Accurate Sensor Technologies

MEASURING ACCURATE
TEMPERATURE IN
EXTREME CONDITION

PYROMETER HANDBOOK

GLOBAL APPROVAL, GLOBAL SOLUTION, GLOBAL SUPPORT

Contents

1. Basic concepts

What we see with our eyes is only the small part (visible region) of a broad spectrum of electromagnetic radiation. On the immediate high energy side of the visible spectrum lies the ultraviolet, and on the low energy side is the infrared (IR) (see Fig. 1). This invisible portion of light carries various supplementary information.

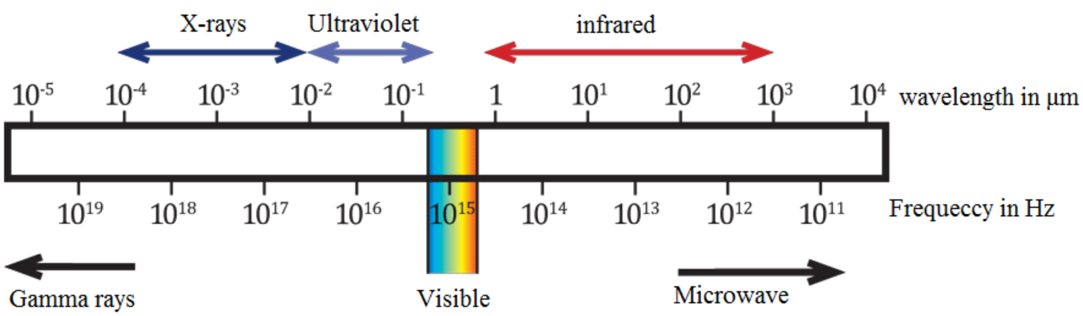


Fig. 1 Electromagnetic spectrum

The IR region can be divided into three different categories: near-IR (NIR/Short wave), mid-IR radiation (MIR/Medium wave) and far-IR radiation (FIR / Long wave). Also, this region is responsible for the heating effect of the sun. Understanding the physical basics like blackbody, Planck, Stefan, Boltzmann, Wien and Kirchhoff laws, etc. is crucial before proceeding to the next section.

Table 1:

Regions	**Wavelength (µm)**
Near Infrared (NIR)	0.78 – 3
Mid Infrared (MIR)	3 - 50
Far Infrared (FIR)	50 - 1000

1.1 Black body

A black body is a hypothetical object that absorbs the entire radiation incident upon it. Such body doesn't reflect any radiation and appears perfectly black. The perfect black body is the most efficient thermal absorber and emitter because any object at thermal equilibrium will emit the same amount of light as it absorbs at every wavelength. The radiation spectrum of a black body is determined only by the temperature and not by the properties, material and structure. These features, as an ideal source to emit or absorb radiation make the black body valuable for many applications. For an ideal black body absorbtivity and emissivity is one.

1.2 Gray body

The body which emits less thermal radiation than a perfect blackbody or its surface emissivity (ε) is less than one but is constant over all frequencies. It's a useful approximation to some real world materials over some frequency ranges. The spectral emission of gray body is shown in Fig. 2.

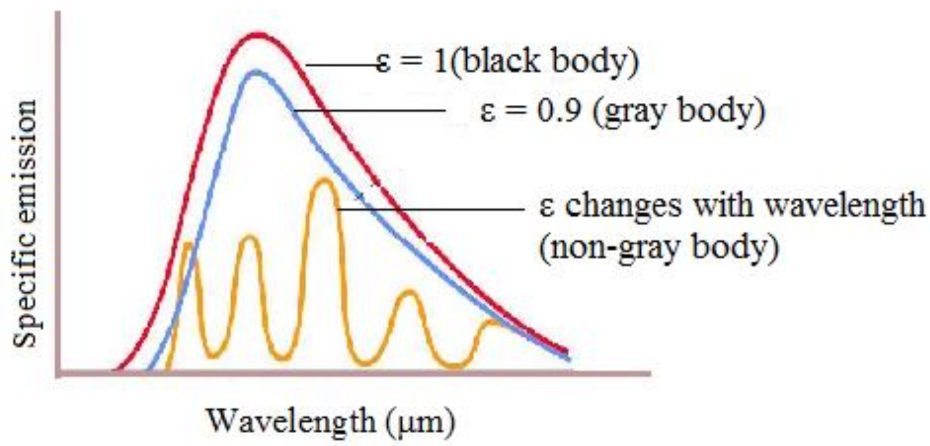


Fig. 2. Specific Emission of Gray body

1.3 Black body to real objects

A perfect blackbody is only a physical abstraction which does not exist in real world. Each body radiates electromagnetic radiation at a temperature above zero (-273.15°C = 0 K). This radiation is nothing but the body's thermal energy which is being converted into electromagnetic energy and therefore termed as thermal radiation. Real materials show slightly different behaviour as compared to an ideal black body. The radiative properties of the real objects always deviate from those of an ideal blackbody. The radiation incident on the real body may undergo following physical phenomenon like reflection, absorption and transmission (permeability) (see Fig. 3.).

