White paper

ABB temperature measurement
Radiation thermometry

Process temperature measurement practice--non-contacting

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Non-contacting temperature measurement techniques for the processing industries complement thermocouple and RTD sensors. Innovations in infrared technology are reducing their cost and size while increasing reliability.

Non-contacting temperature measurements offer several advantages:

- Fast, permitting more consecutive measurements in a given time interval, such as for temperature distribution measurements.
- Measurements on moving objects (conveyer processes, rolling mills, etc.).
- Measurements in dangerous or inaccessible locations (objects at high voltage, long distance measurements).
- High measuring temperatures up to 3000 °C (5432 °F). In such applications, contacting thermometers have a limited life span.
- No interaction with the measured object measurement (suitable for poor heat conductors such as plastics and wood.)
- No mechanical influences on the measured surface (painted surfaces, foams, elastomers.)
- No contamination of the measured object (hygienic applications).

On the other hand, certain considerations must be taken when using non-contacting thermometers.

- The object must by optically visible. Large amounts of dust or smoke affect the measurement as well as solid obstructions. Measurements cannot be made within closed metal reaction vessels.
- The optics in the measuring head must be protected from dust and condensing liquids.
- Only surface temperature measurements can be made.
- Different material surfaces have different radiation properties.

Operation

As a result of internal molecular movements, every object with a temperature above absolute zero emits thermal radiation. The intensity the molecular movements depends on the temperature of the object. Since the molecular movements simultaneously produce charge motions, the object emits an electromagnetic radiation of photons.

A radiation thermometer is comparable to the human eye. The lens of the eye is the optic through which the radiation from the object reaches the light sensitive layer, the retina. At the retina the signal is converted and conducted to the brain. In an infrared thermometer, the lens directs the thermal radiation from the object through a lens and selective IR filters to a sensitive detector and electronics, which converts it to a useful electrical voltage for monitoring or control.

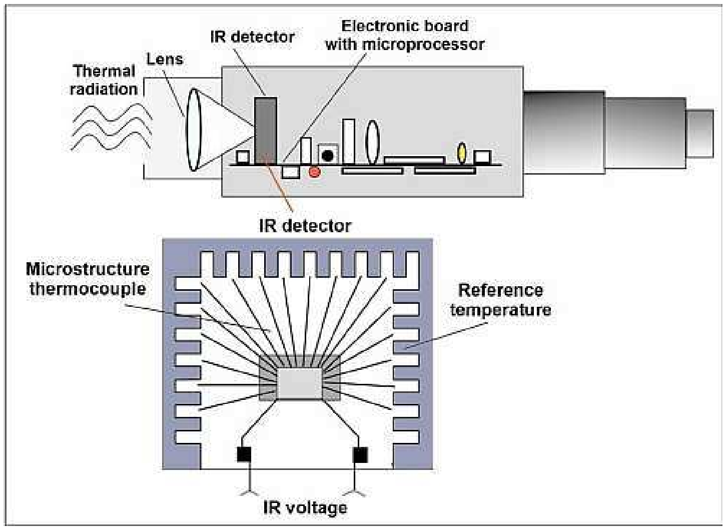

Figure 1. The radiation path flows through collecting optics, lenses and/or fiber optics, spectral filtering, detector , and electronics.

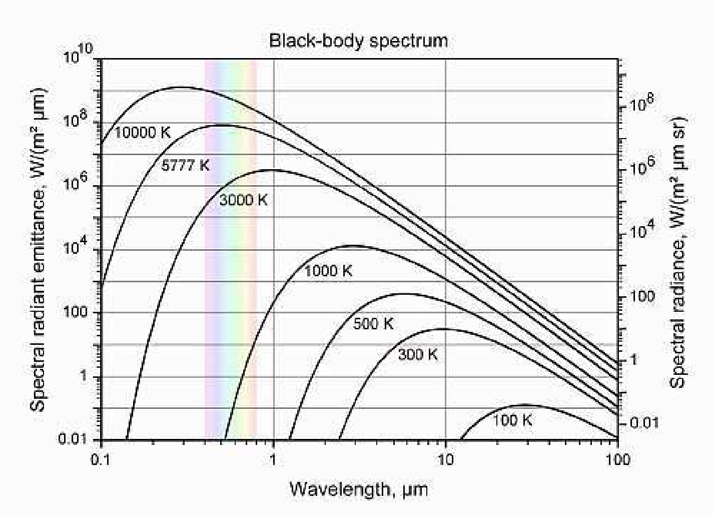

Figure 2. Spectral radiance as a function of infrared wavelength and temperature.

