HOW ADVANCED PYROMETERS INCREASE THERMAL PROCESS REPEATABILITY AND PRODUCT QUALITY

Accurate temperature measurement is key for controlling the stability and repeatability of many temperature-critical processes. This often has a direct influence on product quality and process throughput.

For some processes, non-contact optical pyrometers are ideal for measuring the temperature of moving or inaccessible work pieces, or when direct physical contact would damage the work product. Extremely high temperatures, beyond the range of traditional thermocouple measurements, also call for the use of optical pyrometers.

Closed-loop temperature control systems depend on an accurate temperature reading to maintain precise temperature control. Today's advanced pyrometers meet the challenges of industrial manufacturing with a variety of sophisticated features and functions that support accurate measurement regardless of process conditions. Some of these key pyrometer capabilities include:

- Active ambient compensation
- Robust designs for high-temperature, industrial conditions
- Immunity to view path contamination
- Stray energy compensation
- Active emissivity compensation

TABLE OF CONTENTS

ACTIVE AMBIENT COMPENSATION

With a change in ambient temperature, a pyrometer's internal temperature affects its ability to measure temperature accurately. However, a pyrometer with advanced active ambient compensation continuously monitors its own internal temperature and automatically compensates for this measurement. This ensures ongoing temperature measurement accuracy across a wide ambient temperature variation (5 to 70°C).

ROBUST DESIGN FOR HIGH-TEMPERATURE, INDUSTRIAL CONDITIONS

For industrial manufacturing, instruments must be constructed specifically to ensure precise operation even in harsh environments. These pyrometers feature stainless steel housings, and comply with IP65 protection standards to operate accurately up to 70°C without additional cooling. For environments with higher ambient temperatures, advanced pyrometers offer further options, such as water cooling. Alternatively, for applications with exceptionally harsh conditions, certain pyrometers feature independent lensed optical sensors and fiber optic cables that route the sensor signal long distances to remote instrumentation cabinets, enabling the measurement detector and electronics to be located at a distance (Figure 1), away from potentially damaging ambient or other conditions. In addition, industrially hardened electronics in advanced pyrometers allow instruments to function in environments in which large stray electrical currents are encountered.

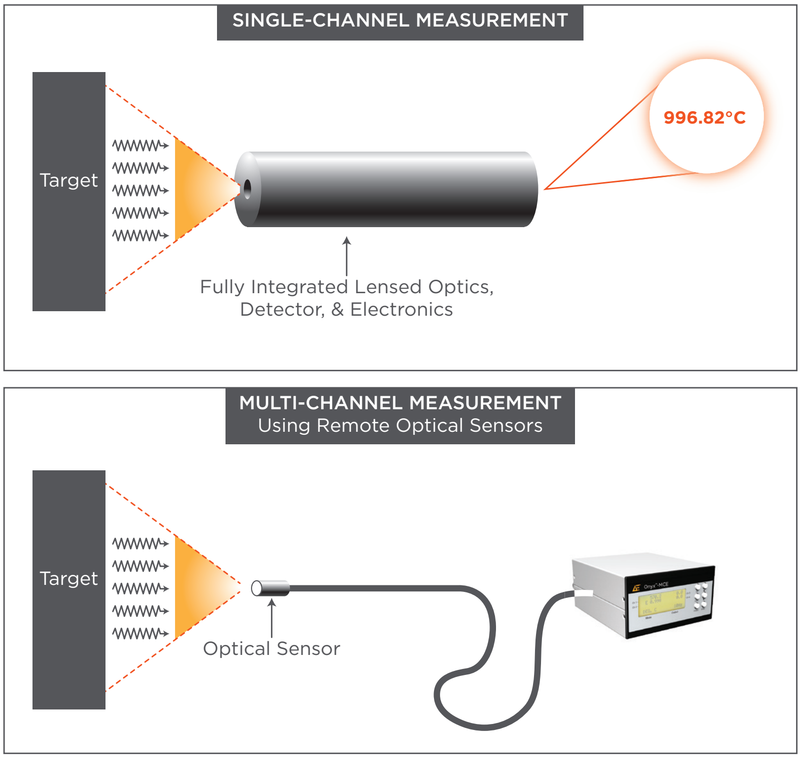

Figure 1. Pyrometers are available in two configurations: integrated (top) or with remote optical sensors (bottom) that enable the detector and electronics unit to be located remotely, away from exceptionally harsh process conditions.