(a) Absorptivity (α)

The fraction of the irradiation absorbed by a surface is called the absorptivity of a material. It can be characterized by both a directional and spectral distribution. It is understood that surfaces may exhibit selective absorption with respect to wavelength and direction of the incident radiation. However, for most engineering applications, it is desirable to work with surface properties that represent directional averages.

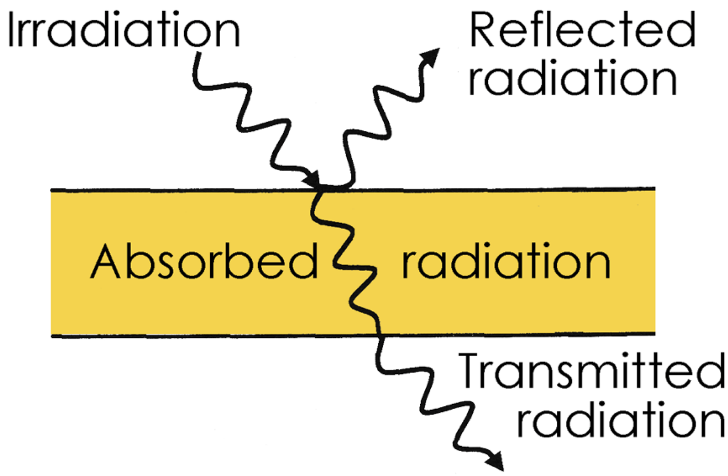


Fig. 3. Annihilation of radiation in real type materials

(b) Reflectivity (ρ)

The reflectivity of a surface describes the fraction of incident radiation reflected by a surface. If the intensity of the reflected radiation is independent of the direction of the incident radiation and the direction of the reflected radiation, the surface is said to be diffuse emitter. In contrast, if the incident angle is equivalent to the reflected angle, the surface is a specular reflector. Although no surface is perfectly diffuse or specular, specular behavior can be approximated by polished or mirror-like surfaces. Diffuse behavior is closely approximated by rough surfaces and is likely to be encountered in industrial applications.

(c) Transmissivity (τ)

The remaining part of the radiation is transmitted out and the amount of radiation transmitted through a surface is transmissivity. This process too may be selective depending on the nature of the material and the incident radiation.

(d) Emissivity (ε)

Emissivity is the ratio of energy radiated from an object to the exterior and energy radiate from blackbody. The emissivity varies with the surface condition of the object and also with temperature variation and wavelength. If this value is not accurate, then the true temperature cannot be measured. In other words, a variation or change in emissivity will cause a change in the indications.

By the Kirchhoff's law of thermal radiation "***At thermal equilibrium, the emissivity (ε) of a body (or surface) equals its absorptivity (α)***". So, for a perfect black body ,ε is 1 while any real object would have ε less than 1. Also the transmissivity (τ) and reflectivity (ρ) is zero. The sum of absorptivity, reflectivity and transmissivity is always 1.

$\alpha + \rho + \tau = 1.$

By the emissivity factor materials can be categorized as:

- Metals
- Non-metals
- Transparent material

(Refer section 3 for detailed description)

1.4 Radiation principles governing the black body

The average or bulk properties of electromagnetic radiation interacting with matter are systematized in a simple set of rules called ***radiation laws***. These laws are applied when the radiating body is a ***blackbody radiator***. Usually, blackbody conditions apply when the body (radiator) has very weak interaction with the surrounding environment and the state of equilibrium is considered. Some of these laws are discussed below:

Planck's law: Planck's law states that the intensity of electromagnetic radiation emitted by a blackbody is a function of frequency (or wavelength). Black body will radiate energy at all frequencies. The Planck's law gives a distribution that peaks at a certain wavelength, the peak shifts to shorter wavelengths for higher temperatures, and the area under the curve raise rapidly with increasing temperature (see Fig. 4.).

