Thermometers

Introduction

About Thermometers

Precise process control is one of the most important factors in maintaining high quality in production, just as precision and accuracy are the key to research. Temperature is one of the most important variables today in research, as well as in production. Up to a few decades ago, thermometers had remained virtually unchanged. They were mainly either glass or dial/metal type.

Glass and metal thermometers use thermal expansion to measure temperature. This method uses a physical law which gives a false sense of reliability since one assumes the measurement is "true" because he or she can see how it works. This system is no longer suitable for many reasons and their accuracy and range are very limited. Glass construction is fragile and can be dangerous to a persons health, as well as to the environment. For these reasons, an alternative way of measuring temperature has become necessary.

Electronic thermometers have provided the versatility, speed and accuracy requested by operators in all areas of temperature measurement. Speed is important when the reactions being monitored are changing rapidly. Small, compact sensors are preferable for tightly arranged areas, such as electronics and other miniature applications. Electronic thermometers allow users to monitor maximum, minimum and even average temperatures. Mechanical stress is no longer a worry with an electronic thermometer. Rain, cold, dust and other natural obstacles common to field measurements are overcome with our rugged instruments.

Dedicated research teams, precision process control, integrated production facilities and an overall team effort is required to meet the demanding applications of our users. HANNA's extensive professional thermometer line constitutes the true dedication HANNA commits to thermometer design and production.

Measurement Unit

Temperature is one of the most common physical properties in our everyday life. It is defined as the property of a body that determines the transfer of heat to or from other bodies. Physically, temperature affects variations in the macroscopic parameters of a body such as volume and pressure, among others.

The fundamental temperature scale is the absolute, thermodynamic or Kelvin scale. The Kelvin (K), unit of thermodynamic temperature, is the fraction 1/273.16 of thermodynamic temperature of the triple point of water. The triple point of water is a standard fixed point at which ice, liquid water, and water vapor are in equilibrium.

Two empirical temperature scales are in common use: the Celsius and Fahrenheit scales. These scales are based on two fixed points.

The Celsius (formally Centigrade) temperature scale uses the Celsius (°C) units, defined as 1/100th of the difference between the temperature of boiling (100°C) and freezing points (0°C) of water. The relationship between the Kelvin and Celsius scales is given by:

$$K = {}^{\circ}C + 273.15$$

The Fahrenheit scale uses Fahrenheit (°F) units, where the temperature of boiling water is taken of 212°F, and the temperature of the freezing point at 32°F. The scale originally used the temperature of a mixture of ice and common salt as 0°F, and the inventor's body temperature as 96°F. The relationship between the Fahrenheit and Celsius scales is calculated by:

$${}^{\circ}F = {}^{\circ}C \times 9/5 + 32$$

Achieving Thermometer Accuracy

Even though it is easy to show resolutions of 0.1°C with digital thermometers, there is no relationship between resolution and accuracy of measurements.

Here is a list of the main causes that can have an effect on accuracy in temperature measurements:

- **Instrument**
  The instrument may have an extended scale and 19,000 points of measurement may be obtained. Within these 19,000 points the instrument may perform differently because of internal linearity.
- **Electronic components**
  The internal electronics have a drift that depends on the ambient temperature. For this reason the accuracy of the instrument is stated at a specific temperature of 20 or 25°C, and the drift has to be specified for each degree of variations with respect to the reference temperature.
- **LCD**
  Liquid crystals have an operating limitation which is a function of temperature. Their normal range is between 0 and 50°C, but there are components capable of performing between -20°C and 70°C.
- **Batteries**
  Instrument battery power supply also has limitations of use.
- **Temperature sensor**
  This is a separate accuracy, which is to be added to the instrument's error.

Also, if the probe supplied is connected to the meter during factory calibration, the probe error is eliminated but will reappear if the probe is replaced.

With all the possible forces influencing accuracy, calibration verification is essential. HANNA's CAL CHECK™ can verify an accurate calibration quickly and easily.

Importance of Accuracy

Up to a few years ago, accuracy was not a very critical aspect and tolerances of a few °C did not jeopardize a process. From the time that HACCP programs became a necessity, measurement accuracy has become a discriminating factor. Due to health risk factors, now an error of a few tenths of a degree can decide whether food can still be kept or must be discarded. In 1990, HANNA began to produce thermometers for our customers' HACCP programs to comply with new government regulations. Soon after, HANNA became the market leader in Europe as a result of the technological solutions offered to our users.