IMMUNITY TO CONTAMINATION

For unusually demanding manufacturing conditions, two-color pyrometers (also called *ratio pyrometers*) offer immunity to dust and view port contaminants. Contaminants in the pyrometer's view path, or on a process view port, can reduce the effective measured signal of a traditional single-wavelength pyrometer, causing it to report an erroneously low temperature. Two-color pyrometers enable accurate measurement despite contaminants by providing a ratio measurement of the two adjacent wavelengths. This method compensates for window contamination, as well as additional factors, including:

- Substrate or work piece emissivity changes
- Airborne particulates or vapors in the pyrometer field of view
- Small substrate size

STRAY ENERGY COMPENSATION

Process heaters often contribute stray IR radiation to the process. This energy comes not from the intended target (usually the work piece), but from the heaters themselves. Since the heaters are sometimes much hotter than the work piece, the extra energy from the heaters can substantially alter the pyrometer reading. The temperature always appears hotter under these conditions. This is especially true on shiny or low-emissivity targets.

Advanced pyrometers offer built-in compensation in the form of background subtraction algorithms. They can be calibrated to partially remove signal from the pyrometer reading in response to chamber conditions.

ACTIVE EMISSIVITY COMPENSATION

Substrate emissivity is one of the most challenging parameters to manage to ensure accurate measurement. It is quantified as an object's thermal emission relative to a "black body," which is an object that absorbs all thermal energy. A black body's theoretical emissivity value is 1. All radiating objects have a specific emissivity behavior. This behavior is expressed as a fraction of the emissivity of a black body, with a value typically between 0.05 and 1.0. All pyrometers require an emissivity value as a correction factor to ensure an accurate temperature calculation.

FIXED VERSUS ACTIVE EMISSIVITY COMPENSATION

Compared to pyrometers that use a fixed emissivity value, those with real-time emissivity compensation offer better temperature measurement accuracy for improved process repeatability, product quality, and yield.

Traditional pyrometers require users to enter a fixed emissivity value, which is based on the work piece material. However, material surface properties often change during the manufacturing process as a result of oxidation or through the introduction of coatings. These changes affect the emissivity of the material being measured. In this situation, use of a fixed emissivity value results in significant measurement errors (Figure 2, on page 4). For accurate measurement, these conditions require real-time emissivity measurement and correction technology, which continuously measures and compensates for emissivity, even as it changes during material processing. In this way, pyrometers with active emissivity compensation (also called *emissometers*) dramatically reduce temperature measurement inaccuracies for better closed-loop temperature control.