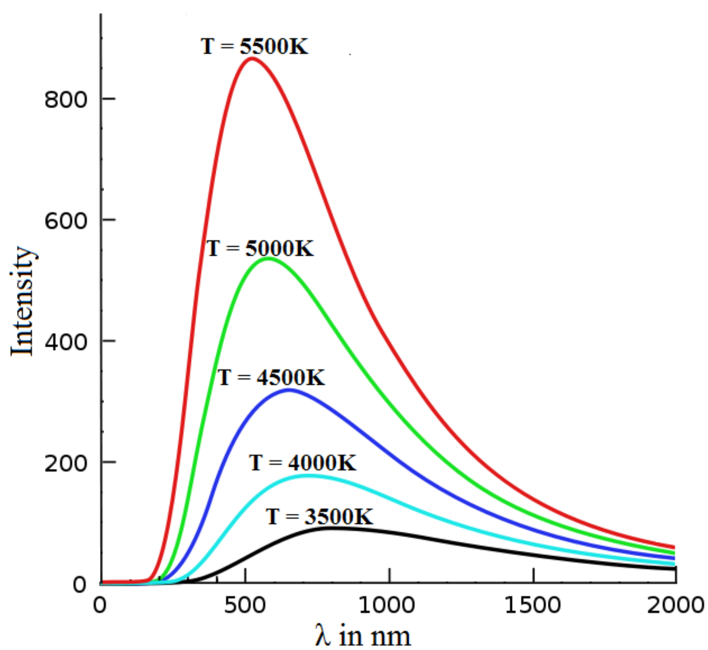


Fig. 4. Blackbody spectrum

Wien's displacement and Stefan' Boltzmann law: *Wien's displacement law* states that the wavelength at which the blackbody emission spectrum varies inversely with the blackbody's temperature or we can say hotter an object is, the shorter the wavelength at which it will emit most of the radiation. *Stefan' Boltzmann law* states that the total energy radiated per unit surface area of a black body per unit time is inversely proportional to the fourth power of the temperature of the black body.

The *Wien law* provides the wavelength of the peak of the radiation distribution, whereas the *Stefan-Boltzmann law* gives the total energy emitted by the blackbody at all wavelengths (i.e., the area under the curve of Planck Law (see Fig. 4)).

Also, the *Wien law* gives explanation to the peak shift to shorter wavelengths with increase in temperature, whilst the *Stefan-Boltzmann law* explains the growth in the height of the curve with increase in temperature. Both these radiation law can be derived from the Plank's law.

2. Pyrometry

A pyrometer is a non-contacting device that intercepts and measures thermal radiation, without making any contact with the radiating body and the process is known as pyrometry. This device is useful for determining the temperature of an object's surface.
Pyrometer is derived from the Greek root '*pyro'* which means fire. The term pyrometer means a device capable of measuring temperatures of objects above incandescence. Early pyrometers (Filament Pyrometer 1917) were restricted to visual measuring method only (i.e., the object becomes red hot, it starts emitting radiation). So, only high temperature measurement is possible with early pyrometers. But now days such pyrometers are also available that can measure temperatures far below the freezing point from a distance and without making contact with the object to be measured.
Temperature is the most frequently measured physical quantity which predicts the condition of a product or part of apparatus, both in manufacturing and in quality control.
Pyrometer strictly works on the principles of black body radiation. Here emissivity of the target plays an important role, as it governs how bright the target appears to the pyrometer. Due to its high accuracy, speed, economy and specific advantages, it is widely being used as a standard procedure in many industrial applications.
There are some critical considerations which have to be included for any infrared pyrometer like emissivity field of view (size of the target and distance), spectral response and temperature range and mounting. Some of the advantages of noncontact pyrometry are discussed below:

- It records temperature within fractions of seconds (fast response time).
- It does not influence the temperature and material of the target.
- Requires less maintenance and hence the longer life time.
- It can measure the temperature of the moving object.
- Measurements can be taken for hazardous or physically inaccessible objects (e.g. high-voltage parts and great measurement distance).
- As it is not in direct contact with target so high temperature can be measured.
- Being noncontact technique, it will not tamper the target mechanically.

3. Choosing the spectral range

As discussed earlier, emission coefficient plays a major role for temperature measurement by pyrometers. So it is mandatory to establish accurate emission coefficient for a given material or target.

Metals

The emissivity of metal strongly gets influenced by the wavelength and temperature. For lustrous (smooth) metal surfaces, emissivity is high at short wavelengths and decreases with increasing wavelengths. Moreover wear and tear, oxidation or soiling, rust, etc may also affect the emissivity of metals. So, it is essential to select an instrument which measures the infrared radiation at a particular wavelength and within a particular temperature range at which the metals have the highest possible emissivity.

