

LASER PYROMETRY OFFERS PRACTICAL TEMPERATURE MEASUREMENT

The physics of measuring temperature pyrometrically can be problematic if the emissivity of a body is not known. Pulsed laser pyrometers help solve this problem.

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Every object radiates thermal energy at temperatures above absolute zero. Measuring an object's temperature using an optical pyrometer is based on the principle that an object's thermal radiation is a function of its temperature. Measuring that thermal radiation sounds like a very straightforward engineering problem, but the real world is more complicated.

Spectral Emissivity

For any particular temperature and wavelength, the energy radiated by a surface is related to the spectral emissivity of the object. Emissivity is the measure

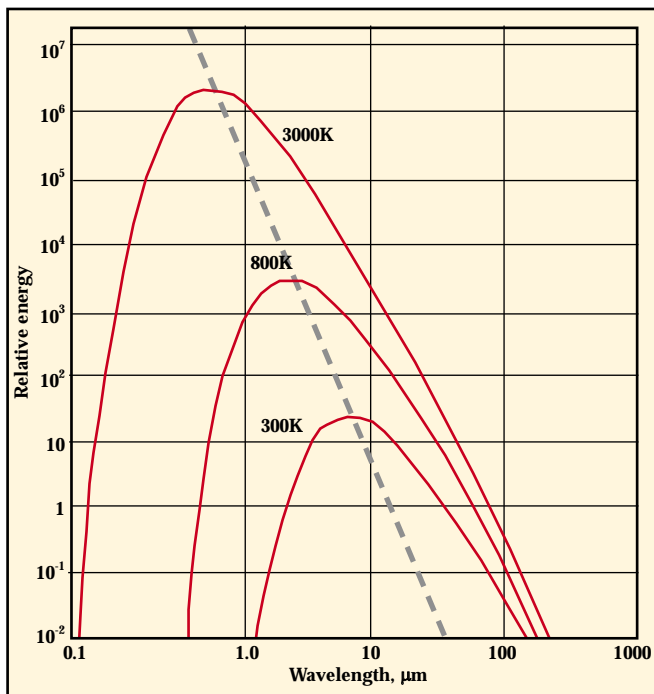
of a surface's ability to disperse heat by radiating thermal energy. Different substances have different emissivities, whose value is expressed as a number from 0 to 1.0. This value expresses the ratio of the energy radiated by object's surface to the energy radiated by a perfect black body at the same temperature. The higher the value, the better the surface is at emitting energy.

In physics, a black body is a substance that absorbs all electromagnetic radiation falling upon it. As it is a perfect absorber it is given an emissivity of 1.0. The laws of thermodynamics, developed by Max Planck and others, specify that it must also be a perfect emitter of radiation, and the energy distribution as a function of wavelength is dependent on the absolute temperature.

In practice, the amount of thermal energy a given object emits is directly related to its temperature, wavelength, wavelength band, and other factors such as surface quality, transparency, reflectivity, absorptivity, angle of observation, etc. These factors need to be considered in the design and use of optical pyrometers.

Pyrometer Design

Since a pyrometer is not an absolute instrument, it is necessary to calibrate it against a blackbody to convert the elec-



Planck's Law: Radiation intensity as a function of wavelength and temperature.

tromagnetic radiance received by the pyrometer to its corresponding temperature. If a pyrometer is used to measure the temperature of an object of unknown emissivity, the reading will not be valid because the object will emit electromagnetic energy proportional to its emitting ability, and temperature shown by the pyrometer will be lower than the actual temperature.

Thus, to accurately deduce the temperature of a given surface from the radiation it is receiving, an operator has to know the emissivity of the material being measured. Usually an emissivity control on the pyrometer allows this value to be set on the instrument being used.

Unfortunately, the main difficulty in the practical use of infrared (IR) thermometry is the necessity of measuring the temperature of objects of unknown emissivity. The lives of scientists, engineers, and technicians who must make precise measurements of temperatures in industrial processes or scientific inquiries would be much simpler if every substance, regardless of its composition, surface texture, or geometry, would emit the thermal radiation at given temperature independent from wavelength. It would also make life a lot simpler for the designer of radiation pyrometers.

Total and Spectral Emissivity

There are many publications that list emissivity values for various materials. It would be relatively simple if these emissivity figures could simply be used as published. However, sometimes this published data lists both total emissivity and spectral emissivity and it is important to pick the correct number.

Most metals with a clean surface or with a thin oxide layer have emissivity that varies with wavelength. Consequently, using the total emissivity value will cause a significant error in the temperature indicated by the pyrometer (if the wavelength band is not wide enough). In order to reduce this error, the effective emissivity and effective wavelength must be used for pyrometer calibration. In each case, the pyrometer operating wavelength and band data must be

Pyrometer Instrument Co. Has 77 Year History

Pyrometer Instrument Company is a leader in the development of temperature measurement instruments for space, defense, science and industry. During its 77-year history, it has solved many hot-temperature measurement challenges.

