Guidelines for Temperature Measurement

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Temperature can be measured with a wide variety of sensors. There are six basic types of sensors most commonly used today, so it is important to understand how each device can dramatically effect the outcome of the temperature reading.

Historically, HPC has found temperature testing can be inaccurate when using popular infrared thermometers (IRT's) due to the inability of the commonly available units to compensate for emissivity. For this reason, the emphasis of this engineering bulletin will be on using infrared thermometers to measure the temperature of components and materials.

Types of Measuring Devices

Changes-of-State temperature sensors offer a variety of measurement methods. These devices are available in decals and labels, pellets, crayon, lacquers, and liquid crystal displays. These devices are designed to allow the materials to melt or change colors once a predetermined temperature is achieved. Although a convenient way to verify that a piece of equipment or component has not exceeded a certain temperature, these types of devices do not give accurate temperature readings and in most cases are not reusable.

Bimetallic Devices work on the difference in expansion between different metals as they are heated. Strips of two alloys are bonded together and the "bending" of the strip as the alloys expand at different rates is measured mechanically by a gauge.

Fluid Expansion Devices are offered in a variety of styles. Most common, is the typical mercury and liquid-filled types. Also available today are gas filled styles. An advantage of these devices is they do not require electricity to operate. A disadvantage is they do not generate data that can be recorded or transmitted via telemetry or wires.

Resistive Temperature Devices, also known as RTD's, utilize resistance changes that occur in various materials as the temperature changes to provide measurements. There are two key types: metallic devices, which are commonly referred to as RTD's and Thermistors. Thermistors are based on resistance changes in a ceramic semiconductor. With an RTD, resistance increases linearly as the temperature increases. With Thermistors, resistance decreases non-linearly as the temperature increases.

Thermocouples are the most commonly used devices for temperature measurement. They consist of two wires made of two different alloys that are joined by twisting, silver soldering or crimping at one end. Increases in temperature induce change in the electromotive force (emf) between the ends. The thermocouple responds to increases in emf.

Infrared Sensors are non-contacting devices used to measure thermal radiation (electromagnetic energy). IR thermometers are a way to quickly and conveniently measure the surface temperature of various objects. Because you do not have to physically touch the surface of an object, they provide a safe method of measuring hot, hazardous, and hard-to-reach surfaces. IR thermometers provide readings in just seconds, whereas contact devices can take up to several minutes to stabilize with an accurate reading.

Infrared thermometers work by sensing the infrared energy emitted by all objects over absolute zero (0° Kelvin [-460° F or -273° C]). Infrared energy is focused through a lens onto a detector, which converts the energy to an electrical signal that is displayed in units of Fahrenheit or Celsius. The wavelength scope of the instrument determines the range of temperature it will accurately measure.

However, many times infrared temperatures are misinterpreted because different materials and surface finishes radiate at different levels of energy. This is known as emmisivity. Emissivity is measured in a decimal number or percentage ranging from 0.00 to 1.00, or 0% to 100%. Emissivity is the ratio of thermal radiation being emitted by a gray body, to that of a blackbody, at the same temperature.

Using IR Sensors to Measure Temperature

Over the years HPC Engineering has helped explain the proper usage of IR sensors to many customers. Understandably, many individuals who are utilizing IR thermometers do not understand emissivity, or how to adjust (compensate) for it when measuring various materials. Furthermore, many entry-level IR thermometers do not provide the ability to adjust for emissivity, which can lead to inaccurate readings.

All objects emit, reflect, and transmit electromagnetic energy (heat). IR thermometers sense all three kinds, but only emitted energy is used to measure the temperature of an object. Therefore the sensor must be adjusted to "see" only the emitted energy. Emissivity tables must be used as guidelines to adjust the IR sensors before accurate readings can occur.

It has been HPC's experience that temperature readings can be inaccurate by as much as 50%, or more, when adjustments are not made for emissivity. For example, when a shiny material (such as HPC's H01 and H05 polished finishes) are measured using an IR thermometer set at 0.95 emissivity value (such as non-adjustable IRT's), readings will be as much as 50% cooler than the actual temperature of the component.

There are several ways to "force" the emissivity to a known level when the value is not known, a table is not available, the material is not listed on the table, the object is shiny, or the user has a non-adjustable IR thermometer.

First, on low temperature components the area to be measured can be covered with masking tape and readings taken from the tape.

Second, for higher temperature applications, matte black high temperature paint can be used over the area to be measured (to remove the reflectivity of a shiny surface). Both masking tape and matte black paint have an emissivity value of approximately 0.95 (or 95%).

Third, if a contact thermometer is available, use it to determine the component temperature, and then while aiming the IR thermometer at a point near it, adjust the emissivity of the IR thermometer up or down until the temperature readings coincide between the thermometers. This can be used as a basis for future readings on the same material, with the same surface finish.

Since sensor input can consist of energy that is reflected from neighboring components, it is important to shield the area being measured to prevent the IR thermometer from "seeing" this energy as well as the energy being emitted from the component being measured.

Emmisivity can become very confusing in regards to infrared thermometers because:

1. IR sensors are inherently colorblind.
2. if the target is visually reflective (as is HPC H01 and H05 polished aluminum finishes), you will be measuring not only the emitted radiation but the reflected radiation from surrounding heat sources as well. This will yield temperature readings that will be higher than the actual temperature of the object being measured.
3. much of the time, applications do not require absolute temperature measurability, but rather require deltas between two measured components. The key is to produce repeatable and drift free operations.

To optimize surface temperature measurement accuracy there are several important factors that must be taken into account: emissivity, distance-to-spot ratio, and the field-of-view.

1. Determine the object's emissivity for the spectral range of the instrument to be used for the measurement.
2. Avoid reflections by shielding the target object from surrounding high temperature sources.
3. Use an IR thermometer appropriate for the temperature range being measured.
4. Hold the IR thermometer perpendicular to the surface being measured whenever emissivity is less than 0.9. In all cases, do not exceed angles of more than 30° from the incidence angle.
5. Make sure the target size is larger than the spot size of the IR thermometer. The smaller the target the closer the IR thermometer must be to it to prevent "spread" of the spot area and sensing of components behind the target. For instance, if the IR thermometer has a spot-to-distance ratio of 8:1, than the measured area will be 1/8 of the distance, or 1.5" diameter at a distance of 12" from the target. Check with your instrument's manufacturer for specifications on the spot-to-distance ratio for your model.
6. Be aware of environmental conditions such as dust, smoke, steam, etc. These can obstruct the IR thermometer's optics and produce inaccurate readings.
7. Do not measure through glass since it has very distinctive reflective and transmission properties that will provide inaccurate readings.
8. If the thermometer is exposed to abrupt ambient temperature changes of more than 20° F, allow at least 20 minutes for the thermometer to adjust to the new ambient temperature before use.

Emissivity values of common materials

Material	Temperature °F (°C)	Emissivity
HPC H05	206 (96.7)	0.16
HPC H05	460 (238)	0.21
Cold Rolled Steel	200 (93)	0.75 - 0.85
301 Stainless (polished)	450 (232)	0.57
316 Stainless (polished)	450 (232)	0.57
321 Stainless (polished)	200 - 800 (93 - 427)	0.27 - 0.32
Lacquer - Black	200 (93)	0.96