Infrared Thermometry

Understanding and using the Infrared Thermometer

Advances in electronic and detector technology have resulted in a variety of non-contact infrared thermometers (IR) for industrial and scientific use. It is important to understand their major differences in order to select the proper unit for a given application.

Infrared Theory

Energy is emitted by all objects having a temperature greater than absolute zero. This energy increases as the object gets hotter, permitting measurement of temperature by measurement of the emitted energy, particularly the radiation in the infrared portion of the spectrum of emitted radiation. Figure 1 shows a typical infrared radiation thermometer.

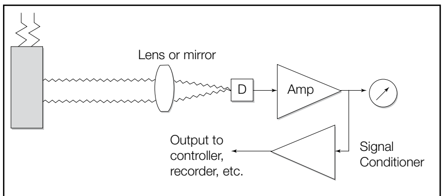


Figure 1: Block diagram, infrared pyrometer

Electromagnetic Spectrum

Infrared radiation is part of the electromagnetic spectrum which includes radio waves, microwaves, visible light, ultraviolet, gamma- and X-rays (Figure 2). These various forms of energy are categorised by frequency or wavelength.* Note that visible light extends from .4 to .7 micron, with ultraviolet (UV) shorter than .4 micron, and infrared longer than .7 micron, extending to several hundred microns. In practice, the .5 to 20 micron band is used for IR temperature measurement.

Planck's Law

The amplitude (intensity) of radiated energy can be plotted as a function of wavelength, based on Planck's law. Figure 3 shows the radiation emission curves for objects at two different temperatures. By convention, longer wavelengths are shown to the right on IR graphs, reverse of electromagnetic spectrum charts, such as Figure 2. The area under each curve represents the total energy radiated at the associated temperature.

Note that two changes occur simultaneously as temperature is increased: (1) the amplitude of the curve increases, increasing the area (energy) beneath it, and (2) the wavelength associated with the peak energy (highest point of the curve) shifts to the shorter wavelength end of the scale.

This relationship is described by Wien's Displacement Law:

$$\lambda_{max} = 2.89 \times 10^3/T$$

where λ_{max} = wavelength of peak energy in microns

T = temperature in degrees Kelvin

For example, the wavelength for peak energy emitted from an object at 2617 degrees Celsius (2890 degrees Kelvin) is:

$$\lambda_{max} = 2.89 \times 10^3/2890K = 1.0\ \mu m$$

Another illustration involves heating a steel billet. At about 600°C (1100°F), a dull, red glow is emitted from the steel. As the temperature increases, the colour changes from red to orange and yellow as the peak passes into the visible light spectrum. Finally, the energy emitted throughout the entire visible spectrum is at such a high level that white light is given off by the steel at about 1650°C. Because the peak of the curve shifts as temperature increases, selection of the optimum portion of the spectrum is important to achieving satisfactory infrared thermometer performance.

Emissivity

Emissivity is defined as the ratio of the energy radiated by an object at a given temperature to the energy emitted by a perfect radiator, or blackbody, at the same temperature. The emissivity of a blackbody is 1.0. All values of emissivity fall between 0.0 and 1.0.

Emissivity (E), a major but not uncontrollable factor in IR temperature measurement, cannot be ignored. Related to emissivity are reflectivity (R), a measure of an object's ability to reflect infrared energy, and transmissivity (T), a measure of an object's ability to pass or transmit IR energy. Since all radiation must be either transmitted, reflected or absorbed:

$$A + R + T = 1.0$$

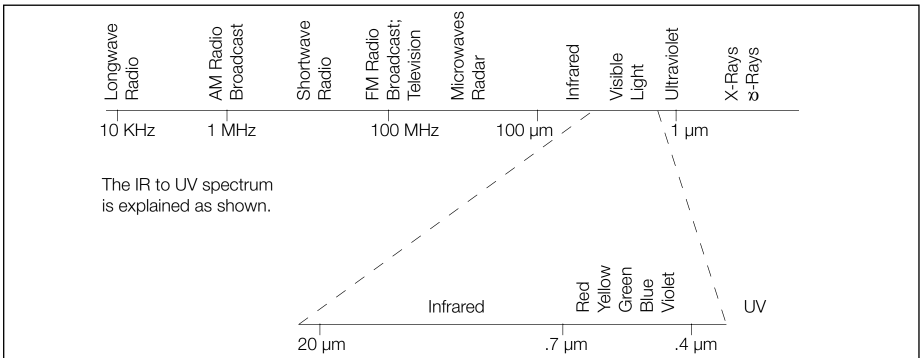


Figure 2: Electromagnetic spectrum and light spectrum

*Wavelength (λ) is inversely related to frequency (f): $\lambda = c/f$, where c = velocity of the wave; λ is measured in microns (μm); 1 μm = 10^{-6}m.