The optimal wavelength for high temperatures in the case of metals is, at around 0.8 to 1.0 µm, at the limit to the visible range. Wavelengths of 1.6, 2.2, and 3.9 µm are also possible. Good results can be achieved using ratio pyrometers in cases (e.g. heating processes) where measurement is to take place across a relatively wide temperature range and the emissivity changes with the temperature.

Plastics

The transmittance of a plastic altered with the wavelength and thickness of the material. So optimal temperature measurement is accomplished with the wavelengths where the transmittance is almost zero. Polyethylene, polypropylene, nylon and polystyrene are some of the plastics which are non-transmissive at 3.43µm while polyester, polyurethane, Teflon FEP, and polyamide non-transmissive at 7.9µm. The optimal spectral bandwidth for measurement can be determined by the manufacture of the infrared device.

Glass

For temperature measurement of the glass with an infrared thermometer, reflectance together with the transmittance has to be considered. Only a careful selection of the wavelength facilitates measurements of the glass surface as well as of the deeper layers of the glass. For measuring deeper layers wavelengths of 1.0µm, 2.2µm or 3.9µm are appropriate while for surface measurements 5µm is recommended. At low temperatures, 8.14 µm should be used with the emissivity set to 0.85, to compensate for reflectance. As glass is a bad heat conductor can change its surface temperature quickly, so a thermometer with short response time is recommended.

Bright flames

To measure the temperature of flames is really a tough job. For exact measurement of temperature of flames, only the radiation coming from the glowing soot or other burning particles should reach the pyrometer. This can be done by flame pyrometers by adjusting the soot factor “n” on the pyrometer.

Non-luminous flames

To measure the temperature of non-luminous flames (e.g. gas burners) spectral pyrometers can be used. This pyrometer measure the radiation of hot carbon dioxide in a very narrow spectral area (4.5 and 4.65 µm).

Ambient conditions

The transmission behavior of the transmission path (usually the ambient air) should also be considered before setting any IR thermometer (spectral radiation pyrometer). There are certain components in the atmosphere (like vapor, carbon dioxide, etc.) which absorb infrared radiations at particular wavelengths due to which transmission is attenuated. So for accurate temperature measurements, these absorption media should be taken in account. There are '*windows'* in the infrared spectrum which do not contain these absorption bands (see Fig. 5). Typical measuring windows are 1.1-1.7 µm, 2 - 2.5 µm, 3.5 µm and 8.14 µm. So the infrared measuring device has to be designed with proper atmospheric correction filters. In Table 2, the various atmospheric windows are listed for different compounds.

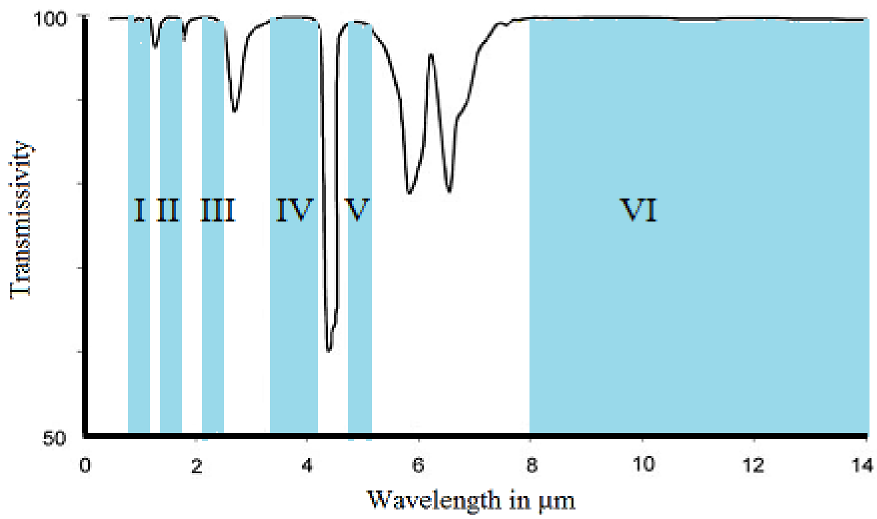


Fig. 5 Atmospheric windows and transmission of air

Table 2.

