the high-temperature range. Since they are somewhat special in application, it is recommended that the user work very closely with the manufacturer.

3.8 Optical Pyrometers

Optical pyrometers are in limited use and the manufacturers should be contacted for recommended installation.