LECTURE 37

Temperature Measurement: Radiation Pyrometry

Contents

Black Body Radiation

Radiation from real surfaces

Principles of radiation pyrometer

Total radiation pyrometer

Limitations of Radiation Pyrometer

Disappearing Filament Pyrometer

Key Words: furnaces, radiation, pyrometer

Black body radiation

A body at higher temperatures emits electromagnetic radiation. The rate at which energy is emitted depends on surface temperature and surface conditions. The thermal radiation from a body is composed of wavelengths forming an energy distribution. The total emissive power of a black body (e_b) at a particular temperature is

$$e_b = \int_0^\lambda e_{b\lambda}\, d\lambda \qquad\qquad (1)$$

In which λ is wavelength and $e_{b\lambda}$ is monochromatic emissive power. Planck's distribution law relates $e_{b\lambda}$ to the wavelength and temperature:

$$e_{b\lambda} = \frac{2\,\pi\,h\,a^2\,\lambda^{-5}}{\exp\left[\frac{ch}{K_B\,\lambda T}\right] - 1} \qquad\qquad (2)$$

In which h is Planck's constant, a is velocity of light, λ is wavelength. T is absolute temperature and K_B is Boltzmann constant.

Total emissive power of a black body is

$$e_b = \sigma\,T^4. \qquad\qquad (3)$$

In which σ is Stefan's Boltzmann constant and its value is 5.67×10^{-8} W m^{-2} K^{-4}.

Radiation from real surfaces

Black body is an idealized concept in radiation. A black body absorbs all incoming radiation and transmits none. Black body is also a perfect emitter, since it emits radiation of all wavelengths. Its total emissive power is theoretically the highest that can be achieved at any given temperature.

Thus, all real surfaces emit thermal radiations lower than black surface at any temperature such that

$$e = \epsilon \, e_b \qquad\qquad (4)$$

In which ϵ is emissivity and e is total radiation from a real surface. Obviously $\epsilon = 1$ for a black body and $\epsilon < 1$ for all a real surfaces. Thus, monochromatic emissive power of a real surface is

$$e_\lambda = \frac{2\,\epsilon\,\pi\,ha^2\,\lambda^{-5}}{\exp\left[\frac{ch}{K_B\,\lambda T}\right]-1} \qquad\qquad (5)$$

In view of the Stefan-Boltzmann equation, the total emissive power of a real surface is

$$e = \epsilon \sigma T^4 \qquad\qquad (6)$$

Qualitatively the spectral emissivity of metals decreases with increasing wavelength. For the bare metal surface, the emissivity decreases with increasing wavelength. Roughness increases emissivity.

Principles of radiation pyrometer

Temperature measurement is based on the measurement of radiation either directly by a sensor or by comparing with the radiation of a body of known temperature. The radiation pyrometer is a non contact type of temperature measurement.

The wavelength region having high intensity is between 0.1 to about 10µm. In this region, 01. to 0.4µm is the ultraviolet region, 0.4 to 0.7 is the visible region and 0.7 onwards is the infrared region. With the increase in temperature, radiation intensity is stronger toward shorter wavelengths. The temperature measurement by radiation pyrometer is limited within 0.5 to 8µm wave length region.

Total radiation pyrometer

A radiation pyrometer consists of optical component to collect the radiation energy emitted by the object, a radiation detector that converts radiant energy into an electrical signal, and an indicator to read the measurements.
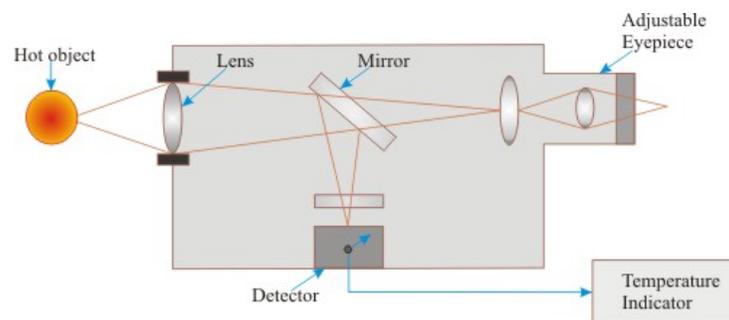
The optical pyrometer is designed to respond narrow band of wavelengths that fall within the visible range of the electro-magnetic spectrum.