Type of detector (material)	**Window**
Silicon	I
Germanium Indium-Gallium-Arsenide	II
Lead sulphide	III
Lead selenide Thermopile Pyroelectric Detector	IV
Thermopile Pyroelectric Detector	V
Thermopile Pyroelectric Detector	VI

4. Methods for determining the emissivity

There are several ways to determine the emissivity of the material to ensure accurate temperature measurements, some of which are discussed below:

1. The temperature of the object is first determined (measured) with a contact thermometer. Then aim the pyrometer to the object. Now adjust the emissivity knob until the same temperature is achieved in both the devices. This method can only be applied for sufficiently large and accessible objects.
2. Coat the material or the portion of it with a special polish (coating) whose) whose emissivity approximately equals to 1, accurately known and is stable up to the temperature to be measured. When pyrometer is aimed to the object it first measures the temperature of the coated surface and then it measures the untouched part of the surface. Simultaneously, adjust the emissivity so as to force the indicator to display the correct temperature.
3. For measuring high temperatures, a hole can be drilled (drilling depth should be ≤ ⅓) to the object which acts a blackbody with emissivity of 1.0. The temperature of the drill hole is measured first, then the pyrometer measure surface temperature. Now emissivity is so adjusted such that the correct temperature of the material is displayed on the indicator.
4. The emissivity of a sample object can be determined by spectrometer analysis.
5. Standardized emissivity values for most materials are available. These can be entered into the instrument to estimate the material's emissivity value.

5. Basic Design, construction and operation of pyrometer

This section describes the basic construction of a pyrometer and its functioning. Pyrometer is any temperature-measuring device that includes a sensor and a read out. An optical system gathers the visible and infrared energy from an object and focuses it to the detector. The detector receives the photon energy from the optical system and converts it to an electric signal to drive a temperature display or control unit. The block diagram of infrared thermometer is shown in Fig. 6.
Infrared thermometers have various configurations and designs, which differ in optics, electronics, technology, size and housing. However, the method of signal processing is same (i.e., it always starts with an infrared signal and ends with an electronic temperature output signal). The working mechanism of the pyrometer is shown in the flow chart (see Fig. 7).

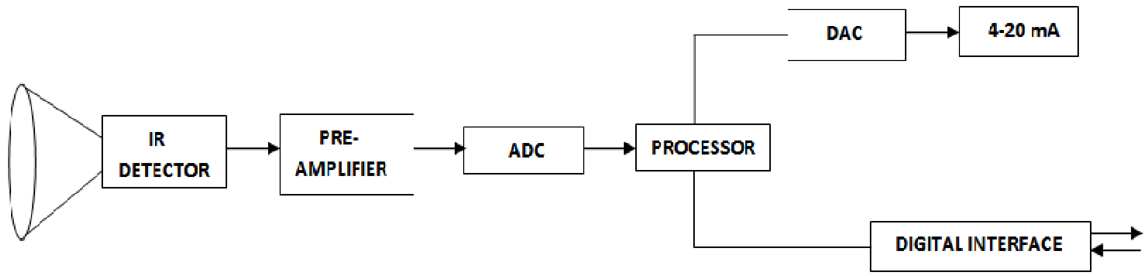


Fig. 6 Block Diagram of Infrared thermometer

5.1 Optical system, protection windows, spot size and measuring distance

The detector and optical system are the major components in the pyrometer. So, they should be carefully selected to yield the optimum compromise based upon the conflicting parameters of price, accuracy, speed of response, and usable temperature range.

Optical system and protection windows

An optical system mostly consists of windows, lenses and filters. A lens system can be used for particular wavelength ranges due to their material wavelength ranges. Usually for fixed focus optical instruments mirror system is used while for varying the focus instrument requires moving parts, which is less complicated in a lens system. So lens system is preferably used.

The characteristics (transmission values) of the lens, filters and protection window material should be in accordance with spectral sensitivity of the sensor. At high temperatures quartz glass is commonly used. At low temperatures (in the range 8.14 µm) special IR transmissive materials (i.e., Ge and ZnSe) are required.

With the help of filters the transmission properties can be modified so that the unwanted wavelengths can be prevented from reaching the detector. They are placed in front of the detectors.

Spot size and measuring distance

The optics of a pyrometer transmits the image of a section of the target area of the measured surface to the detector. The common law of optics used in photography is that as the distance between the camera and the target increases. So the distance between the camera and the target should be considered explicitly. The dimensions of the measured object determine the required spot size of the pyrometer. So the target size should be larger than the detector spot (spot size).The distance ratio describes the size of the measuring spot at a certain distance. Also, the ratio of the distance of the measuring device from the target, and the diameter of the spot (D:S) describes the optical resolution. Better the optical resolution of the pyrometer smaller the target can be. To avoid errors in the measurements, the spot size should completely fill the object otherwise the sensor will read the other temperature radiation from the background.

