

Temperature

FUNDAMENTALS

Temperature is a basic thermodynamic property of a substance, is determined by the amount of kinetic or heat energy in the substance. Increasing the kinetic energy in a substance will increase its temperature, while decreasing the kinetic energy will lower the substance's temperature. When two bodies at different temperatures are put into thermal contact, energy will be transferred from the warmer body to the colder body until the two bodies are at the same temperature.

If two bodies are in thermal equilibrium with each other, they are at the same temperature. If two bodies have equality of temperature with a third body, they in turn have equality of temperature with each other. This is the zeroth law of thermodynamics.

In order to be able to repeatedly and accurately report temperatures, standard temperature scales have been devised. The most common are the Fahrenheit and the Celsius scales. The relationship between these two scales is:

$$^{\circ}\text{F} = 32 + (9/5)^{\circ}\text{C}$$

In addition to the two common scales mentioned above, there are two absolute scales, the Rankine and Kelvin scales. These scales define temperatures independent of any particular substance and should be used in any calculation that requires reference to absolute temperatures, such as the ideal gas law.

The English system for absolute temperature is the Rankine scale and is related to degrees F as follows:

$$^{\circ}\text{R} = ^{\circ}\text{F} + 460$$

The international system for absolute temperature is the Kelvin scale and is related to degrees C as follows:

$$^{\circ}\text{K} = ^{\circ}\text{C} + 273$$

TEMPERATURE SENSORS

Temperature is the most commonly measured variable in process control. As a result, there are proliferation of sensors and physical construction options. However, while the options are numerous, the optimum choice for a particular application is not always clear.

To make these decisions easier, the following information provides some theoretical background on temperature sensors and details on the standard sensors offered. Some of the background topics include the operation of thermocouple and RTDs, choosing between them, and application considerations.

THERMOCOUPLE OPERATION

The industrial thermocouple is based on the principle that when two dissimilar metals are joined together, an electromotive force (EMF) will exist. If the circuit is closed, a current will flow as a result of the EMF. This principle of operation has made it possible to construct thermocouples capable of measuring a wide range of temperatures using different metal combinations.

As shown in Figure 1, a thermocouple circuit has two sides that are called "junctions". The process side of the circuit is called the "hot junction", while the opposite side is called the "cold junction". The voltage (V) across this circuit is proportional to the temperature difference between the hot and cold junctions (T_1 and T_2 , respectively).

Figure 2 shows how this is implemented with a temperature transmitter. The hot junction is at the thermocouple, and the cold junction is at the transmitter's terminal strip. The voltage produced at the cold junction is proportional to the temperature difference between the thermocouple's hot junction and a transmitter's terminal strip. A reference junction sensor is typically used to measure the temperature of the terminal strip. By measuring the reference junction (T_2) and the voltage (V), the temperature at the hot junction (T_1) can be determined.

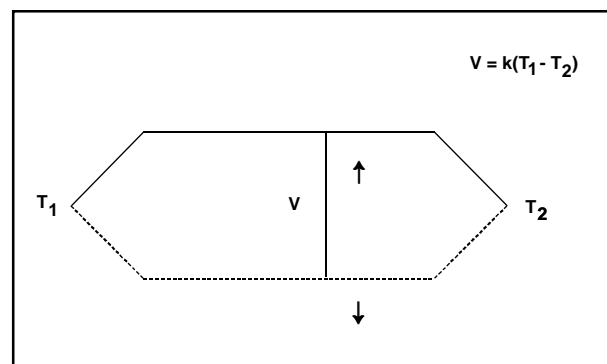


FIGURE 1 Basic T/C Circuit

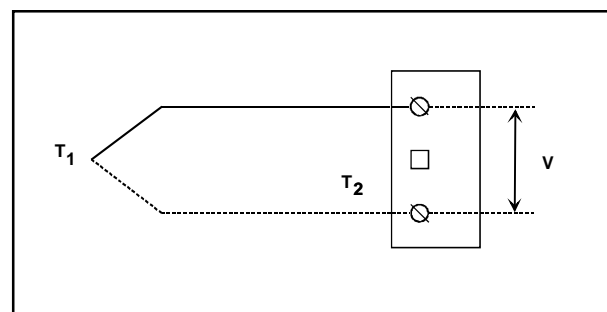


FIGURE 2 Temperature Transmitter T/C Circuit

RESISTANCE TEMPERATURE DETECTOR (RTD) OPERATION

An RTD is based on the principle that the resistance of a conductor varies with temperature. One of the most common conductors used in RTDs is platinum, which provides a resistance of 100 ohms at 0 degrees C and is the most repeatable and stable of all metals.

