8. PYROMETRY FUNDAMENTALS

Being part of a highly specialized field of measuring techniques has developed a certain mysterious aura about it. This mystery stems from the false perception that the technique is difficult to master. In fact, pyrometers are easy to operate in industrial applications so long as the basic principles are known and observed.

◈ 8.1 PYROMETRY FUNDAMENTAL

Pyrometry measures the temperature of objects without touching them i.e. it is a non contact temperature measurement instrument and which is a standard procedure in many industries today. Due to its accuracy, speed, economy and specific advantages, pyrometry is steadily gaining acceptance in new fields. But how is it possible to measure temperatures without physical contact?

The answer is here. Every object whose temperature is above absolute zero (-273.15 K) emits radiation. This emission is heat radiation and is dependent upon temperature. The term infrared radiation is also in use because the wavelengths of the majority of this radiation lie in the electro-magnetic spectrum above the visible red light, in the infrared domain.

Temperature is the determining factor of radiation and infrared radiation transports energy. This radiated energy is used to help and determine the temperature of the body being measured. Similar to radio broadcasting where emitted energy from a transmitter is captured by a receiver via an antenna and then transformed into sound waves, the emitted heat radiation of an object is received by a detecting device and transformed into electric signals. Thus, the energy emitted by an object is utilized by remote (i.e. non-contact) temperature measuring devices. The instruments, which determine an object's temperature in this fashion, are called radiation thermometers, radiation pyrometers, or simply pyrometers

Originally, pyrometry was a strictly visual measuring method. Experienced blacksmiths and steel workers could with surprising accuracy, gauge the metal's temperature by its brightness and coloration. The first pyrometers (Filament Pyrometer 1917) could only utilize the visible radiation from an object. Since radiation is visible only when the object is made red hot, early Pyrometry could only be successful when measuring high temperatures. But technical advances have made it possible today to measure temperatures far below freezing point from a distance and without making contact with the object to be measured.

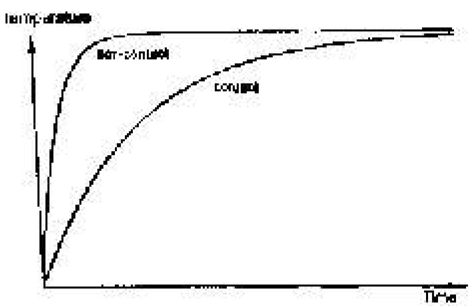
In industrial manufacturing and in engineering processes, pyrometry is standard procedure and can no longer be ignored. In glass manufacturing, metal-working, or food production, accurate temperature measurement remains one of the most important factors to consider during processing.

Pyrometer's expanding use is primarily due to its advantages over temperature measurement by means of physical contact.

◈ 8.2 ADVANTAGES OF PYROMETER :

The advantages of pyrometers are:

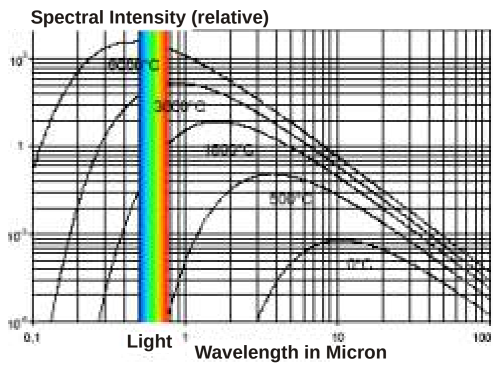
- Fast response
- No adverse effects on temperature and materials
- Measure temperature of moving objects
- Measure temperature of objects which are difficult to access
- Measure temperature of electricity conducting objects without danger of short circuiting
- Poor heat conductors
- Small mass, low heat
- Analog and digital output
- Viewing through windows



Response Time

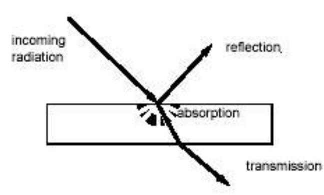
◈ 8.3 SPECTRAL INTENSITY:

Visible light with all its colors, infrared radiation, x-rays or γ - rays (gamma), is similar in nature. Their differences lie in wavelength, or frequency. The wavelength is expressed, as the "color" of the light; one should consider the energy or the intensity of the radiation coming from the black body. Following illustration shows the relative distribution of heat radiation (spectral intensity) across the wavelengths. The exponential correlation of intensity and wavelength requires double logarithmic scaling for graphic representation. Following illustration demonstrates that the intensity curve moves left toward the shorter wavelength as the temperature rises. At temperatures over 550 °C the curve reaches the area of visible light. The object to be measured begins to glow. At higher temperatures the intensity rises in the visible area. Steel glows red hot at first, then, as the temperature rises, one speaks of white-hot which means all spectral colors are represented.