Thermal detectors are used as sensors. Their hot junction is the radiation sensing surface. Thermopiles can detect radiation of all wavelengths.

A number of semiconductors are developed to sense the radiation. These are materials of Si, PbS, indium antimonides etc. Their response is though instantaneous but it is selective to wavelength.

Silicon is suitable only around $0.8 - 0.9$ μm and lead sulphide around 1 to 2μm.

It is important that gases like CO_2, H_2O and dust should not obstruct the path of radiation. The dust particles scatter the radiation, whereas CO_2 and water vapor selectivity absorbs radiation.

Any instrument built to sense the radiation has to be in an enclosure to avoid dirt, dust and gases present in industrial environment. Normally a window is provided with some optical materials to see the radiating body. The materials should have good transmissivity. All optical materials allow only particular wavelength to pass through it with sufficient intensity. For other wavelengths they are opaque.

Material for windows	Transmissivity
Glasses like quartz, Pyrex, ruby etc.	Good in ultraviolet and visible region of wavelength but are opaque to infrared. Glass windows are useful for wavelengths lower than 2.5μm. Beyond wavelength of 2.5μm , transmissivity decreases drastically.
Barium fluoride and zinc sulphide	They have $60 - 80\%$ transmissivity in the infrared and visible region.
Calcium fluoride	It has a very good transmissivity in visible and infrared region.

**Limitations of Radiation Pyrometer**

1. Availability of optical materials limit on the wavelengths that can be measured.
2. The surface of the hot object should be clean. It should not be oxidized. Scale formation does not allow to measure radiation accurately.
3. Emissivity correction is required. Change in emissivity with temperature need to be considered.

Disappearing Filament Pyrometer

In this type of pyrometer, the tungsten filament of an electric bulb is used as a radiator. The intensity of radiation of filament is compared with the intensity of the radiation of the hot surface. When both intensity match, the filament disappears against the back ground.

The intensity of the filament can be controlled by the current flowing through it. The maximum temperature of the filament is $2800 - 3000°C$ at the rated voltage. The minimum visible radiation is at $600°C$. Hence we can measure the temperature in between $600 - 2800°C$.

The ampere meter in the lamp circuit is calibrated is degree centigrade
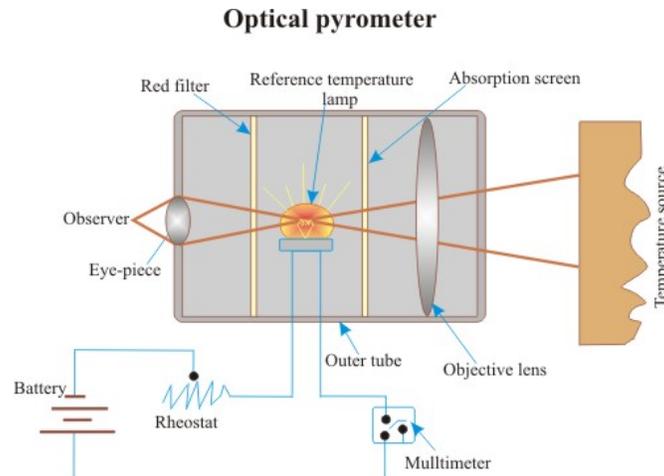
Optical pyrometer

Figure 37.2: Disappearing Filament Pyrometer

Figure shows an optical pyrometer. The radiations from the source are focused onto the filament of the reference temperature using an objective lens. Now the eye piece is adjusted to focus the images the hot source and the filament. Now the lamp current is controlled such that filament appears dark if it is cooler than the source, the filament will appear bright if it is hotter than source and filament will not be seen if the filament and the temperature source are at same temperature.