Measuring Temperature by Indirect Means

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Noncontacting infrared thermometers can be used in many applications that are too harsh or impractical for thermocouples and resistance temperature detectors. Understand their principles of operation and their advantages and limitations to select and use these instruments effectively.

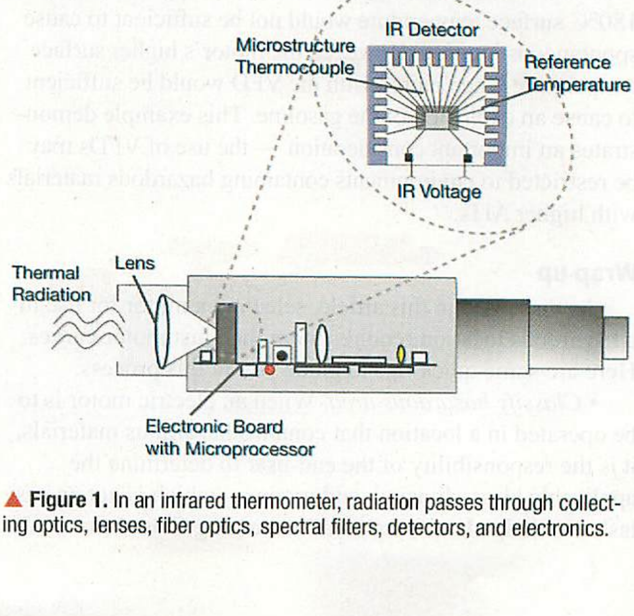
Noncontacting infrared (IR) temperature-measurement techniques are a valuable complement to thermocouples (TCs) and resistance temperature detectors (RTDs), the most common direct-contact temperature sensors used in the chemical process industries and the subject of a previous *CEP* article (Sept. 2011, pp. 26–30).

The use of noncontacting methods offers several advantages over contacting techniques. The measurements are fast, so more measurements can be made in a given time interval, allowing temperature distributions to be compiled more easily. Measurements can be made on moving objects (*e.g.*, conveyors and rolling mills) and in dangerous or inaccessible locations (*e.g.*, objects at high voltage). Temperatures as high as 3,000°C (5,430°F) can be routinely measured without damage to the sensor, whereas direct-contact thermometers have a limited life span at such high temperatures. Because no interaction with the object being measured is necessary, noncontact techniques are suitable for monitoring poor heat conductors, such as plastics and wood. And, noncontact techniques do not mechanically influence or alter the object's surface (which is important when dealing with painted surfaces, foams, or elastomers) or contaminate the object (allowing their use in hygienic applications).

Noncontact thermometers also have limitations, and certain factors must be taken into consideration when using them. The object of interest must be optically visible, with a clear line of sight between it and the detector. Large amounts of dust, smoke, mist, etc., will interfere with the measurement, so the optics in the measuring head must be protected from dust and condensation. Temperatures cannot be measured within closed metal reaction vessels — only surface temperature measurements can be made. In addition, all material surfaces have unique radiation properties that affect the accuracy of the measurement.

Principle of operation

Temperature is a measure of the average kinetic energy of the random movements of molecules within an object — the more intense the molecular movement, the higher



▲ **Figure 1.** In an infrared thermometer, radiation passes through collecting optics, lenses, fiber optics, spectral filters, detectors, and electronics.

the temperature. Since measuring the molecular movement is impractical, other methods have been developed to determine the temperature of an object. Noncontacting methods, for instance, measure thermal radiation, which is emitted by all objects that have a temperature above absolute zero.

The only commercially available noncontacting measurement technique is the infrared thermometer, which measures the radiation emitted in the infrared range. This type of thermometer functions like a human eye. In the eye, visible radiation emitted by an object passes through the eye's lens to the light-sensitive layer — the retina. The retina converts the incoming light to an electrical signal, which is then transmitted to the brain. In an infrared thermometer (Figure 1), the thermal radiation emitted by the object passes through a lens and selective IR filters to a detector and electronics, which convert it to a useful electrical voltage.