8.4 PROPERTIES OF REAL OBJECTS

The connections and relationships discussed so far concern black bodies. Real objects, however, have different properties. To clarify this we will look at conditions in the area of visible light, which can also be applied to the infrared region. Real objects have properties called reflection, absorption, and transmission (permeability). A large part of incoming rays are reflected off by bright and smooth surfaces. On the one hand we find focused reflection, such as off a mirror or a lacquered surface. On the other hand we have diffuse reflection such as in objects with rough surfaces. Paper, for instance, reflects light in all directions.



Another part of incoming rays is absorbed by dark, rough surfaces. This may happen across a wide or narrow band of the spectrum. In cinemas, much light has to be absorbed by the sidewalls of the room (often fitted out with dark colored curtains) so that clear viewing is not impaired by reflections. These dark wall hangings absorb nearly all-incoming light. Colors and lacquer, on the other hand, only absorb light selectively. A red car appears red because all other colors are absorbed.

The remaining part of incoming rays penetrates the object and is transmitted through it. We speak of transparent materials. This process too may be selective. While normal window glass lets all of the spectrum of visible light pass through, tinted sunglasses let only a certain part of the spectrum through.

Every object has the above-mentioned properties, but they are represented in different percentages according to the material under observation. They are described mathematically as reflection rate α, absorption rate β, and transmission rate γ. They refer to the ratio of reflected, absorbed, or transmitted intensity to the intensity of the incoming light. The values for α, β and γ lie between 0 and 1). Their sum is always 1.

With these values, a black body's behavior may be theoretically described as, one which absorbs all incoming rays. Its absorption coefficient, α, is 1 (one). It follows then that $\beta = 0$ (zero), and $\gamma = 0$ (zero).

In thermal equilibrium, a body, which absorbs well is the body which emits well (Robert Kirchhoff, 1824-1877). This means that its absorption coefficient α equals its emission coefficient ε. At a given temperature maximum flow of radiation comes from black bodies. Therefore, this object is also called a black body radiation source. In practical terms this condition is evident in soot or in flat black color. The emission coefficient ε is the relationship of the emission output of an object to the emission output of a black body radiation source at the same temperature. ε is influenced by the object's material and changes with the wavelength, the temperature or other physical values.

◈ 8.5 EMISSIVITY OF VARIOUS MATERIALS

As already described, the emission coefficient å of an object is the most important value when determining its temperature with a pyrometer. If one wants to measure the true surface temperature of an object with a pyrometer one must know the emission coefficient, or emissivity, of the object and enter its value in the pyrometric measuring system.

To adjust for the material being measured, pyrometers therefore have an emissivity setting. The values for the various materials may be taken from tables. In principle, the emissivity of a material is influenced by wavelength, temperature, etc.

Because the emissivity is dependent upon wavelength most materials can be grouped as follows:

1. Metals
2. Non-metals
3. Transparent materials (opaque)

The emissivity of smooth metal surfaces is high at short wavelengths and decreases with lengthening wavelengths. With oxidized and soiled metal surfaces results are not consistent; emissivity may be strongly influenced by temperature and/or wavelength. The emissivity of metals also changes with time due to wear and tear, oxidation or soiling. Pieces of metal are often smooth after processing and their surfaces are changed by heat. Discoloration occurs and can be followed by rust and scale. All this can change the emissivity and must be considered to avoid errors. However, so long as surfaces are not shiny, metals can be measured well in most cases. Smooth and shiny metal surfaces reflect light strongly, their reflection coefficient is high, and their emission coefficient is low. A hot object has a high reflection coefficient and if it is close to where a temperature reading needs to be taken (for example, a furnace crown), it can affect the value of that reading. Therefore, smooth metal surfaces are the most difficult objects to measure in pyrometry.

Emissivity modifiers, such as black lacquer or adhering plastic film, improve the emissivity of metals at low temperatures. Lacquer or plastic film have a high and known emissivity and assume the temperature of the metal surface. The non-metal group includes organic materials, such as foodstuffs, wood or paper, as well as ceramics or fire clay. The emissivity of non-metals rises with increasing wavelength. Generally speaking, from a certain wavelength, the emissivity is nearly constant. With dark materials this begins in the visible spectrum, but with light colored materials it is above 4 µm.