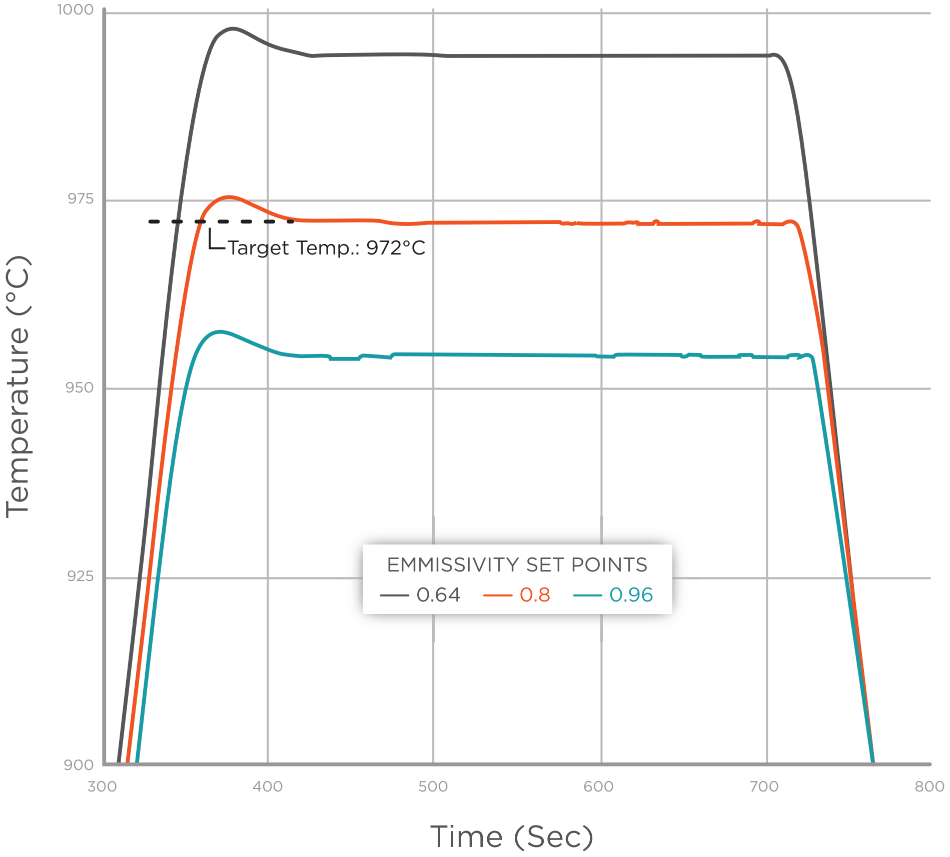

Figure 2. Temperature measurement using fixed emissivity

Figure 2 shows a study in which the use of fixed emissivity values as correction factors resulted in actual measured temperatures that varied as much as ±20°C. With a target temperature of 972°C, the pyrometer was set to fixed emissivity values of 0.64, 0.8, and 0.96, which resulted in significant inaccuracies.

ACTIVE EMISSIVITY COMPENSATION

Figure 3, on page 5, shows the high accuracy of a pyrometer using active emissivity compensation compared to the measurement error of a pyrometer using a fixed emissivity value.

TEMPERATURE MEASUREMENT ACCURACY FOR AN OBJECT WITH CHANGING EMISSIVITY
Fixed Emissivity vs. Active Emissivity Compensation