The electrical voltage, which corresponds to the amount of IR radiation emitted by the object, is one part of the temperature measurement. The other piece of information needed is the emissivity of the object of interest.

Emissivity

Emissivity is the ratio of radiation emitted by a particular object to that emitted by a blackbody at the same temperature. A blackbody is a perfect emitter of radiation; it absorbs and emits 100% of the radiation correspond-

An object's emissivity depends on the material, the condition of its surface, and whether it is a solid, liquid, or gas.

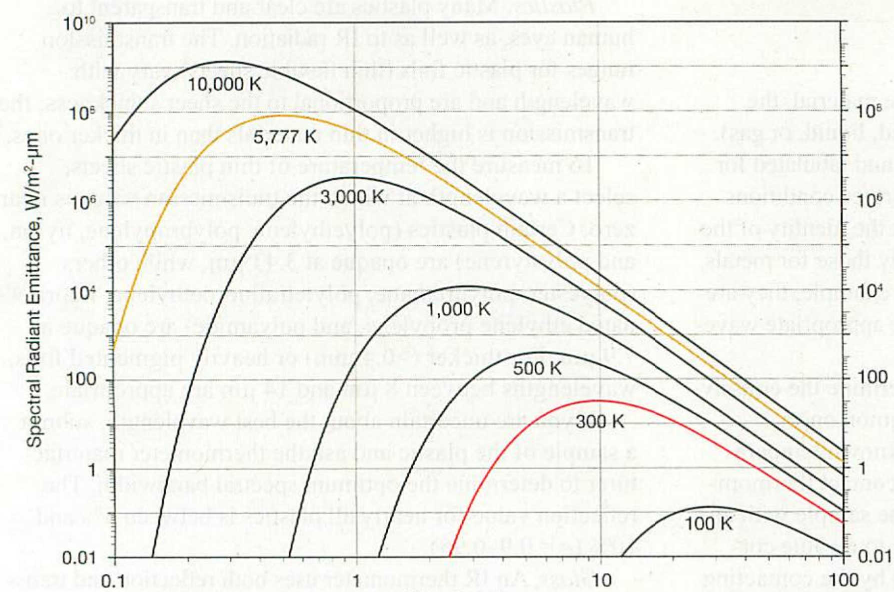
ing to its temperature (*i.e.*, it exhibits no transmission or reflection). Thus, the emissivity (*e*) of a blackbody is one, while that of real objects is less than one. Objects with constant emissivity (less than one) are called graybody radiators; those with an emissivity (less than one) that varies depending on the temperature and wavelength are called non-graybody radiators.

Visibly transparent objects, such as glass, are opaque to certain IR wavelengths, and many solid objects do not transmit radiation in the IR range. Many nonmetallic objects, such as wood, plastic, rubber, organic materials, stone, and concrete, are minimally reflective and have high emissivities (0.8–0.95). Metals, especially those with polished and shiny surfaces, have emissivities of about 0.1.

Figure 2 depicts typical spectral radiance (*i.e.*, emitted power received by an optical system) curves for an ideal blackbody at various temperatures. Very hot blackbodies emit radiation not only in the infrared range (wavelengths >0.7 μm), but also in a portion of the visible spectrum (0.39–0.70 μm), which is why very hot objects appear red or white (depending on the temperature). Experienced steel workers can estimate the temperature of hot metal by its color with relatively good accuracy.

These radiation curves serve as the basis for noncontact temperature measurement. The portion of the infrared range used in such noncontacting systems is 0.70–14 μm. An infrared sensor detects the total infrared radiation coming from an object, including reflected energy and transmitted energy.

Infrared thermometers must be able to compensate for the emissivity of the surface whose temperature is being measured. Ratio infrared thermometry involves measuring the temperature of an object at two different IR wavelengths. Assuming the object is a graybody and its emissivity is the same at both wavelengths, a simple calculation can cancel out emissivity and provide the correct temperature.