8.5.1 EMISSIVITY OF GLASS

Glass is transparent in visible light and near the infrared region (to about 3 µm), its transmission coefficient γ is high, and therefore its ε is low. Illustration 11 shows that its emission coefficient is very high in the area of 4.5 to 8.5 µm. The absorption band of glass falls within this area. To measure the glass surface temperature, one uses the wavelength of around 5.14 µm, because the absorption band of water vapour or carbon dioxide does not influence the values there, above 7 µm the reflection of glass increases.

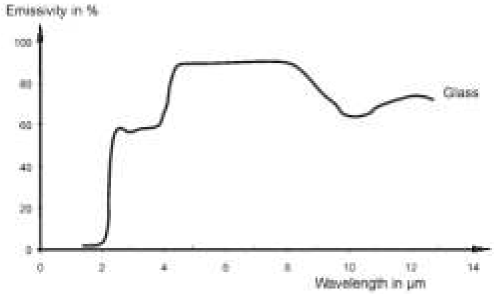


Illustration 11: *Emissivity of glass (qualitatively)*

8.6 CHOOSING THE SPECTRAL RANGE

Choosing the correct spectral range is extremely important for accurate measurements using pyrometers.

Here are some rules which should be observed to avoid emissivity errors. The most important rule is to choose a pyrometer those measures in the shortest wavelength band. This rule may be a disadvantage by not fully utilizing the radiated energy, but it diminishes the influence of the emissivity. It is best to disregard this rule when strong daylight or artificial light influences the measurement, when the emissivity in the short wavelength band is poor (for example, white lacquer) or when a certain area of the spectrum is needed for the measurement (for example, glass).

Just by choosing the right band of the spectrum, errors can be reduced nine fold.

This rule is very important when measuring metal objects. With metals the emissivity rises in the short wavelength band which helps prevent errors. In addition, the variation of the emission coefficient that is dependent upon the composition of the material and on the condition of the surface, is diminished when dealing with metals.

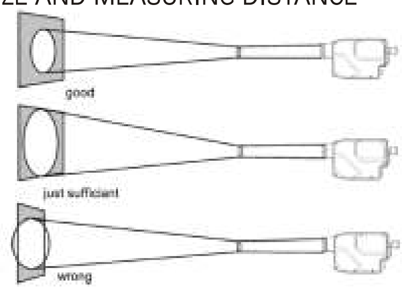
For example: The emissivity of pure steel in the spectral area of 0.85 to 1.15 µm shows a value of 0.4 to 0.45. The value for emissivity in the spectral area of 8 to 14 µm, however is 0.1 to 0.3. A potentially false setting of the emission coefficient is reduced to about 6 % in the short wavelength band, but can reach 50 % in the long wavelength band. Because of their emissivity, measuring the temperature of non-metals by means of a pyrometer is less complicated.

In this case one must choose pyrometers, which the manufacturer has designated for certain materials (for instance, glass, plastics, ceramics, textiles, etc.). The spectral areas in quality pyrometers are chosen so that they are in the wavelengths, which have a high and constant emissivity. At those wavelengths, the material is impenetrable and absorption bands of water vapour and carbon dioxide are not found here. In cases where the emission coefficient varies strongly, such as in metalworking processes, it is advisable to use pyrometers, which can measure in more than one spectral range. 2-colour pyrometers have proven especially successful

8.7 SELECTION OF SENSORS

Type of Sensors	Temperature Range	Wave length
Silicon	Over 550 ° C	0.8 - 1.1 µm
InGaAs Germanium	Over 250 ° C	1.45 - 1.8 µm
Lead Sulphide	Over 75 ° C	2 - 2.8 µm
Thermopile	Over 100 ° C	8 - 14 µm
Pyroelectric	Over -50 ° C	8 - 14 µm

8.8 SPOT SIZE AND MEASURING DISTANCE



8.9 PYROMETER TYPES

The differences between spectral band pyrometers, total band pyrometers, and 2-colour pyrometers are described below.

8.9.1 SPECTRAL BAND PYROMETERS

In this category are narrow band pyrometers and broadband pyrometers.

8.9.2 NARROW BAND

These pyrometers measure the radiation from a narrow wavelength band, usually just around one wavelength. By using interference filters and appropriate detectors a certain wavelength or a certain wavelength band is chosen. They are frequently used when measuring glass at 5.14 µm. Metals are also measured with them since their rate of emissivity is high only in a narrow band.