An RTD is connected to a transmitter that supplies a sense current and measures the RTD's resistance. The sense current is a small current passed through the RTD to generate a voltage that can be read by the transmitter.

There are several types of RTDs available, with the most common being 2-, 3-, and 4-wire RTDs (Figure 3). The 3- and 4-wire versions provide an additional wire loop to compensate for connection wire resistance and, in turn, improve accuracy.

For accuracy the measurement value should be based only on sensor resistance. However, in practice, the RTD's wires add resistance to that measurement, introducing an error. The 3- and 4-wire versions provide a way to greatly reduce the influence of that error.

Figure 4 shows a 3-wire RTD. With this type of RTD, the sense current between two wires is connected across the voltage sense terminals. The third wire essentially cancels out the errors introduced by the wire resistance of the first two wires.

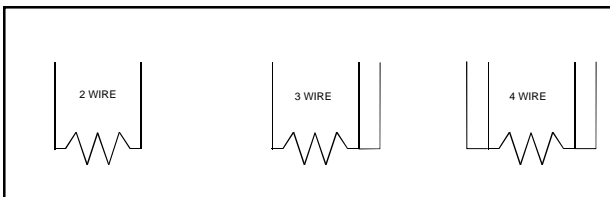


FIGURE 3 Common RTD Types

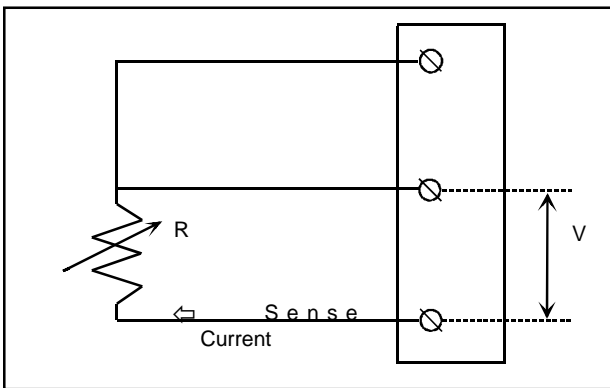


FIGURE 4 Temperature Transmitter RTD Circuit

THERMOCOUPLE vs. RTD

One of the commonly asked questions is whether to use a thermocouple or an RTD. The answer is that it depends primarily on the application's performance requirements and temperature range.

Each type of sensor has trade-offs. In general, RTDs are more accurate and stable than thermocouples, but they have a slower response speed. RTDs will not work at extremely cold or hot temperatures, while thermocouples accommodate a broad range of temperatures.

TABLE 1 Sensor Temperature Ranges & Accuracies

Sensor Type	Temperature Range °C (°F)	Typical Accuracy (1)
100 ohm RTD	-200 to 850 (-328 to 1562)	+/-1.6°C
Type B T/C	100 to 1815 (-212 to 3299)	+/-2°C
Type E T/C	-185 to 1000 (-301 to 1832)	+/-0.55°C
Type J T/C	-185 to 1095 (-301 to 2003)	+/-0.6°C
Type K T/C	-185 to 1370 (-301 to 2498)	+/-0.9°C
Type N T/C	-185 to 1300 (-301 to 2372)	+/-1.4°C
Type R T/C	-18 to 1760 (0 to 3200)	+/-1.7°C
Type S T/C	-18 to 1650 (0 to 3002)	+/-1.65°C
Type T T/C	-200 to 400 (-328 to 752)	+/-0.55°C

NOTES:

- (1) Accuracy is a combination of the absolute digital accuracy of the unit and the ambient temperature effect over the entire operating range of the transmitter.
- (2) This accuracy is for temperatures of 400°C and above. For temperatures between 100 and 400 °C, the accuracy is +/-9°C. Common applications are above 800°C.