Figure 2 shows typical spectral radiance (emitted power received by an optical system) curves for a ideal blackbody at various temperatures. Obviously, very hot bodies not only emit radiation in the infrared range (greater than 0.7µm), but also emit in a portion of the spectrum that lies in the visible spectrum (0.39 to 0.70µm). This is why we can see very hot objects as red hot to white hot. Experienced steel workers can estimate the temperature of hot metal by its color with relatively good accuracy.

The graph also makes two other points. The maximum radiated power shifts to shorter wavelengths as the temperature of the object increases. And the curves for a body at various temperatures do not cross.

The information in these radiation curves form the basis of making temperature measurements of an object without touching it. The portion of the infrared range used in such non-contacting temperature measurement systems is from 0.70 to 14µm wavelengths.

All bodies emit infrared radiation, which is only visible to human eyes at very high temperatures (glowing iron). The goal in designing an infrared thermometer is to capture as much of the emitted energy as possible (the area under the curve). At higher temperatures instruments look at a narrow wavelength range. At lower temperatures they look at larger spectrum of wavelengths, such as from 7 to 14µm. Different wavelenghts also become useful in measuring temperatures of certain materials, such as glass, metals, and plastic foils.

Emissivity factors

As noted earlier, Figure 2 shows curves for ideal blackbody radiation. Blackbody radiators absorb or emit 100% of the radiation that corresponds to their temperature. Many objects emit less radiation at the same temperature. The relationship of the real radiation value to blackbody radiation is known as the emissivity e. Emissivity has a maximum value of 1 for an ideal blackbody. Objects with emissivity values less than 1 are called graybody radiators. Objects whose emissivity value also depends on the temperature and wavelength are called non-graybody radiators.

When evaluating emissivities, the Law of Conservation of Energy applies. An infrared radiation sensor will see the total infrared radiation from an object, including reflected energy and transmitted energy. Visibly transparent objects such as glass are opaque to certain infrared wavelengths. Many solid objects do not transmit radiation in the infrared range, leaving emitted and reflected energy. Ideal blackbody radiators exhibit no transmission or reflection: the case where e = 1.

Many non-metallic bodies such as wood, plastic, rubber, organic materials, stone, or concrete surfaces reflect minimally and so have high emissivity values between 0.8 and 0.95. Metals, on the other hand, especially those with polished and shiny surfaces, have emissivity values of about 0.1. Radiation thermometers must have the ability to select an emissivity factor to match the surface measured. Many control applications require repeatability and drift-free operation rather than precise temperature measurement.

Ratio radiation thermometry involves measuring the temperature of an object at two different infrared wave

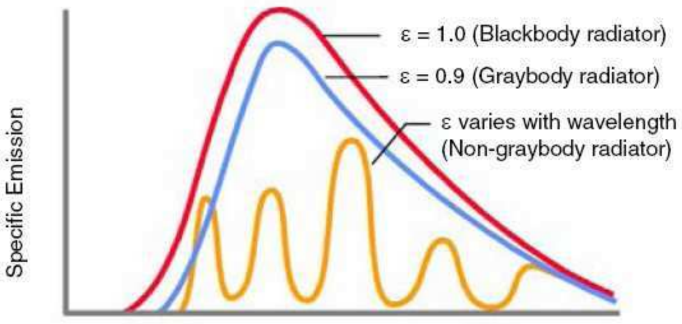

Figure 3. Emissivity values of materials must be evaluated for measurements with radiation thermometers.

lengths. Assuming the emissivity value is the same for both wavelengths, a simple calculation can cancel out emissivity and provide the correct temperature. Ratio instruments can also provide correct temperatures when their field of view is partially obstructed by relatively cold materials such as dust, screens, and translucent windows.