▲ **Figure 2.** Spectral radiance (the emitted electromagnetic power at a particular frequency) of a blackbody is a function of infrared wavelength and temperature. As shown in this graph, the maximum radiated power shifts to shorter wavelengths as the temperature of the object increases, and the curves for a blackbody at various temperatures do not cross.

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Accounting for Atmospheric Effects

The accuracy of the temperature measurement can be affected by contaminants (*i.e.*, anything that absorbs IR radiation) in the atmosphere surrounding the object of interest.

Air. Normally, air fills the path between the detector and the object of interest. Thus, the air's transmission characteristics must be considered to obtain reliable measurements. Components of air such as water vapor and carbon dioxide absorb IR radiation at certain wavelengths, causing transmission losses. In some cases, these losses result in an indicated temperature that is lower than the actual temperature.

Certain regions of the infrared spectrum do not correspond with these absorption wavelengths. In general, infrared radiation passes through air essentially unimpeded at wavelengths of 1.1–1.7 μm, 2–2.5 μm, 3–5 μm, and 8–14 μm. Commercially available IR thermometers operate within these wavelengths.

Other interferences. Additional effects, such as dust, smoke, and suspended matter, could contaminate the instrument's optics and cause incorrect measurements. Some thermometers accommodate for this with connections to compressed air to prevent particles and condensation from adhering to the optics. Ratio pyrometers may be used if large quantities of dust or smoke are present. Compensation techniques may be necessary to correct for nearby high-temperature thermal radiation sources. In addition, the infrared sensor may have to be air- or water-cooled if it is installed in an area of high ambient temperatures.

Determine emissivity

An object's emissivity depends on the material, the condition of its surface, and its state (solid, liquid, or gas). Emissivity values have been determined and tabulated for common materials. However, because surface conditions can affect the emissivity value more than the identity of the material itself, tabulated values, especially those for metals, should serve only as a starting point. For example, they are useful in selecting an instrument with the appropriate wavelength range.

Several methods are available to determine the emissivity of any material. Here are several common ones:

• Heat a sample of the material to a known temperature, as measured by an accurate direct-contact thermometer. Then measure the temperature of the sample with an infrared thermometer. Set the emissivity to a value corresponding to the temperature measured by the contacting thermometer. This emissivity value can then be used for subsequent temperature measurements made on objects of the same material.

• For relatively low temperatures, up to 260°C (500°F), attach a plastic label with an adhesive backing and a known emissivity ($e = 0.95$ is common) to the object. Measure the temperature of the label with an IR thermometer. Then measure the temperature of the surface of the object without the label, and adjust the thermometer's emissivity value until it indicates the correct temperature. This emissivity value can then be used for subsequent temperature measurements of objects made from the same material.

• Paint the surface of the object of interest with a matte black coating having an emissivity of about 0.95. Use the temperature of this blackbody radiator to adjust the emissivity value for measurements taken of the uncoated object. Once the emissivity is known, it can be used for uncoated samples of the same material.

Choose the right wavelength

Metals. The emissivity of a metal depends on the wavelength and temperature. Since metals are often reflective, they tend to have lower emissivities. These lower values could lead to variable and unreliable measurements.

For applications involving metals, select an instrument that measures the IR radiation at the specific wavelength and temperature range at which the metal has the highest emissivity. For many metals, measurement error increases with wavelength, so use the shortest possible wavelength for the measurement. The optimum wavelengths for measuring high temperatures are between about 0.8 μm and 1.0 μm — at the limit of the visible range. Wavelengths of 1.6 μm, 2.2 μm and 3.9 μm may also be appropriate.

Plastics. Many plastics are clear and transparent to human eyes, as well as to IR radiation. The transmission ranges for plastic foils (thin flexible sheets) vary with wavelength and are proportional to the sheet's thickness; the transmission is higher in thin materials than in thicker ones.