TABLE 2 Thermocouple Characteristics

Type	Characteristics
B	<ol style="list-style-type: none"> 1. 70% Platinum/30% Rhodium (+), 94% Platinum/ 6% Rhodium 2. High resistance to oxidation and corrosion. 3. Can only be used in nonmetallic sheaths, as it can be contaminated by hydrogen, carbon, and many metal vapors. 4. Extremely stable. 5. Output is indeterminate below 73.33°C (100°F). 6. Susceptible to noise due to low output level. 7. Requires expensive platinum leadwires.
E	<ol style="list-style-type: none"> 1. Chromel (+), Constantan (-) 2. Suitable for vacuum, inert, mildly oxidizing, or reducing atmospheres. 3. Best choice for low temperatures due to high resistance to corrosion at low temperatures. 4. Low susceptibility to noise due to high output level. 5. Good for detecting small temperature changes.
J	<ol style="list-style-type: none"> 1. Iron (+), Constantan (-) 2. Recommended for reducing atmospheres. 3. Low susceptibility to noise due to high output level 4. Relatively inexpensive thermocouple wire. 5. Caution should be exercised if using it above 760°C (1400°F) due to magnetic transformations changing properties over all temperatures. 6. Low Price. 7. Impurities in the iron result in pure conformance.
K	<ol style="list-style-type: none"> 1. Chromel (+), Alumel (-) 2. Recommended for clean, oxidizing atmospheres. 3. Unstable; characteristics change over time.
N	<ol style="list-style-type: none"> 1. Nicrosil (+), Nisil (-) 2. More stable than type K
R	<ol style="list-style-type: none"> 1. 87% Platinum/13% Rhodium (+), Platinum (-) 2. Expensive platinum lead wire required. 3. Susceptible to metallic vapor diffusion; must be used with nonmetallic sheath or bare wires. 4. Very stable. 5. Susceptible to noise due to low output level.
S	<ol style="list-style-type: none"> 1. 90% Platinum/10% Rhodium (+), Platinum 2. Most stable; used as a standard between 631°C (1168°F) and 1064°C (1947°F). 3. Expensive platinum lead wire required. 4. Susceptible to noise due to low output level. 5. Use with nonmetallic sheath or bare wires.
T	<ol style="list-style-type: none"> 1. Copper (+), Constantan (-) 2. Can be used at temperatures below 0°C (32°F). 3. Has one copper lead, allowing special-purpose differential temperature measurements and reduced installation costs.

APPLICATION

A temperature sensor is applied in conjunction with a temperature transmitter and a thermowell. The sensor is housed in a sensor probe, which protects the sensor and its wires in a sheath. A thermowell provides further protection via an industrial housing designed for a direct process connection. The transmitter accepts the signal from the sensor and determines the temperature measurement.

The sensor probe, thermowell, and transmitter can be ordered separately or together according to the application. The sensor probe and thermowell are often specified as a single unit called the thermowell assembly. This assembly can be integral to the transmitter or mounted separately.

Figure 5 shows a transmitter with an integral thermowell assembly. In this type of installation, the transmitter must be far enough away from the process to keep its ambient temperature from rising above 85°C (185°F). It is also important to support the transmitter with a mounting bracket, as the thermowell assembly is not strong enough to support the weight of the transmitter.

When a remote thermowell assembly is used, the proper type of wire must be used for passing the signal from the thermowell assembly to the transmitter to prevent an improper signal from being generated.