It all began in 1928, when Mr. Bollerman opened Pyrometer Instrument Company on Lafayette Street, New York, NY. The first products were contact and immersion thermocouple pyrometers for molten iron and steel foundries. Five years later, the company introduced a traditional non-contact optical pyrometer that incorporated a photoscreenic wedge, which acts as a neutral density filter that enables the measuring instrument to provide a clear, enlarged view of the target.

Steady market growth continued throughout the years of WWII. Soon after the war, the company moved its headquarters to Bergenfield, NJ. In subsequent years a number of new products and innovations were introduced. In 1969 the company moved its headquarters to Northvale, NJ.

In the 1980s, Dr. E. K. Matthews purchased the company from the founding family. Ownership change was followed by partnerships with other companies and product line acquisitions, including thermal vision and infrared thermometry equipment.

In 1987, Pyrometer purchased exclusive patent rights from Exxon Corporation to develop emissivity measurement systems. Emissivity is crucial to accurate temperature measurement. With the Exxon rights, Pyrometer developers went to work on creating an automatic emissivity correcting IR thermometer that would solve these problems. The result was the Pyrolaser Portable automatic IR thermometer. This device so improved the accuracy of temperature measurement that it received the 1988 Photonics Circle of Excellence Award.

Today, Pyrometer Instrument Company claims a leadership role in the development of temperature measurement instruments for science and industry. The company is a wholly-owned subsidiary of MAKKE LLC, which owns several companies specializing in the instrumentation field.

matched with the published spectral emissivity table.

Emissivity Is Variable

There are also other complications. The emissivity of an object is not a fixed number. It continuously varies because of changing surface conditions such as oxidation and recrystallization, and these variations must be considered if an accurate temperature measurement is to be made.

In most cases, temperature has to be measured under a variety of conditions presented by objects such as clean metal surfaces, partially oxidized metal surfaces, mixtures of molten metal and slag, semiconductor wafers, ceramics, and semi-transparent objects.

Unfortunately, a universal method suitable for all applications doesn't exist. However, a number of approaches have been developed to

overcome some of these difficulties that will produce reliable and consistent temperature measurements.

The use of standard pyrometers will often require a certain amount of 'guesstimation' on the part of the instrument operator. Rarely is it possible to achieve accurate and repeatable measurements in this manner.

Measuring Emissivity

The best way to solve typical emissivity problems is to just measure the emissivity. But the emissivity of an object is not easy to measure accurately because it heavily depends on many physical and chemical properties, such as temperature, wavelength, angle, oxidation, surface texture, etc.

Emissivity data can be obtained in number of ways. If the temperature of the object can be measured with a contact thermometer, the pyrometer's

emissivity setting can be varied until it indicates the same temperature, and measurements can then be made of that particular surface using that setting. Any change in the area or surface being measured would require repeating the measurement.

Another technique is to blacken part of the object with soot or special high temperature black paint that approximates a coefficient of 1.0. The pyrometer measures the temperature of the blackened area, with the instrument set at its highest (1.0) emissivity setting. That temperature is noted. Then the bare surface is measured and the emissivity control setting on the pyrometer is changed until the instrument shows that same temperature.

An approximation of a black body can also be achieved by drilling a deep narrow hole in the object to create what is known as a black body cavity. Using this method, the pyrometer must be able to focus into the narrow hole. A reference gold cup pyrometer can also be used to figure the actual object temperature and the pyrometer emissivity adjusted to get the same temperature reading. Finally, a spectrometer and reference source can be used to analyze the emissions of the surface. The pyrometer may then be calibrated accordingly. This is a costly process that usually must be done in a laboratory.

Drawbacks

All these techniques have drawbacks. In real world processes, a body's emissivity may change by the time it has been measured by these methods. Other difficulties are that they can be time consuming and expensive to carry out, and must be repeated each time there is any change in the object being measured or in the measurement setup. In some cases, these methods cannot be used at all if the subject of interest is physically inaccessible.

Another factor that can lead to erroneous temperature readings is the body's surface geometry of the surface being scanned. A concave surface will tend to concentrate more energy into the scanned area, just as a magnifying shaving mirror focuses sunlight, and presents a higher emissivity. Similarly, a convex surface will disperse the energy for an opposite effect, showing a lower emissivity.

Flat surfaces, especially polished ones, do not emit radiation equally in all directions so the angle at which a flat surface is viewed will have an effect. The more the angle deviates from straight on, or 90 degrees to the surface, the lower the apparent emissivity becomes, and the greater the possible temperature error if this is not taken into consideration. And for highly reflective objects polarization effect has to be taken into account.