To measure the temperature of thin plastic sheets, select a wavelength at which the transmission value is near zero. Certain plastics (polyethylene, polypropylene, nylon, and polystyrene) are opaque at 3.43 μm, while others (polyester, polyurethane, polytetrafluoroethylene, fluorinated ethylene propylene, and polyamide) are opaque at 7.9 μm. For thicker (>0.4 mm) or heavily pigmented foils, wavelengths between 8 μm and 14 μm are appropriate.

If you are uncertain about the best wavelength, submit a sample of the plastic and ask the thermometer manufacturer to determine the optimum spectral bandwidth. The reflection value for nearly all plastics is between 5% and 10% ($e = 0.9$–0.95).

Glass. An IR thermometer uses both reflection and transmission to measure the temperature of glass. A thermometer designed to operate at the right wavelengths can measure both the surface temperature and the internal temperature within the glass.

For temperature measurements below the surface, use

IR measurement is useful where contact methods are impractical or where a quick and comparative measurement will be sufficient.

a sensor with a wavelength of 1.0 μm, 2.2 μm, or 3.9 μm; for surface temperature measurements, a sensor with a wavelength of 5 μm works well. For temperatures below 500°F, use wavelengths of 8 μm to 14 μm with the emissivity set to 0.85.

Thermal target diameter

The optic system of an IR thermometer, which consists of a mirror or, more commonly, a lens, views the IR energy emitted by a specific circular target area and focuses it on the detector (Figure 3). The target area must completely fill the sensor's detector. If the object being measured is smaller than the detector's measuring spot, the temperature displayed will be an average of the hot object's temperature and that of the surrounding (and colder) area. Sudden increases in the object's temperature may be missed because of such measurement error.

Optical resolution is the distance from the instrument to the object divided by the diameter of the target spot being measured. The larger this ratio is, the smaller the object that can be measured at a specific distance.

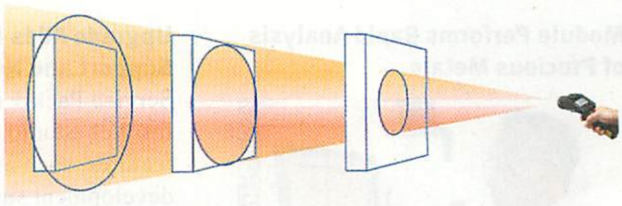
New principles of measurement and sighting techniques provide improved precision for IR thermometers. Multiple-laser arrangements within the sensor offer the ability to mark spot sizes and determine the precise dimensions of the target.

In simpler, lower cost IR thermometers, a single-point laser indicates the center of the spot. The user, knowing the distance, estimates the spot size with the help of a diagram.

Protection glass and window materials

When measuring temperatures inside closed reaction vessels, furnaces, or vacuum chambers, readings are usually taken through an appropriate window (or sight glass). To select a window material, make certain that the transmission value of the window is compatible with the spectral sensitivity of the sensor. For high temperatures, quartz glass tends to be the material of choice, while at lower temperatures and wavelengths in the 8–14-μm band, IR-transparent materials, such as germanium, amtir glass, or zinc selenite, are necessary.

Other factors to consider when selecting the window material include the window diameter, temperature requirements, maximum pressure differential across the window, ambient conditions, and the ability to clean both sides of the glass. And, of course, the window must be visually transparent enough to allow the user to accurately aim the instrument at the object of interest.



▲ **Figure 3.** An infrared sensor collects IR energy from a circular target spot and focuses it on the detector. To obtain accurate temperature readings, the object being measured must be the same size as or larger than the instrument's target spot of measurement.

Closing thoughts

Infrared temperature measurement has several inherent complexities that can lead to significant error in measurement. Where possible, a contact method of temperature measurement is preferable, especially where accuracy of the measured temperature is required. IR measurement has its place where contact methods are impractical or where a quick and comparative measurement will be sufficient.

One classic application for a portable IR thermometer is to find "hot spots" on a pipeline, which may be indicative of a blockage or restriction. In this application, absolute accuracy is not needed, only the ability to identify differences in temperature.

Where accuracy of the temperature measurement is required and a contact method is impractical, IR may be the only solution. In these cases, care needs to be taken in setting up this measurement. CEP

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