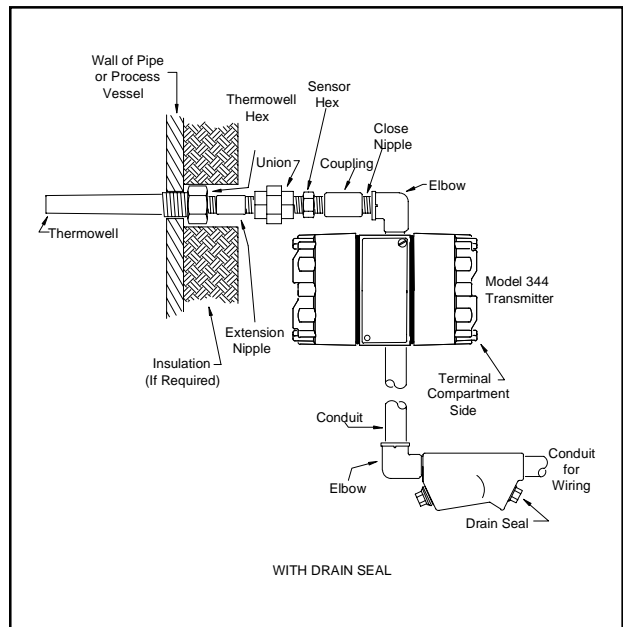
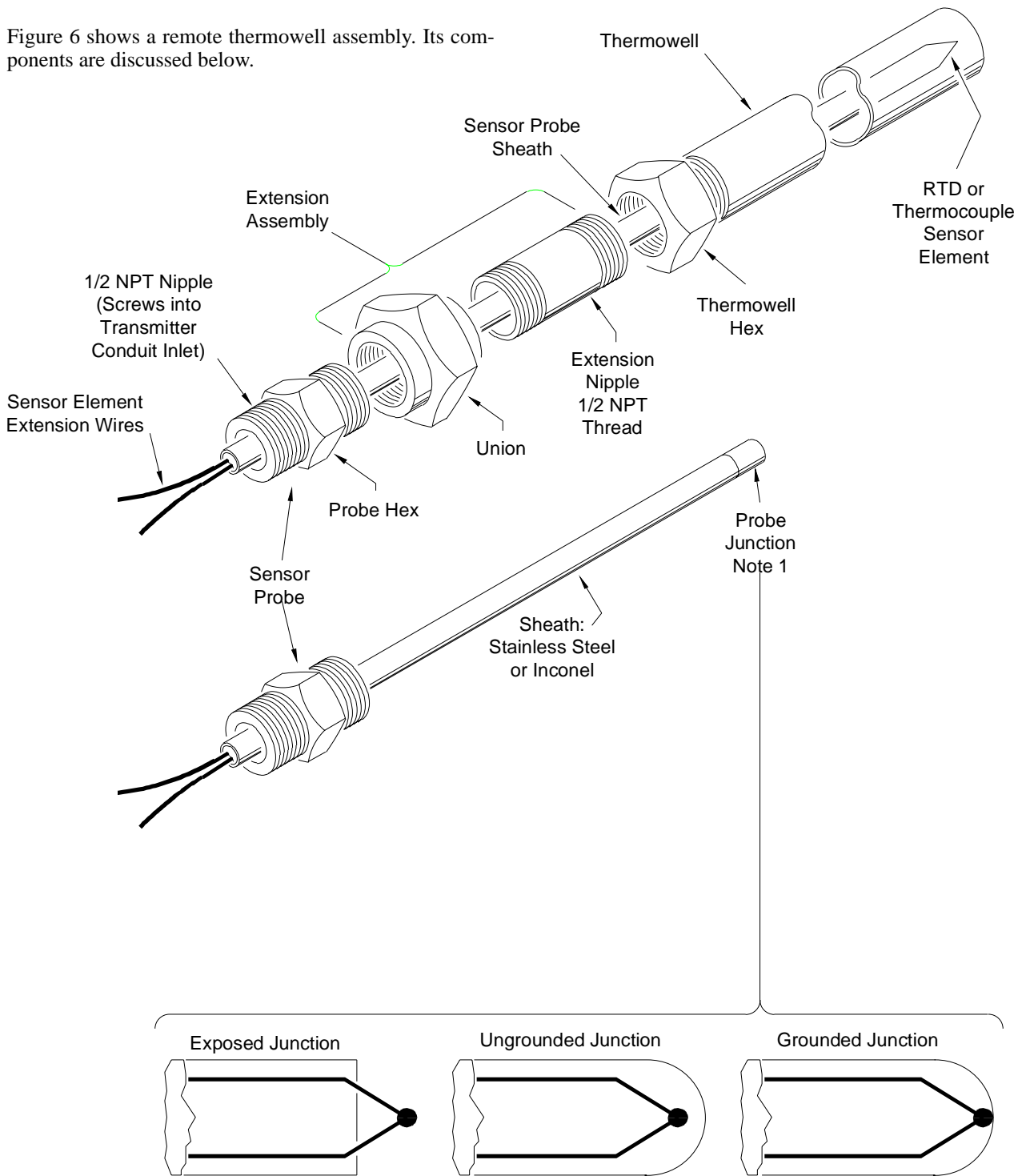


FIGURE 5 Temperature Transmitter Installation

THERMOWELL ASSEMBLY

Figure 6 shows a remote thermowell assembly. Its components are discussed below.



