Pyrometers

The Principle and its applications

Submitted by

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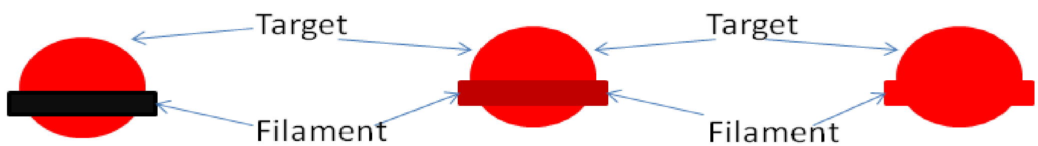
Pyrometers

- Derived from the Greek word “pyro” which means fire.
- It’s a temperature measuring device but unlike RTDs and thermocouples it’s not in contact with the surface.
- Could be optical or a radiation pyrometer.

Optical Pyrometer

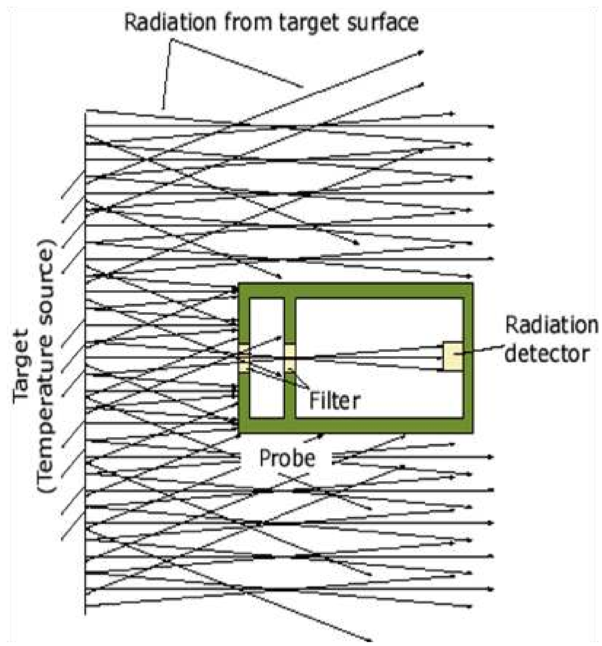
- Optical Pyrometers work on the principle of using the human eye to match the brightness of the hot object to the brightness of a calibrated lamp filament inside the instrument.



- The brightness of a lamp filament inside the device is matched to the brightness of the target. The amount of power required by the filament to match the brightness of the target is calibrated with temperature.
- This is called the Disappearing Filament method.
- Designed for thermal radiation in the visible spectrum.

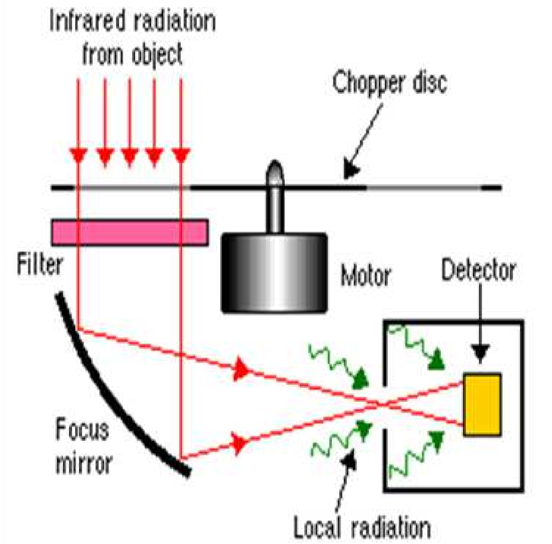
Radiation Pyrometer

- Every object radiates thermal energy at temperatures above absolute zero and the radiation emitted is a function of its temperature.
- In practice the energy radiated is proportional to the emissivity at a particular temperature and wavelength. To deduce the accurate temperature of a given surface from the radiation it is receiving, an operator has to know the emissivity of the material he is measuring.
- The radiation is focused using a lens onto a sensor which is a photo sensitive device and generates a voltage proportional to the radiation falling on it. (Thermal detector)



Radiation Pyrometer

- The impact of local radiation emitted by components within the sensor -This radiation may be far greater than that from the object being measured. An alternate and generally preferred solution is to convert the incoming signal into an AC (alternating current) signal by mechanically chopping the signal beam with a slotted rotating disc. The signal is then amplified with an AC amplifier that rejects the local DC signal.