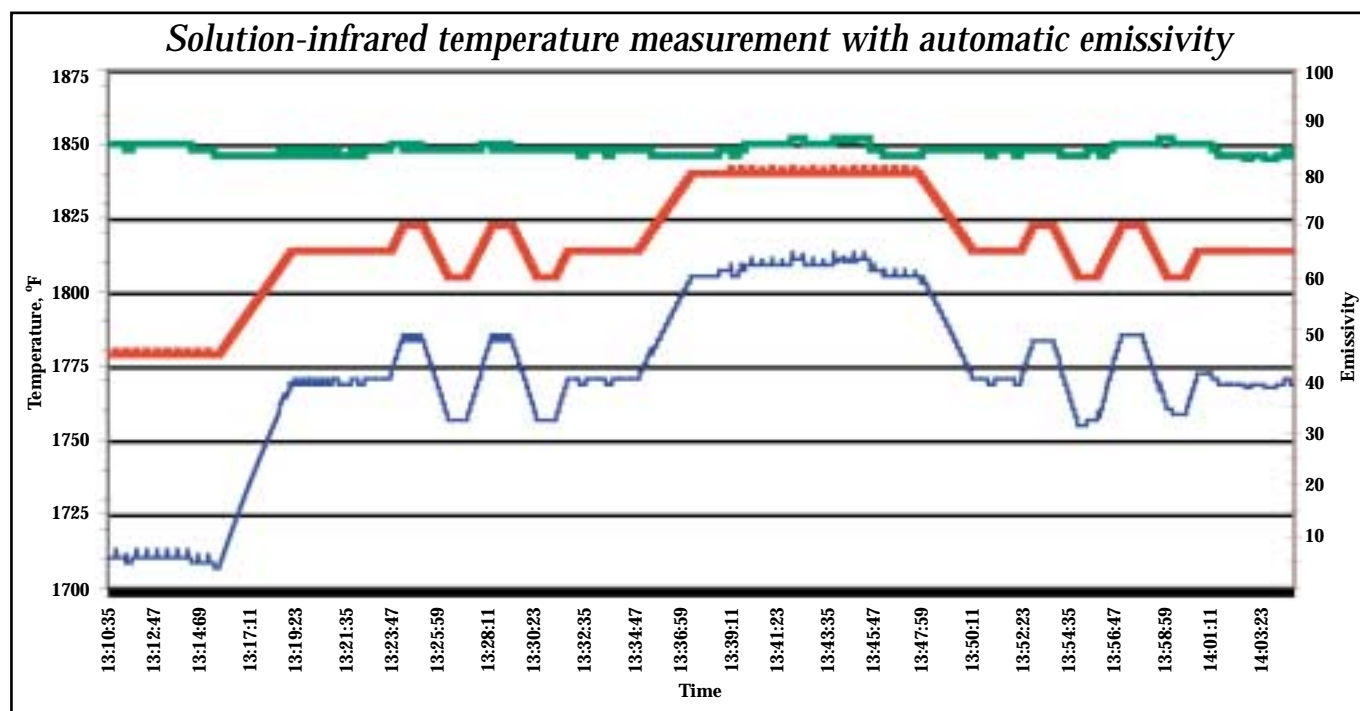
Additional errors can occur when extraneous energy, such as that from the higher temperature inner wall of a furnace, is reflected by the target object and integrated into the object's radiation signature. Finally, but probably not least, in high temperature industrial processes there can be intervening gases, smoke, or vapor that add an obscuring or filtering effect.

Dual and multi-wavelength pyrometers use a mathematical technique to sidestep this emissivity problem, but are not valid for many applications. Those methods are applicable only for so-called 'gray' objects, in which the emissivity stays constant and is independent of wavelength.

Pulsed Laser Technique

Precise measurement and control of temperature is vital in many industrial processes to assure product quality and yield, as well as safety. The Pyrometer Instrument Company (PIC) offers its ePyroCal Emissivity Calculator on its website at www.pyrometer.com. This can help estimate the possible error for different types of pyrometers.

With all these complicating factors is it ever possible, in the real world, to get accurate and repeatable temperature readings with an IR radiation pyrometer from an object of unknown emissivity? It is when



instruments employing special techniques to compensate for the above effects are used for the measurements. By using a patented pulsed laser technique to determine a target's emissivity at the same time, location, and wavelength that the infrared temperature measurement is being made, the precise temperature can be measured. This low-powered, pulsed laser is fired at the target along a dedicated optical path, and both the reflected laser return signal and the infrared signal are detected. With the known output energy of the laser, the pyrometer will measure how much of the laser energy is returned. Assuming the target is opaque, the laser energy must either be reflected or absorbed. By measuring the reflectivity of the target at the same location, temperature, wavelength and instant as the radiance measurement, the instrument is able to determine the emissivity and thus the True Emissivity Correct Temperature.


For situations in which the temperature reading of the target may be in-

fluenced by stray radiation from a hotter surface (such as the walls of a furnace), use of a laser pyrometer can eliminate this error. It does this by taking a radiant measurement of the hotter surface, and by knowing the reflectivity of the target.

PIC's portable Pyrofiber pyrometer incorporates pulsed laser technology and provides precise temperature measurements in industrial or scientific environments. Several other instruments using this method of emissivity determination have been developed for special applications. The company's On-Line Pyrofiber fiber optics-based instrument permits temperature measurements to be made where there is a space limitation, electromagnetic interference, a hazardous environment, or where a direct line of sight reading cannot be obtained with a standard instrument.

While determining real-time emis-



sivity in infrared thermometry has long been a serious problem, current laser-equipped pyrometers offer near laboratory accuracy in even the most difficult industrial situations. 

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