User Calibration

To calibrate typical thermometers you need:

- **for thermocouple thermometers:** a simulator of the emf (electromotive force) generated by the thermocouple
- **for thermometers with NTC/PTC sensor:** at least two thermostatic baths
- **for Pt100 thermometers:** a resistance simulator
- **for infrared thermometers:** a heat source (panel) at controlled temperature

Few users can afford this investment in time and materials for checking their thermometers' accuracy. HANNA's exclusive CAL CHECK™ is a quick and cost effective way to verify accuracy.

CAL CHECK™ Feature

As previously described, the electronic components of an instrument shift with time. HANNA has made it possible for users, with the simple touch of a button, to verify whether the response of the instrument is within the tolerance limit of ±0.02°C.

The CAL CHECK™ system acts by substituting the sensor with an internal resistor, which corresponds to 0°C, and thus simulating the response that the temperature probe would have at 0°C.

Standardization

HANNA has designed a series of pre-calibrated temperature probes with a maximum error of 2°C for trouble free replacement.

Thermocouple Thermometer Calibration

Although quite fast, thermocouple thermometers read with a response time much slower than other sensors and technologies. Unfortunately, the measurement of the thermocouple emf (electromotive force) loses accuracy because of the measuring system itself, based on the emf generated by the temperature difference between cold and hot junctions. The same emf may be generated under different conditions:

- **Hot junction at 100°C; cold junction at 20°C; difference: 80°C or:**
- **Hot junction at 90°C; cold junction at 10°C; difference: 80°C**

A temperature difference of 80°C is obtained with two different temperatures of the sample. It is, therefore, very important to determine the cold junction temperature very precisely. The ability to do this has a large effect on the accuracy of the measuring system. A thermocouple thermometer is made of two thermometers, one that measures the cold junction, and one for measuring the emf generated by the thermocouple. The cold junction is usually measured with an NTC type sensor, which has response times different from those of the thermocouple. Another crucial point is measuring the actual value of the cold junction, without any environmental influence and dispersions.

To partially solve this problem, HANNA has devised the calibration of the instrument-thermocouple system, by dipping the probe in melting ice, and thus allowing the user to calibrate the measuring system at 0°C.

Thanks to this solution, it is now possible to use thermocouple thermometers for HACCP controls with an accuracy of ±0.3°C, which is the same performance of our Pt100 or NTC thermometers, but with a higher response time.

Calibration Test Keys

To check the calibration status of the instrument, calibrated keys have been prepared in the range from -18°C to 70°C. These keys reproduce the value of the sensor at different temperatures. Simply disconnect the measuring probe, replace it with the key and make sure that the instrument reads the simulated value.

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HANNA calibrates all thermometers with a standard probe. All NTC temperature probes are inspected and calibrated with standard instruments. During quality inspection our technicians make sure that the reading errors are within the stated accuracies.

In addition, HANNA provides users with the necessary tools to verify that your thermometers read accurate values.

Our complete line of electronic thermometers provides fast and precise measurements down to a tenth of a degree Celsius.

HANNA thermometers may be divided into four main categories: thermistor thermometers, thermocouple thermometers, Pt100 thermometers and infrared thermometers.

Thermistor Thermometers

The thermistor is a semi-conductor device whose resistivity (r) varies as a function of temperature (T)

$$r = ro\,(1 + aT)$$

where

ro = characteristic resistivity of material

a = temperature resistance coefficient of material

The temperature resistance coefficient is the parameter that determines if the resistivity variation is positive (as with the Positive Temperature Coefficient sensors) or negative (as with the Negative Temperature Coefficient thermistors). It is possible to determine the temperature by applying a potential difference and measuring the resistance.

Thermistor sensors are suitable for a temperature range of -50 to 150°C (-58 to 302°F). Higher temperatures may damage the semi-conductor sensor. Accurate temperature measurements are possible (tenths of degree) due to the high sensitivity of the sensor.

Thermocouple Thermometers

The thermocouple consists of the junction of two wires of different metals. At a given temperature, a potential difference results at the opposite extremes of the two wires (Seebeck effect), with the respective variations linearly related within small intervals. It is therefore possible to determine the temperature given the potential difference and characteristics of the two metals. The measurement end of the thermocouple probe is called the hot junction, while the connection of the thermocouple to the meter is the cold junction. An error is introduced as the cold junction is exposed to the ambient temperature. This error can be eliminated by physically putting the cold junction into an ice bath and forcing a reference temperature of 0°C, or by electronically compensating for the cold junction temperature effect. There are various types of thermocouples, identified by an ANSI code using a letter of the alphabet. The K type is the most commonly used.