Radiation Temperature Sensor

Applications

- Propulsion Testing
  Pyrometers are used to monitor the reaction temperature of a structure at critical locations while propellant is being consumed remotely using a non-contact type of measurement.
- Specific applications include measuring temperatures at points which are not easily accessible.
- In the steel industry to measure the temperature of the molten iron in casting channels and pour streams during continuous and non continuous casting.

Challenges

- Difficult to use in dusty conditions.
- In optical pyrometers it is based on an observer judging 2 colors to be the same.
- The object has to be hot enough to radiate visibly to use an optical pyrometer.
- Emissivity values depend on temperature , wavelength, shape, angle and the texture of the surface. With radiation pyrometers the emissivity of the target should be known beforehand hand and has to be set every time hence cannot be used to measure temperature of objects with unknown emissivity.
- Even in optical pyrometers the difference in emissivity of the pyrometer filament and the object will introduce an error.
- Expensive due to their complex structure.

Pyrometers

Radiation Pyrometer:

Pyrometer is derived from the Greek root pyro, meaning fire. The term pyrometer was originally used to denote a device capable of measuring temperatures of objects above incandescence, objects bright to the human eye. The original pyrometers were non-contacting optical devices which intercepted and evaluated the visible radiation emitted by glowing objects. A modern and more correct definition would be any non-contacting device intercepting and measuring thermal radiation emitted from an object to determine surface temperature. Thermometer, also from a Greek root thermos, signifying hot, is used to describe a wide assortment of devices used to measure temperature. Thus a pyrometer is a type of thermometer. The designation radiation thermometer has evolved over the past decade as an alternative to pyrometer. Therefore the terms pyrometer and radiation thermometer are used interchangeably by many references.

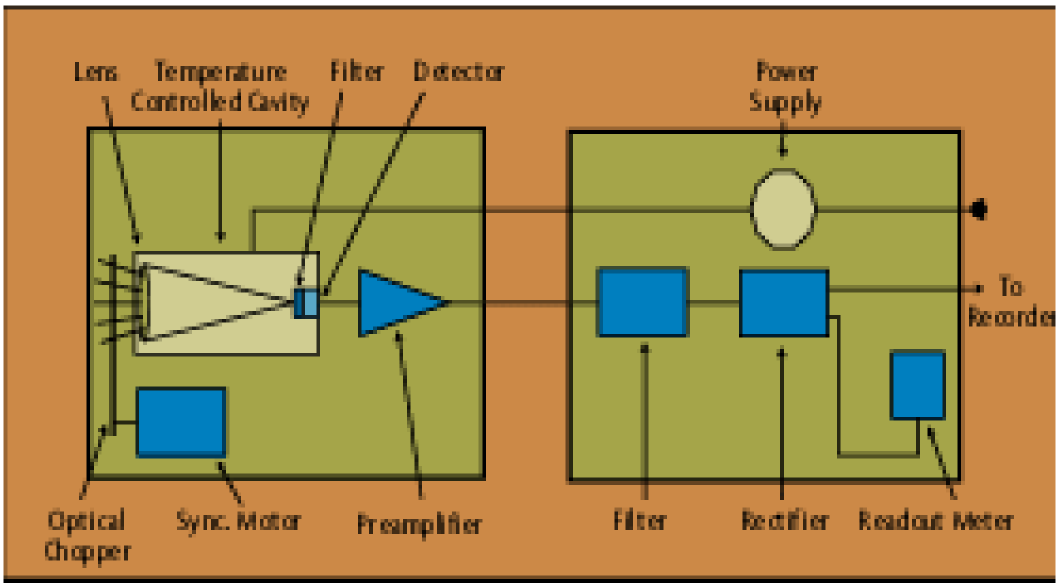
A radiation thermometer, in very simple terms, consists of an optical system and detector. The optical system focuses the energy emitted by an object onto the detector, which is sensitive to the radiation. The output of the detector is proportional to the amount of energy radiated by the target object (less the amount absorbed by the optical system), and the response of the detector to the specific radiation wavelengths. This output can be used to infer the objects temperature. The emittivity, or emittance, of the object is an important variable in converting the detector output into an accurate temperature signal.