8.9.3 BROADBAND

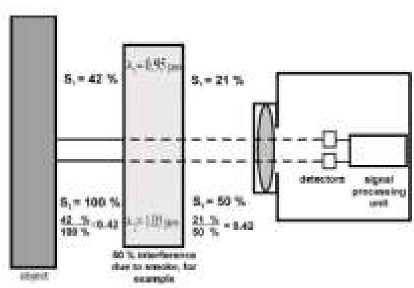
These have a similar construction to that of the narrow band pyrometer. By using other filters and detectors the radiation from a wider wavelength band is measured (for example, 8 to 14 µm). These pyrometers are used for measuring organic materials because they have, in general, a high and constant emissivity at longer wavelengths.

8.9.4 TOTAL BAND PYROMETERS

These pyrometers are built to detect more than 90% of the emitted radiation of an object. This requires special detectors, lenses and filters which are sensitive to almost the whole spectrum. Today, total band pyrometers are rarely used due to the major errors experienced (atmospheric window, emissivity).

8.9.5 2-COLOUR PYROMETER

2-colour pyrometers measure the radiation using two different wavelengths, then calculate the ratio from the signals, and finally determine the temperature. When forming the ratio, the emissivity is eliminated as part of the calculations; in other words the temperature measurement becomes independent of the emissivity of the object. The wavelengths are close together in order to equalize, as much as possible, emissivity (for example 0.95 µm and 1.05 µm). The output signal will not change when the object does not fully cover the spot size, or when interference like smokes or suspended matter is present, providing they occur equally in both wavelengths. If the emissivity is different at the two wavelengths, then it is possible by setting the å-slope to give an input to the instrument of the ratio of the emissivity at the two wavelengths.



2-colour pyrometers are used for difficult measuring tasks.

- High temperatures
- Blocked views or interference in the atmosphere (for example, smoke, suspended matter)
- The object is smaller than the spot size (down to 10% of the spot size)
- Changing, low, or unknown emissivity (for example, molten metal).

8.9.6 DIGITAL PYROMETERS : STATE-OF-THE-ART-TECHNOLOGY

With advancing miniaturization and integration, today's pyrometers are digital. This means that a microprocessor is built into the pyrometer. It does all the calculations and controls the memory functions.

Normally, the output signals are either standard analogue or digital. Digital interfaces are usually RS 232 and RS 485. Analogue output signals are 4 ... 20 mA, 0 ... 20 mA, 0 ... 10 V, etc.

◈ 8.10 ADVANTAGES OF DIGITAL SIGNAL CONVERSION ARE:

The liberalization of the detector characteristic is applied at many points. The results are much better than with electronic linearisation. Today we are able to achieve accuracies to within ± 0.3 % of the measured value.

Confined spaces: The optical head is small and can fit through narrow openings until it is nearer the object.

Digital communication: Communication with the pyrometer is also possible. A PC connected with the appropriate software is usually sufficient. All relevant data can be entered into the pyrometer, such as emissivity, response time, measuring range, maximum value storage, etc.

Changing the measuring range: Within the determined basic temperature measuring range, any sub-range can be set via the PC/Portable battery operated parameter configuration. Accuracy is not affected by changing the measuring range.

The advantages are:

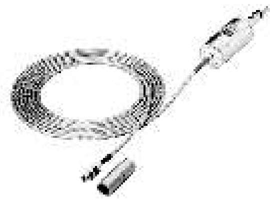
Old equipment · when replacing old equipment the existing measuring range can be entered. Other equipment and the cables can all be reused.

Reducing stores stock: Stores stock levels can be reduced as one range of digital pyrometer can be programmed to cover several different ranges of analogue instruments.

New digital equipment : The new equipment is easier to use and reduces complications.

Optimum adaptation · Optimum adaptation to a specific application.

Simple recalibration: By using an appropriate black body source and software, digital pyrometers can be quickly recalibrated and checked.



Fiber Optics Pyrometer

A fiber optics pyrometer consists of 3 parts: an optical head, a glass fiber and a signal-processing unit. The optical head contains only the optics and no electronics. In the converter are the detector and the signal-processing unit.

The radiation, coming in through the optical head, is transported via the lens system into the fiber where it can be transmitted along for up to 30 meters to the converter. The glass fiber of the optical fiber is no longer transparent at higher wavelengths. Consequently, the measurement of temperatures with glass fibers is limited to 150 °C and above.

Fiber optics pyrometers have proven themselves in difficult situations. Splitting the two components has advantages in these instances:

- High ambient temperatures (up to 250°C)
- Confined spaces
- Strong electromagnetic fields
- Measuring in a vacuum

◈ 8.11 PYROMETER ACCESSORIES

- Air purge unit
- Cooling accessories
- Adjustable mounting accessories
- Sighting Tubes
- Indicators
- Power supply
- Parameter configuration
- Signal converters