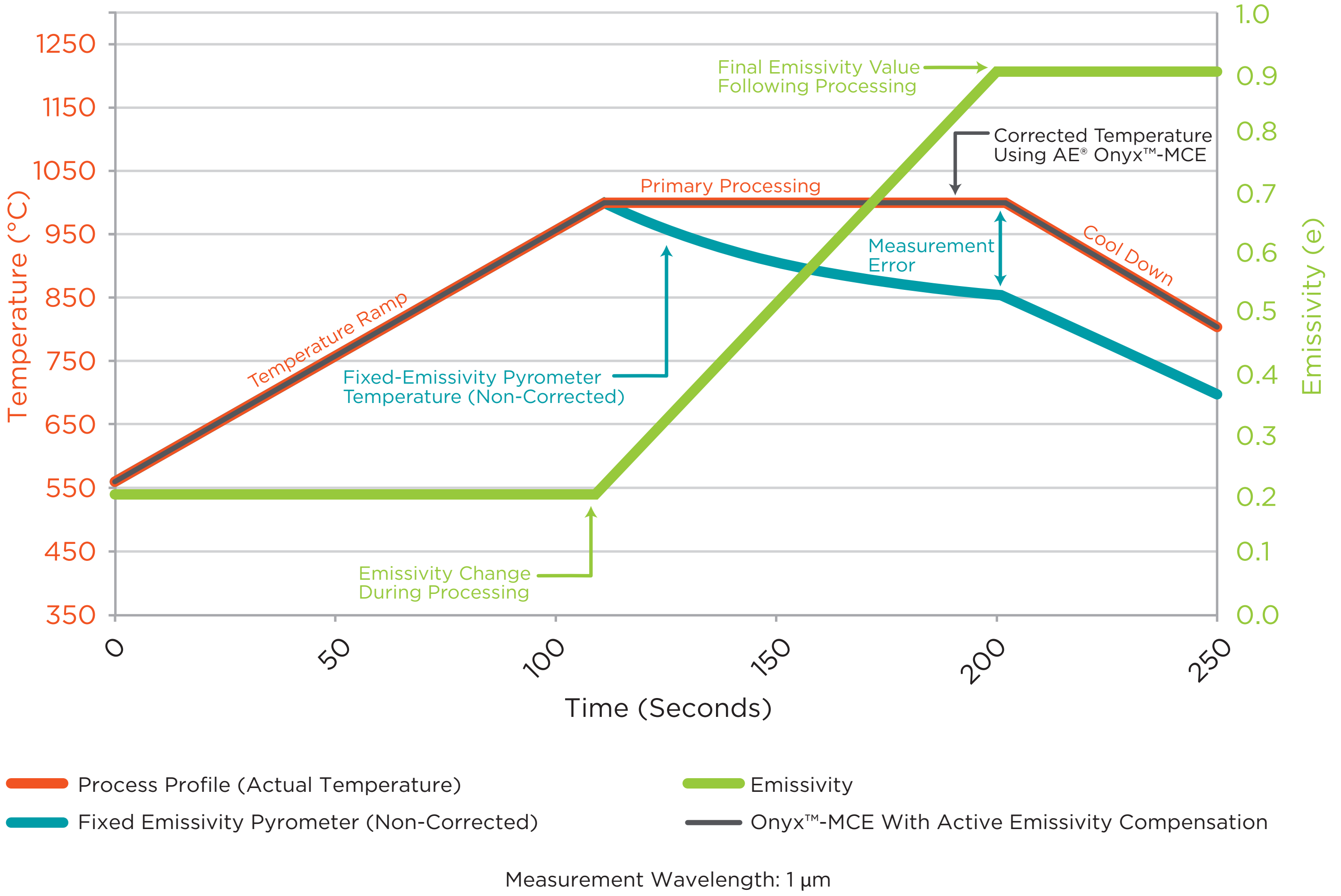

Figure 3. Temperature measurement accuracy for an object with changing emissivity: fixed emissivity vs. active emissivity compensation

With active emissivity compensation, temperature measurement accuracy remains constant despite substrate emissivity changes. Without active emissivity compensation, false temperature measurements may be introduced into your temperature-critical process, degrading temperature control accuracy and product quality.

MEASURING AND ADJUSTING EMISSIVITY

Pyrometers with real-time emissivity compensation continuously monitor the reflected intensity of light incident on the target and use this to calculate the emissivity. Therefore, they are able to correct the process temperature in real time. This occurs according to the following process:

1. The emissometer illuminates the target with series of LED or laser pulses at a specific intensity and a complementary wavelength. These pulses are transmitted from the center of a multi-fiber cable.
2. The emissometer receives the reflected pulses via the outer fibers of the multi-fiber cable and measures the intensity of light reflected from the target (Figure 4, below).
3. Reflectivity is measured and calculated real time with the following formula:

   $\text{Reflectivity} = \dfrac{\text{Incident Light Intensity}}{\text{Reflected Light Intensity}}$ (Figure 5, on page 7).
4. Emissivity is then calculated in real time with the following formula:

   Emissivity = 1 − Reflectivity.

   (Formula applies to opaque, specular targets only.)
5. The pyrometer's temperature measurement is compensated based on the change in measured target emissivity.