Infrared radiation thermometers/ pyrometers, by specifically measuring the energy being radiated from an object in the 0.7 to 20 micron wavelength range, are a subset of radiation thermometers. These devices can measure this radiation from a distance. There is no need for direct contact between the radiation thermometer and the object, as there is with thermocouples and resistance temperature detectors (RTDs). Radiation thermometers are suited especially to the measurement of moving objects or any surfaces that can not be reached or can not be touched.

But the benefits of radiation thermometry have a price. Even the simplest of devices is more expensive than a standard thermocouple or resistance temperature detector (RTD) assembly, and installation cost can exceed that of a standard thermowell. The devices are rugged, but do require routine maintenance to keep the sighting path clear, and to keep the optical elements clean. Radiation thermometers used for more difficult applications may have more complicated optics, possibly rotating or moving parts, and microprocessor-based electronics. There are no industry accepted calibration curves for radiation thermometers, as there are for thermocouples and RTDs. In addition, the user may need to seriously investigate the application, to select the optimum technology, method of installation, and compensation needed for the measured signal, to achieve the performance desired.

Emittance, Emissivity, and the N Factor

The terms emittance and emissivity are often used interchangeably. There is, however, a technical distinction. Emissivity refers to the properties of a material; emittance to the properties of a particular object. In this latter sense, emissivity is only one component in determining emittance. Other factors, including shape of the object, oxidation and surface finish must be taken into account.



The apparent emittance of a material also depends on the temperature at which it is determined, and the wavelength at which the measurement is taken. Surface condition affects the value of an object's emittance, with lower values for polished surfaces, and higher values for rough or matte surfaces. In addition, as materials oxidize, emittance tends to increase, and the surface condition dependence decreases.

The basic equation used to describe the output of a radiation thermometer is:

V (T) = e K TN

Where:
- e = emittivity
- V(T) = thermometer output with temperature
- K = constant
- T = object temperature
- N = N factor (= 14388/(lT))
- l = equivalent wavelength

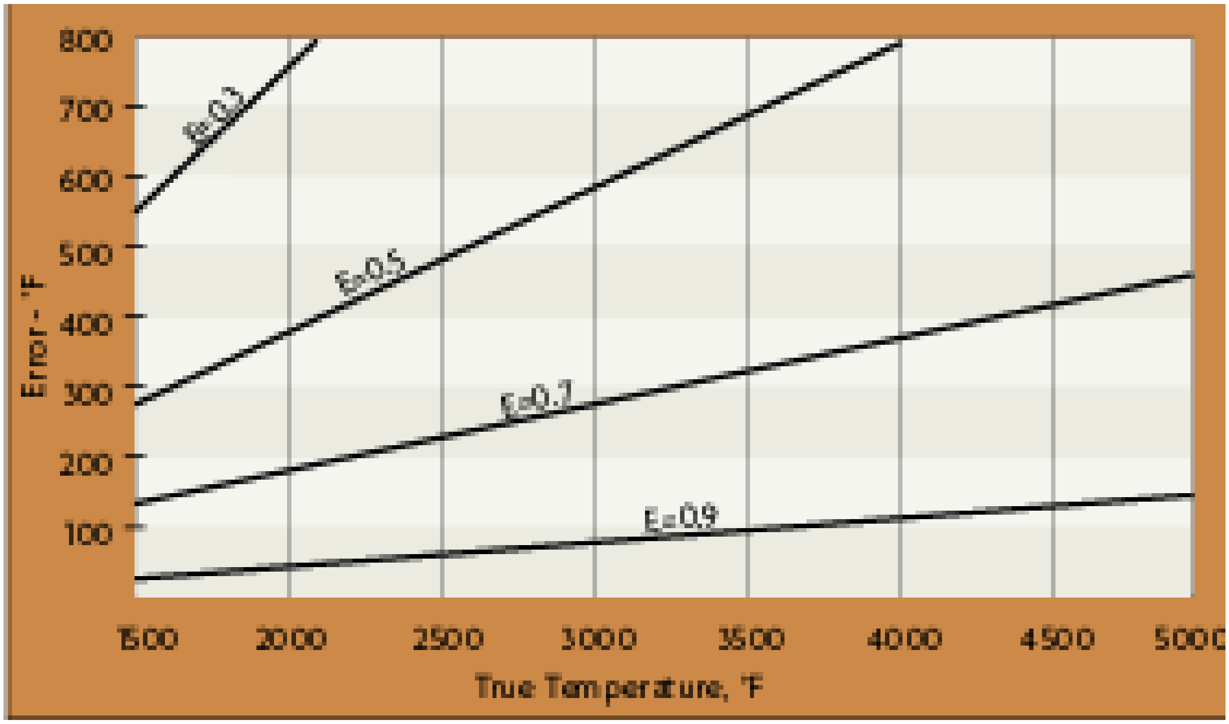
A radiation thermometer with the highest value of N (shortest possible equivalent wavelength) should be selected to obtain the least dependence on target emittance changes.