Determining emissivity values

Emissivity values for a measured object depend on the material, surface conditions, and state (solid, liquid, or gas). Emissivity values have been determined and tabulated for common materials. Tables of emissivity values also help in selecting the correct measuring instrument by noting the appropriate wavelength ranges.
But these tabulated values, especially for metals, should only serve as a starting point because surface conditions can affect the emissivity value more than the material itself.

Several methods have been developed for determining the emissivity value for any special material and surface. Often a radiation thermometer (pyrometer) with the capability of setting different emissivity values plays a role. Below is a sampling of these alternative methods.

1. Heat a sample of the material to a known temperature measured with an accurate contacting thermometer. Then measure the temperature of the sample with an radiation thermometer. Set the emissivity to a value corresponding to the temperature measured by the contacting thermometer. This emissivity value can then serve for all subsequent measurements of objects made from the same material.

2. For relatively low temperatures (up to 260 °C [500 °F]) attach special plastic labels with an adhesive backing and with a known emissivity value such as 0.95 to the object to be measured. Measure the temperature of the label with the radiation thermometer. Then measure the surface of the object without the label and change the thermometer's emissivity value until it indicates the correct temperature. The emissivity value can serve for all subsequent temperature measurements of objects made from the same material.

3. Make a blackbody radiator from of the material to be measured. Drill a hole into the object whose depth is at least five times its diameter. This diameter must correspond to the diameter of the target area of the radiation thermometer. If the emissivity value of the hole's inside walls is greater than 0.5, then the emissivity value of the cavity radiator is about 1. So the temperature measured in the hole is the correct temperature for the measured object. If the radiation thermometer is then pointed at the object's surface, the emissivity value can be changed until the temperature indication agrees with that measured in the cavity.

4. Sometimes the measured object can be coated with a matte black color having an emissivity value of about 0.95. Use the temperature of this blackbody radiator for adjusting the emissivity value for measurements made on the uncoated object.

Metals--The emissivity value of metals depends on the wavelength and the temperature. Since metals often reflect, they tend to have lower emissivity values. These lower values could result in variable and unreliable measurements. In such applications, select an instrument which measures the infrared radiation at a specific wavelength and temperature range at which the metal has the highest emissivity. For many metals the measurement error increases with the wavelength, so use the shortest possible wavelength for the measurement.

The optimal wavelengths for measuring high temperatures of metals is between about 0.8 to 1.0µm at the limit of the visible range. Wavelengths of 1.6, 2.2 and 3.9 µm may also be appropriate.

Plastics--Many plastics are by nature clear and transparent to human eyes, as well as to infrared radiation. The transmission ranges for plastic foils varies with the wavelength and is proportional to their thickness. The transmission is higher in thin materials than in thicker materials. For optimal temperature measurements of such foils, select a wavelength at which the transmission value is near zero. Certain plastics (polyethylene, polypropylene, nylon and polystyrene) are opaque at 3.43 µm, others (polyester, polyurethane, PTFE, FEP and polyamide) at 7.9µm. For thicker (> 0.4 mm [0.016“]) or heavily pigmented foils, wavelengths between 8 and 14µm will work.

If uncertainty still exists, submit a sample of the plastic to the manufacturer of the radiation thermometer to determine the optimal spectral bandwidth. The reflection value for practically all plastics is between 5% and 10% (e = 0.9...0.95).

Glass--When an radiation thermometer measures the temperature of glass, both reflection and transmission are considered. By a careful selection of the wavelengths you can measure both the surface and internal temperatures within the glass. For temperature measurements below the surface, use a sensor with wavelengths 1.0, 2.2 or 3.9µm. For surface temperature measurements a sensor with a wavelength of 5µm works. For temperatures below 500 °F use wavelengths of 8 to 14µm with the emissivity set to 0.85.

Taking measurements

Normally, air fills the measuring path between the detector and measured object. The air's transmission characteristics must be considered for reliable measurements. Components such as water vapor or carbon dioxide absorb infrared radiation of certain wavelengths, resulting in transmission losses. In some cases these losses will indicate a lower temperature than actual.