NOTE:

1. Three styles of the thermocouple probe junctions are shown. An RTD probe is a closed end tube only RTD sensors are not grounded.

FIGURE 6 Thermowell Assembly

EXTENSION ASSEMBLY

The extension assembly joins the connection head (or transmitter) and thermowell. It simplifies installation into the vessel and allows easy removal of the sensing element, if necessary. This component, which is also called the “E” length, has a standard length of 6" (152.4 mm). Other lengths are available on request.

SENSOR PROBE

The sensor probe contains the replaceable thermocouple or RTD. At the tip is the actual sensor, which is flush up against the thermowell; the thermowell assembly includes a spring to ensure this position.

PROCESS CONNECTION

This portion of the thermowell assembly provides the connection to the vessel. Its standard size is 2" (50.8 mm) long. Other lengths are available on request.

THERMOWELL

The thermowell is the industrial housing for the sensor probe. It protects the sensor probe against harsh conditions.

“U” LENGTH

This is the length of the thermowell to be inserted into the process. The following standard lengths are available, with other lengths available on request.

3.5"	(88.9 mm)
6"	(152.4 mm)
8"	(203.2 mm)
10"	(254.0 mm)
12"	(304.8 mm)

CONTACT POINT

The contact point is where the tip of the sensor probe makes contact with the bottom of the thermowell. This contact is necessary for the fastest response time, as it ensures the greatest conductivity.

When a thermocouple is used, the contact point is where its two metals meet to create an electromotive force (EMF). Thus, it is the location of the hot junction.

Generally, options are available for a grounded, ungrounded, or exposed junction. For industrial process applications, the grounded option is the most advantageous. An exposed loop, while providing the fastest response time, cannot withstand more than mild conditions. At the other end of the spectrum, an ungrounded junction, which consists of the conductors welded together with electrical insulation from the thermowell, provides a very slow response time.

With a grounded junction, the sensor probe is completely sealed from contaminants, and the hot junction becomes an integral part of the tip of the probe. This allows the response time to approach that of an exposed loop, while providing protection against harsh environments.

ENVIRONMENTAL CONSIDERATIONS

When choosing a thermowell assembly, it is important to consider the process environment in which it is to be installed. Three of the most important considerations are corrosion, fluid velocity, and location.

CORROSION

It is important that the material of the thermowell assembly is resistant to the process to be measured. Standard thermowell assemblies are available in 316SS or 304SS, depending on the sensor type.

FLUID VELOCITY

When a thermowell assembly is inserted into a flowing stream, it is subjected to a vibration. This vibration is caused by the Von Karman Trail, which results from vortices being generated alternately on either side of the thermowell. The vortices cause the thermowell assembly to vibrate and can result in its premature failure.

Tables 3 and 4 give the maximum velocity for a tapered 1" NPT screwed process connection at some standard insertion lengths. Note that this information is for reference only. Please consult Moore for critical applications.

TABLE 3 Maximum Velocity - Saturated Steam

“U” Length	Velocity (Max.)
3.5" (88.9mm)	386 (ft./sec.)
6" (152.4mm)	167 (ft./sec.)
8" (203.2mm)	94 (ft./sec.)
10" (254mm)	60 (ft./sec.)
12" (304.8mm)	42 (ft./sec.)

TABLE 4 Maximum Velocity - Water

“U” Length	Velocity (Max.)
3.5" (88.9mm)	109 (ft./sec.)
6" (152.4mm)	63 (ft./sec.)
8" (203.2mm)	47 (ft./sec.)
10" (254mm)	38 (ft./sec.)
12" (304.8 mm)	31 (ft./sec.)

LOCATION

Caution should be used when installing a thermowell assembly close to another transmitter that is measuring flow, such as a DP transmitter measuring flow through an orifice or a vortex meter. Depending on the proximity of the thermowell to the other transmitter, the thermowell could disrupt the flow profile, causing an error in the measurement. Consult each transmitter’s installation for specific distance guidelines.