The values for the emissivities of almost all substances are known and published in reference literature. However, the emissivity determined under laboratory conditions seldom agrees with actual emittance of an object under real operating conditions. For this reason, one is likely to use published emissivity data when the values are high. As a rule of thumb, most opaque non-metallic materials have a high and stable emissivity (0.85 to 0.90). Most unoxidized, metallic materials have a low to medium emissivity value (0.2 to 0.5). Gold, silver and aluminum are exceptions, with emissivity values in the 0.02 to 0.04 range. The temperature of these metals is very difficult to measure with a radiation thermometer.

One way to determine emissivity experimentally is by comparing the radiation thermometer measurement of a target with the simultaneous measurement obtained using a thermocouple or RTD. The difference in readings is due to the emissivity, which is, of course, less than one. For temperatures up to 500°F (260°C) emissivity values can be determined experimentally by putting a piece of black masking tape on the target surface. Using a radiation pyrometer set for an emissivity of 0.95, measure the temperature of the tape surface (allowing time for it to gain thermal equilibrium). Then measure the temperature of the target surface without the tape. The difference in readings determines the actual value for the target emissivity.

In addition, if the radiation pyrometer sights through a window, emissivity correction must be provided for energy lost by reflection from the two surfaces of the window, as well as absorption in the window. For example, about 4% of radiation is reflected from glass surfaces in the infrared ranges, so the effective transmittance is 0.92. The loss through other materials can be determined from the index of refraction of the material at the wavelength of measurement.

The uncertainties concerning emittance can be reduced using short wavelength or ratio radiation thermometers. Short wavelengths, around 0.7 microns, are useful because the signal gain is high in this region. The higher response output at short wavelengths tends to swamp the effects of emittance variations. The high gain of the radiated energy also tends to swamp the absorption effects of steam, dust or water vapor in the sight path to the target. For example, setting the wavelength at such a band will cause the sensor to read within +/-5 to +/-10 degrees of absolute temperature when the material has an emissivity of 0.9 (+/-0.05). This represents about 1% to 2% accuracy.



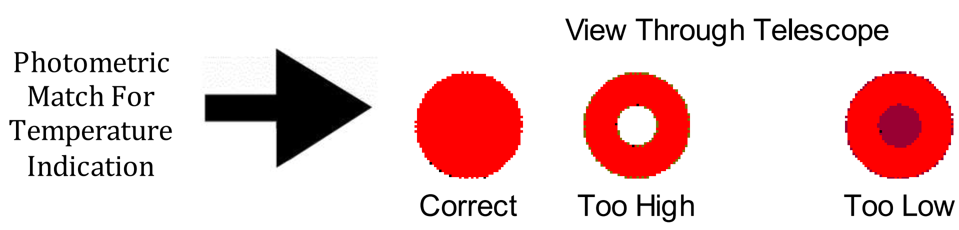
800
700
600
500
400
300
200
100
Error - °F
E=0.3
E=0.5
E=0.7
E=0.9
1500
2000
2500
3000
3500
4000
4500
5000
True Temperature, °F