Sighting techniques
There are several techniques for the adjustment of pyrometer which assist in capturing precise radiated temperature from the target. Some of them are described below:

Trough the lens sighting technique: In this technique, user looks at the object in the similar way as he looks through the camera. The centre of the viewing area is indicated by some marks which is the target area. Here user is in direct contact with radiations, so some filters are fitted inside for the protection of eyes.

Pilot lights/Laser-pointer: Halogen lamp, LED, or laser can be used as Pilot lights. The light beam facilitates the user to aim at the measuring spot more quickly and precisely, and hence accurate temperature can be measured in darkness.

5.2 Detectors

Detectors play the vital role in any pyrometer. They are the radiation receivers which converts the received infrared radiation into electrical signals. These electrical signals are converted then displayed as temperature values by the electronic system. Detectors may be classified into two different categories viz. thermal detectors and quantum detectors. The behavior of thermal detectors is similar to any thermocouple. When the photons interact with the sensitive element in the thermal detectors the temperature of this element get varied which in turn modifies the property of the detector. This modification is then electrically analysed which similar to the voltage generated in any thermocouple
Quantum detectors works on the principle of photoelectric effect. They interact directly with the impacting photons. So they are also known as photodiodes. Quantum detectors are faster than thermal detectors. They are mainly used for imaging systems and line scanners. The performance of these detectors is strongly affected by the variation of ambient temperature. This ambient drift should be compensated for high accuracy measurements.

5.3 Electronics

The function of the electronics of the infrared thermometer radiation is to amplify, regulate, linearise and convert the signal from the detector to an electric signal (mV or mA) which is proportional to temperature. The output of the pyrometers can be viewed with analog and digital devices.

Analog devices
In portable thermometers measured temperature (signal) is displayed on the LCD. However, high precision LED indicator for non contact temperature measurement is also being used. With indication of measured temperature user can easily parameterize a connected digital pyrometer without any PC.

Digital devices
By connecting the pyrometer output to some suitable software (via PC) the digital output can be obtained. The pyrometer can communicate with PC using RS232 or RS485. RS 232 is used only for short distances including electromagnetic interferences which affect the transmission. RS485 is well suited for long distance transmission. Standard on PC is RS232, so a converter is used which converts RS485 to RS232.
Thermographic solutions are completed with software for the online video display and recording of fast thermodynamic processes with manifold tools for picture analysis. Comfortable transfer and management of data from the infrared pyrometer as well as subsequent analysis of the data support the processing of the temperature results. Some of the functions available in the software are discussed below:

- **Target emissivity:** It can set the emissivity of the target.

- **Peak picker:** It locates the maximum temperature of the target temperature value from specified number of stored real temperatures in the sensor memory. Once the peak temperature is determined, its value will be transmitted constantly even at out of range condition till a new picker process finishes.

- **Switch off Level:** Ratio pyrometer shows true temperature even when the target is partially visible. The user can adjust this value, so when temperature of object is below this limit, the pyrometer will stop temperature measurement.

- **Response Time:** This function is used to set the response time of the pyrometer. It is adjustable from 20 ms to10 seconds.

- **Record View:** This option provides data logging. The temperature and Emissivity read by both the pyrometer with time and date is displayed.

- **Spot size calculation:** It calculates the spot size or Actual working Distance of the Pyrometer. This option in the software is capable of calculating the spot size for real working distance corresponding to the value of ***actual working distance*.**

- **Analog scale:** User can select the sub-range with in the basic range of Pyrometer. Analog output will automatically adjust to the selected range.

- **Change sensor type:** This parameter display pyrometer sensor type and user can also change two colour sensors to single and vice versa within the same software.

5.4 Calibration

To achieve a reasonable level of accuracy, new pyrometers should be properly calibrated. Initial calibration is likely to be performed by the manufacturers. But for the most qualitative measurements periodic recalibration is required. There are three different methods of calibration which are:

Method I

A commercial blackbody simulator which is an isothermally heated cavity having very small aperture can be used as calibrator. The depth of this cavity should be at least six times as long as its diameter and the temperature of this cavity is controlled by a temperature controller (using a thermocouple probe). The emissivity of a cavity type blackbody source is usually 0.98 or higher which makes them ideal for exact calibration tasks.

Method I:

Calibrated tungsten filament lamps are commonly used as references at higher temperatures.

Method III

A last option is to use a reference pyrometer whose calibration is known to be accurate. Adjust the output of the pyrometer until it matches the value of reference pyrometer.

6. Sources of interference

Other than the emissivity factor there are several other interference sources which hinder the accuracy of measurements. Some of these factors are discussed below:

- Additional heat source present in the surroundings of the measuring object (e.g. measuring temperatures of metals in industrial ovens, where the oven walls are hotter than the measuring object) strongly influence the measurements. This additional heat may get reflected off by the target and actual temperature may get affected.