Fortunately, certain ”windows“ in the infrared spectrum do not contain these absorption wavelengths. Typical measuring windows in which infrared radiation passes essentially unimpeded are 1.1 to 1.7µm, 2 to 2.5µm, 3 to 5µm and 8 to 14µm. For this reason, commercially available radiation thermometers operate within these wavelengths when evaluating the signals.

Additional effects such as dust, smoke, and suspended matter could contaminate the optics and lead to incorrect measurements. Some thermometers accommodate connection to compressed air to keep prevent particles and condensation from adhering to the optics. Ratio pyrometers may be used if large quantities of dust or smoke are present that affect the measurement. Special compensation techniques may be necessary to correct for high temperature thermal radiation sources in the vicinity of the measured object. In addition, the radiation sensor may have to be air- or water-cooled if installed an area of high ambient temperatures.

Thermal target diameter

The optic system of an radiation thermometer views the infrared radiation energy emitted by a specific circular target area and focuses it on the detector. The target area must completely fill the sensor's detector. If the object being measured is smaller than the measuring spot, temperature rises are displayed as an average value of the hot object area and the ambient cold area. So sudden dangerous increases in the object's temperature may be missed because of measurement error.

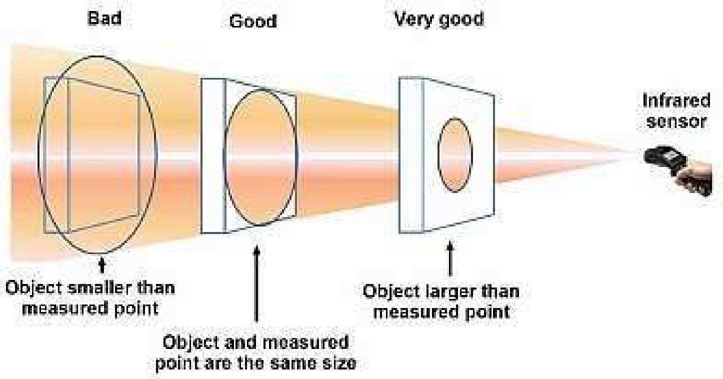

Figure 4. The measurement's target spot must be the same size or smaller than the object for accurate temperature measurements.

Optical resolution is the ratio of the distance between the instrument and the measured object to the measured target diameter. The larger this value the better the instrument and the smaller the measured object can be for a specific distance. The optics consists of a mirror or more commonly a lens.

New principles of measurement and sighting techniques provide improvements and more precision for radiation thermometers. Multiple laser arrangements within the sensor now offer the ability to mark spot sizes. These new laser crosshair techniques help to determine the real spot size within the object field regardless of distance. With the help of this technology the precise dimensions of a measuring spot can be observed, improving the practical use of radiation thermometers.

In simpler, more cost-effective radiation thermometers, a single-point laser indicates the center of the spot with parallax for distance. With this technique the user, knowing the measuring distance, estimates the spot size with the help of a diagram. Protection glass and window materials

For measurements in closed reaction vessels, furnaces, or vacuum chambers, measurements are usually taken through an appropriate measuring window. When selecting a window material make certain that the transmission value of the window is compatible with the spectral sensitivity of the sensor. For higher temperatures, quartz glass tends to be the material of choice. At temperatures in the 8 to 14µm band, the use of special infrared transparent materials such as germanium, amtir glass or zinc selenite will be necessary.

In addition to the spectral sensitivity, other parameters may be considerations when selecting the window material. These include the window diameter, temperature requirements, maximum pressure differential across window, ambient conditions, and the ability to clean both sides. Of course the window must be sufficiently transparent visually to accurately aim the instrument at the measured object.

In summary, all bodies emit infrared radiation, which is only visible to human eyes above 600 °C (1112 °F) (e. g. glowing iron). The wavelength range extends from 0.7 ?m to 1000 ?m. Blackbody radiators absorb or emit 100 % of the radiation that corresponds to their temperature. The radiation of all other bodies are expressed as ratios to the blackbody. This ratio is called the emissivity value.

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