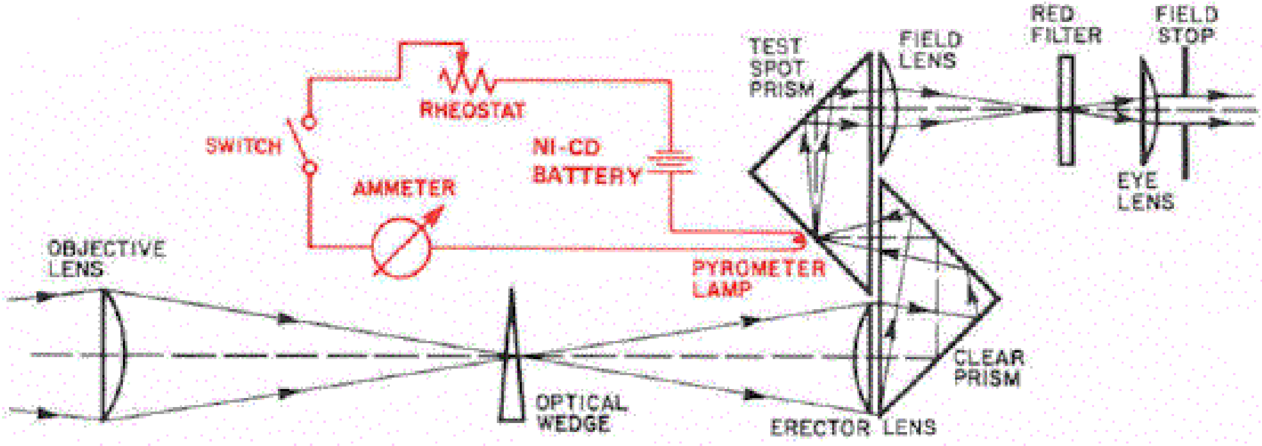
Optical Pyrometers:

Optical Pyrometers work on the basic principle of using the human eye to match the brightness of the hot object to the brightness of a calibrated lamp filament inside the instrument. The optical system contains filters that restrict the wavelength-sensitivity of the devices to a narrow wavelength band around 0.65 to 0.66 microns (the red region of the visible spectrum).

Other filters reduce the intensity so that one instrument can have a relatively wide temperature range capability. Needless to say, by restricting the wavelength response of the device to the red region of the visible, it can only be used to measure objects that are hot enough to be incandescent, or glowing. This limits the lower end of the temperature measurement range of these devices to about 700 °C. Some experimental devices have been built using light amplifiers to extend the range downwards, but the devices become quite cumbersome, fragile and expensive.

Optical pyrometer is easy to use. The operator rotates the knurled photoscreenic wedge ring on the housing of the optical pyrometer while viewing the target. A color blend is made between the internal calibrated lamp through the instruments photoscreenic wedge and the target. The temperature measurement is indicated on a direct reading scale on the housing of the instrument. The light viewed by the operator is monochromatic. Therefore, readings are not affected by individuals color sensitivity.





A typical optical pyrometer specification by PYRO

Model Number	Type	Min Target Size	Temperature Range °F	Temperature Range °C
81F or 81C	Single Range	.090" (2.2mm)	1420°F - 2500°F	770°C - 1400°C
82F or 82C	Single Range	.090" (2.2mm)	1800°F - 3400°F	1000°C - 1900°C
83F or 83C	Double Range	.055" (1.39mm)	1420°F - 2200°F	770°C - 1200°C
			1800°F - 3400°F	1000°C - 1900°C
84F or 84C	Foundry Type	.055" (1.39mm)	1800°F - 3400°F	1000°C - 1900°C
			2200°F - 3700°F	1200°C - 2000°C
85F or 85C	Triple Range	.055" (1.39mm)	1420°F - 2200°F	770°C - 1200°C
			1800°F - 3400°F	1000°C - 1900°C
			2200°F - 3700°F	1200°C - 2000°C
87F or 87C	Triple Range	.055" (1.39mm)	1420°F - 2200°F	770°C - 1200°C
			1800°F - 3400°F	1000°C - 1900°C
			3200°F - 5800°F	1800°C - 3200°C

References:

1. Wikipedia.com

2. Tempertures.com/pyro

3. A Fast-response Two-color Pyrometer (Research Papers) by Health and Safety Executive.

4. Pyrometer.com