- If the target is transparent and there is some hot body behind it then the target will let the additional heat pass through modifying the original temperature.

- The presence of dust, water vapor, smoke, and window also reduce the strength of the infrared radiations.

7. Pyrometer types

Generally pyrometers can be classified in two categories which are:

- Broadband pyrometers
- Narrow band pyrometers

Note: This is not a rigid classification. For an instance, optical pyrometers can be considered a subset of narrow band devices. Fiber optic pyrometers can be classified as wide band, narrow band, or ratio devices.

Broadband pyrometers

Broadband pyrometers are simplest and less expensive device which have the response from 0.3 microns wavelength to an upper limit of 2.5 to 20 microns. The name itself indicates that these pyrometers measure a significant fraction of the thermal radiation emitted by the object. They greatly rely on the emissivity of the surface being measured.

The path to the target must be clear from water vapor, dust, smoke, steam and radiation absorptive gases present in the atmosphere, as these can attenuate emitted radiation from the target resulting in inaccurate measurements. Also, the optical system and sighting window should be clean. High and constant emissivity at longer wavelengths makes these pyrometers suitable for measuring temperature of organic materials.

Narrow band pyrometers

There are several other categories in narrow band pyrometers which are as follows:

- Single color pyrometers
- Ratio type pyrometers (two colour pyrometers)
- Multi wavelength pyrometer

Single color pyrometers

These pyrometers operate over a narrow range of wavelengths. They are also called as single color pyrometers. The spectral response of these pyrometers is usually less than 1 micron. They are normally used for measuring glass at 5.14 μm. Metals can also be measured as their rate of emissivity is high only in a narrow band. The spectral response of the particular device depends on the type of the detector used. For an instance, the response of a pyrometer with a silicon cell detector is around 0.9 - 1.1 microns. These pyrometers are can work on selected wavelength range with the help of filters. But for this more sensitive detectors and advances in signal amplifiers are required.

Ratio radiation pyrometers (two colour pyrometers)

This pyrometer measures the radiated energy of an object between two narrow wavelength bands and then calculates the ratio of the two energies. This ratio is the function of the temperature of the object. This is also called as two colour pyrometer because the two wavelengths corresponded to different colors in the visible spectrum. Even if the object does not fully cover the spot the output signal will not change. Also the temperature measurement is independent of emissivity, so the errors caused by the emissivity variation, surface finish, and energy absorbing materials (e.g. smoke, smog, water vapor, etc.) between the pyrometer and the target can be minimized or removed (see Fig. 8). It is used for measuring high temperature (e.g. molten metal).

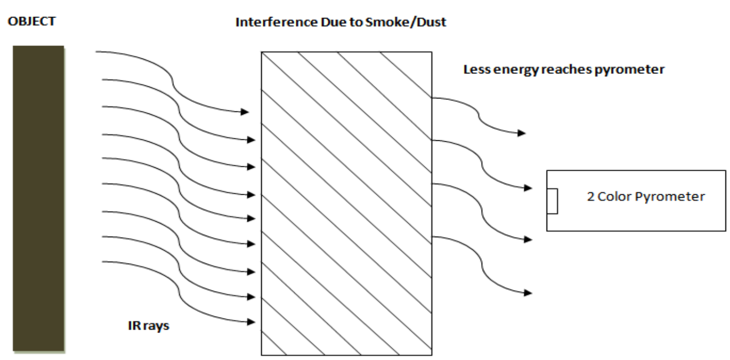


Fig. 8. Working of 2 color pyrometer

Multi wavelength pyrometers

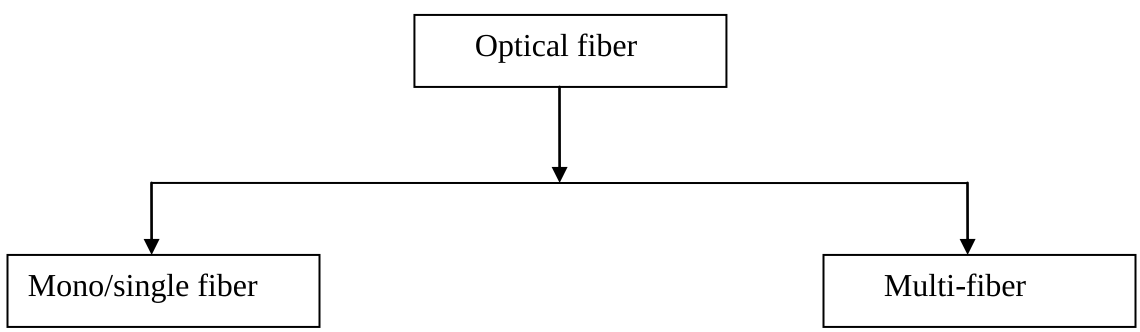
This type of pyrometer is capable of measuring more than two wavelengths. They are also called spectropyrometers. Here instrument compares all the measured values and then decides where the accurate temperature lies.