Pt100 Thermometers

The operating principle of resistance thermometers is based on the increase of electric resistance of metal conductors (RDT: Resistance Temperature Detectors) with temperature.

This physical phenomenon was discovered by Sir Humphry Davy in 1821. In 1871, Sir William Siemens described the application of this property using platinum, thereby introducing an innovation in the manufacturing of temperature sensors. Platinum resistance thermometers have been used as an international standard for measuring temperatures between hydrogen triple point at 13.81 K and the freezing point of antimony at 630.75°C (1167.26°F).

Among the various metals to be used in the construction of resistance thermometers, platinum, a noble metal, is the one that can measure temperatures throughout a wide range; from -251 (-419.8°F) to 899°C (1650.2°F), with a linear behavior.

Platinum RTD thermometers were common in the seventies but now they have been replaced with thermistor sensors because of their smaller dimensions and faster response to temperature changes. The most common RTD sensor, using platinum, is the Pt100, which means a resistance of 100Ω at 0°C with a temperature coefficient of 0.00385Ω per degree Celsius. For a higher price one can buy platinum sensors with 250, 500 or 1000Ω (Pt1000).

The main disadvantage of RTD probes is the resistance of the connection cable.

This resistance prevents the use of standard two-wire cables for lengths over a few meters, since it affects the accuracy of the reading. For this reason, to obtain high levels of accuracy in industrial and laboratory applications, the use of a three or four-wire system is recommended.

For all its Pt100 thermometers and probes, HANNA has chosen the multiple-wire technology for higher accuracy.

Infrared Thermometers

All objects emit a radiant energy in the infrared (IR) spectrum that falls between visible light and radio waves.

The origins of IR measurements can be traced back to Sir Isaac Newton's prism and the separation of sunlight into colors and electromagnetic energy. In 1800, the relative energy of each color was measured but it was not until early 20th century that IR energy was quantified. It was then discovered that this energy is proportional to the 4th power of the object's temperature.

IR instrumentation using this formula has been around for over 50 years. They almost exclusively use an optic device that detects the heat energy generated by the object that the sensor is aimed at. This is then amplified, linearized and converted into an electronic signal which in turn shows the surface temperature in Celsius or Fahrenheit degrees.

Infrared measurements are particularly suitable for areas where it is difficult or undesirable to take surface measurements using conventional contact sensors. Applications for IR meters include non-destructive testing of foodstuffs, moving machinery, high temperature surfaces and hazardous areas, such as high voltage wires.

An ideal surface for IR measurements is a black body or radiator with an emissivity of 1.0. Emissivity is the ratio of the energy radiated by an object at a certain temperature to that emitted by a perfect radiator at the same temperature.

The shinier or more polished the surface, the less accurate the measurements. For example, the emissivity of most organic material and rough or painted surfaces is in the 0.95 region and hence, suitable for IR measurements.

On the other hand, surfaces of highly polished or shiny material, such as mirrors or aluminum, may not be appropriate for this application without using some form of filtration. This is due to other factors, namely, reflectivity and transmissivity. The former is a measure of an object's ability to reflect infrared energy while the latter is its ability to transmit it. Another important and practical concern is the field of view. Infrared meters measure the average temperature of all objects in their field of view. To obtain an accurate result, it is important that the object completely fills the instrument's field of view and there are no obstacles between the meter and the object. The distance-to-target ratio, or the optic coefficient, is therefore an important consideration.

Reference Temperatures

In 1990, NIST established 17 fixed points of the International Temperature Scale (ITS-90) related to reproducible physical phenomena in nature. The ITS-90 Fixed Points are shown in the chart below:

Equilibrium state	K	°C
Vapor pressure point of helium	3 to 5	-270.15 to -268.19
Triple point of hydrogen	13.8033*	-259.346*
Boiling point of hydrogen at a pressure of 33.330.6 Pa	17.042*	-256.108*
Boiling point of equilibrium hydrogen	20.28*	-252.87*
Triple point of neon	27.102	-246.048
Triple point of oxygen	54.361	-218.789
Triple point of argon	83.8058	-189.3442
Triple point of mercury	234.3156	-38.8344
Triple point of water	273.16	0.01
Triple point of gallium	302.9146	29.7646
Melting point of indium	429.7485	156.5985
Melting point of tin	505.078	231.928
Melting point of zinc	692.677	419.527
Melting point of aluminum	933.473	660.323
Melting point of silver	1234.93	961.78
Melting point of gold	1337.33	1064.18
Melting point of copper	1357.77	1084.62

* Given for e-H2 , which is hydrogen at the equilibrium concentration of the ort and para molecular forms.