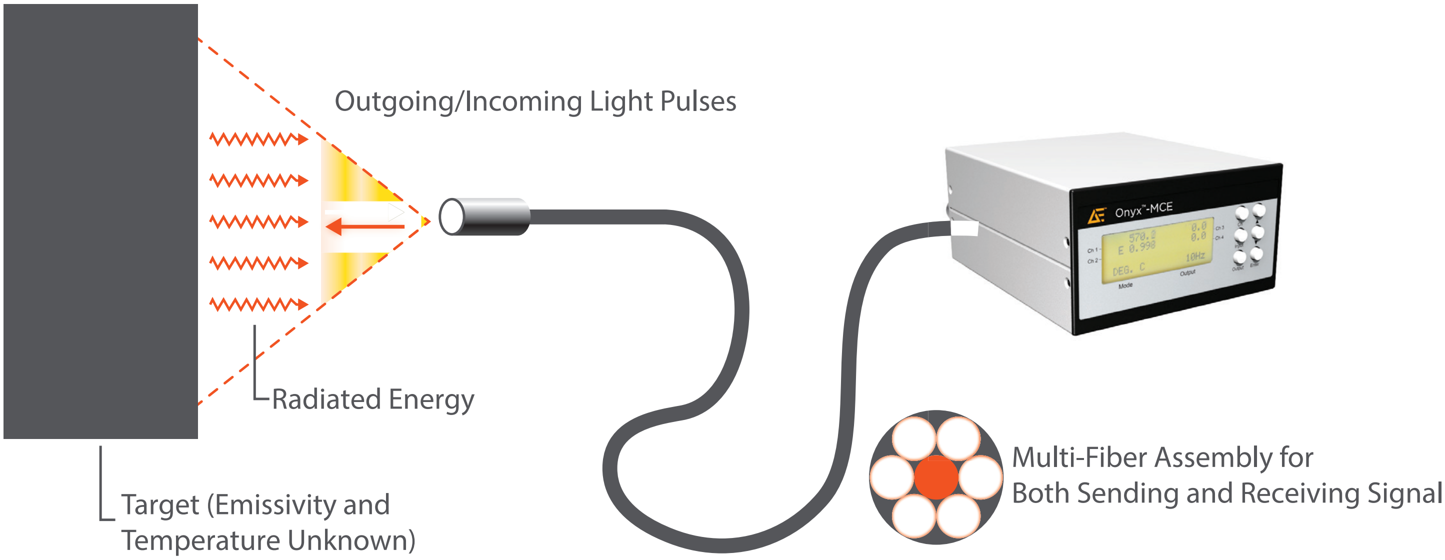

Figure 4. Measuring emissivity

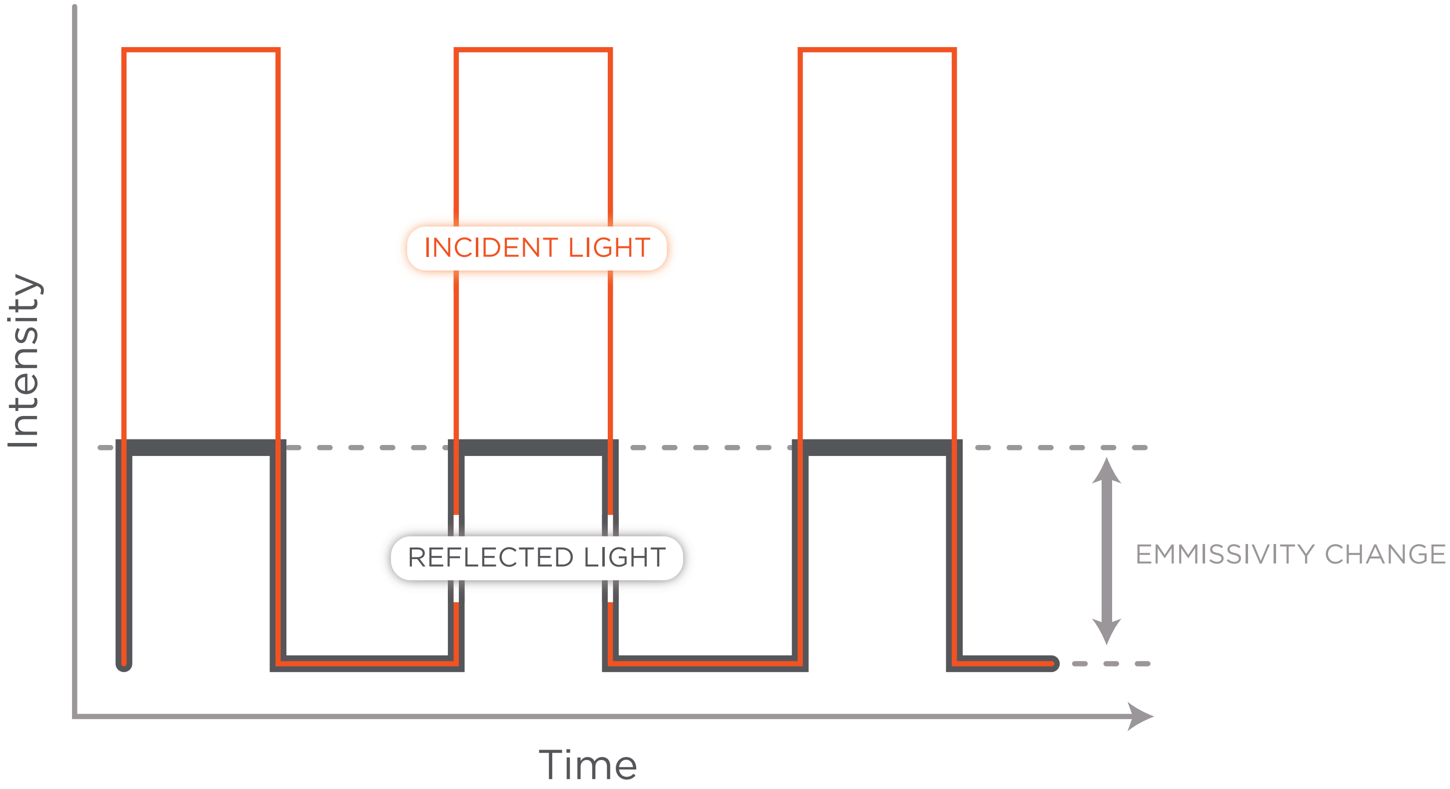

Figure 5. Calculating emissivity change

ACCURATE TEMPERATURE MEASUREMENT IN CHALLENGING INDUSTRIAL CONDITIONS

Industrial conditions present a variety of challenges to optical pyrometer temperature measurement, even though this type of measurement is often the only solution for moving or inaccessible work pieces, or for extremely high-temperature processes. Factors such as changes in ambient temperature, stray energy, process contamination, and changing material emissivity present challenges to measurement accuracy. To address these challenges, today's most advanced temperature measurement solutions offer technologies that support excellent repeatability and product quality in even the harshest manufacturing environments.

For international contact information, visit advanced-energy.com.