Fiber optic radiation pyrometers

Optical pyrometers can be considered a subset of narrow band devices. Fiber optic pyrometers can be classified as wide band, narrow band, or ratio devices. These devices use an optical fiber (light guide) to direct the radiation to the detector (see Fig. 9). The spectral response of these fibers is extended to about 2 microns so it is useful in measuring object temperatures to as low 100°C. An optical head, a glass fiber and a signal processing unit together forms a fiber optic pyrometer. The optical head doesn't contain any electronics. It is basically used where the sighting path to the target is not clear (pressure chamber). Some inherent advantages of fiber optics over other pyrometers are:

1. They are unaffected by strong electromagnetic fields therefore can be easily used where such type of interference fields are present.
2. It can be placed in hard-to-reach fields.
3. As it does not carry any electrical current, so it is ideal for explosive and hazardous locations.
4. Optical head and the fiber are free from any electronic components so cooling is not required and hence can be used to measure high temperatures (near about 250 °C). However pyrometer unit requires cooling.
5. The diameter of a optical fiber is small therefore the small spot size can be obtained.

In an optical fiber the captured radiation is transmitted by total internal reflection. The inner layer is called core and outer layer is cladding. Therefore signal can be transmitted without any loss. Optical fiber consists either of a single fiber (mono-fiber) or multi-fiber.



The comparison between a single fiber and multi-fiber is given below:

- Breakage in the mono fiber can be immediately detected than in multi fiber.
- No wear and tear is required for mono fiber but in multi fiber the cladding of individual fiber may get damaged due to friction amongst them.
- Multi fiber optical fiber is relatively less expensive and also their minimum curving radius makes them useful in many applications.

Fig. 9. A fiber optic pyrometer

8. Accessories

Pyrometers are available with a various features and accessories to solve a wide range of application conditions. Here we have listed some of those mechanical and electrical/electronic accessories.

Mechanical accessories:

1. ***Cooling accessories***: Facilitate the pyrometer to be operated at higher surrounding temperature and maintains internal temperature of electronics in the pyrometer.
    - Radiation shield
    - Cooling plate
    - Cooling jacket
2. ***Mounting devices***: Used to fix pyrometer in a particular position.
    - Angle brackets
    - Adjustable positioning devices
3. ***Flange systems***: Used to append the pyrometers to the furnaces, containers or pipes.
    - Mounting tube
    - Lamination slide

- Ball and socket mounting

4. ***Sighting accessories***: It is very helpful to sight on the spot size for the measurement of moving objects and in poor light conditions.

    - Sight tubes
    - Laser pointing devices
    - Scopes

5. ***Air purge units***: It is attached to front end of sensor which protects the optics of the pyrometer from dust, smoke, moisture and other contaminations. It is in the form of round nozzle which and provides positive air pressure in front of the lens.

6. ***Emissivity enhancer***: It is used for shiny and highly reflective metal surfaces having very low emisivity at low temperatures. It is a gold plated concave mirror, which is mounted close to the measuring object. The incident radiation undergoes multiple internal reflections between the measuring object and the emissivity enhancer due to which the energy of infrared energy is mechanically increased. This mechanically increased energy is measured by the pyrometer through a small hole in the concave mirror which improves the results of temperature measurements.

7. ***Scanners***: Scanners are used to move the spot size back and forth across the target to be measured. It is used to measure the temperature of moving objects. Maximum value storage unit is always used with scanners. Scanners can be in-built or attached to the front of the optics of the pyrometer which assists them to be used as line scanners.

Electrical/electronic accessories:

1. ***Indicators and controller***: This unit displays the measured signal as temperature (°F or °C). They are available from a simple digital panel meter to complex multi-channel processors.
2. ***Analoge Converters***: Converts the output signal of 2-wire equipment from 4 to 20 mA into 0 to 20 mA.

3. ***Digital converters***: Converts a RS 485 signal into a RS 232 signal.

4. ***Gateways***: permits the conversion of RS 485 signals to several bus systems.

5. ***Calibrators***: These are used to check the precision of the pyrometers.

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