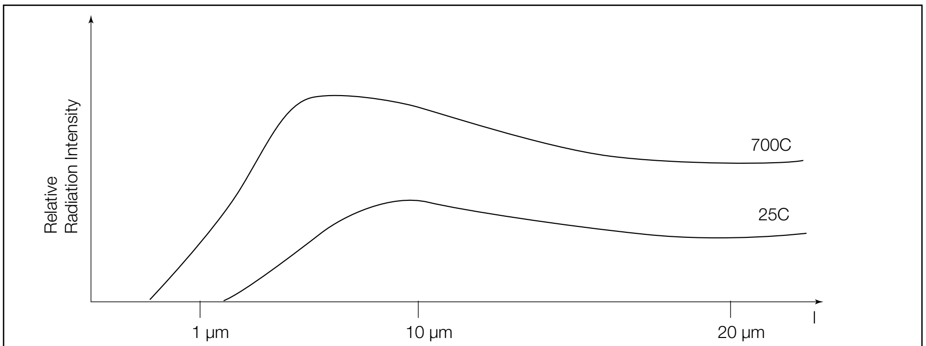


Figure 3: Radiation intensities derived from Planck's Law (Blackbody radiation curves)

Consider the example in Figure 4a. Object X is a hot block of material, Y is colder; therefore, heat will be radiated from X to Y. Some heat will be absorbed by Y, some reflected, and some transmitted through Y. The three dispositions must equal 100%, represented as 1.0 for coefficients of absorption, reflection, and transmission. If A = 1.0, all the heat is absorbed; if R = 1.0, then A = T = 0. Usually some combination exists:

A = .7 (70% absorbed)
R = .2 (20% reflected)
T = .1 (10% transmitted)

Sum = 1.0 (100% energy radiated from X to Y)

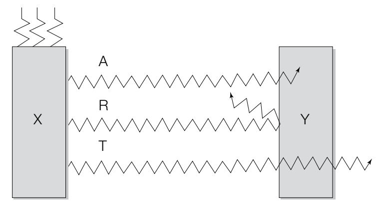


Figure 4a: Energy budget for all radiated IR energy

If an object is in a state of thermal equilibrium, it is getting neither hotter nor colder; the amount of energy it is radiating must equal the amount of energy it is absorbing, so A = E (emissivity). By substitution:

$$E + R + T = 1.0$$

If any two of these values are known, the third is easy to find. Figure 4b illustrates this relationship.

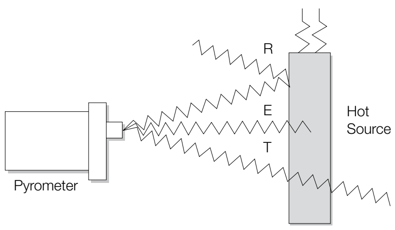


Figure 4b: Total IR radiation reaching pyrometer

Transmission

In some applications, particularly glass and thin-film plastics, transmission becomes an important factor. If it is desired to measure the temperature of these substances using IR, a wavelength must be chosen where the material appears opaque or semi-opaque. Often it is desired to measure temperatures under the surface of an object. This is possible when the material is somewhat transparent at the measured wavelength. Otherwise, selecting a wavelength where the material is opaque minimises measurement errors due to transmitted energy reaching the IR thermometer. If it is desired to make measurements of objects through a glass or quartz window, a short wavelength must be used to take advantage of the ability of the window to pass a high percentage of the IR energy at that wavelength.

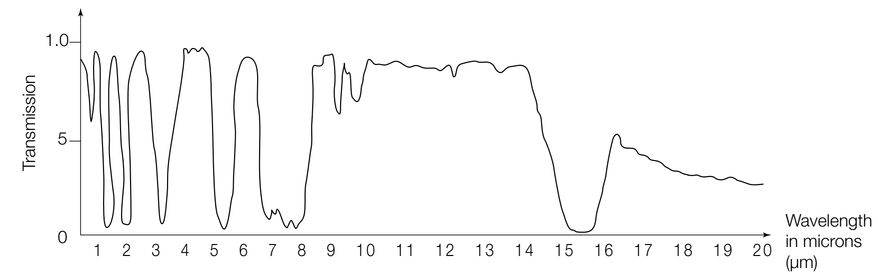


Figure 5: IR transmission through atmosphere

Atmospheric Absorption

One of the first considerations in selecting the spectral response (wavelength range at which an instrument is sensitive to IR) of a device is atmospheric absorption. Certain components of the atmosphere, such as water vapour, CO_2 and other materials, absorb IR at certain wavelengths, increasing the amount of energy absorbed with the distance between the object and the instrument. Therefore, if these absorbents are ignored, an instrument may read correctly when near the object, but several degrees lower a few feet away because the displayed temperature represents an average of the object temperature and the atmosphere temperature. The reading may be affected by changes in humidity or the presence of steam or certain gases. Fortunately, there are "windows" in the IR spectrum which allow these absorption bands to be avoided. Figure 5 illustrates these windows.

Optics

Target size and distance are critical to accuracy for most IR thermometers. Every IR instrument has a field of view (FOV), an angle of vision in which it will average all the temperatures it sees (Figure 6).

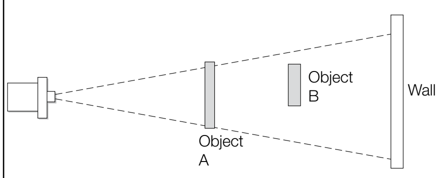


Figure 6: Field of view of instrument

Object A fills the field of view of the sensor; the only temperature seen is that of object A, so the temperature of object A will be accurately indicated. But if object A is removed, object B and the wall share the field of view. The indicated temperature, somewhere between that of object B and the wall, will depend on the relative areas of each filling the circular field of view. If it is desired to measure the temperature of object B, one of four things must be done:

1. Move the thermometer closer to object B, or vice versa.
2. Increase the size of object B until it fills the thermometer's FOV.
3. Decrease the emissivity compensator (described later) to compensate for the loss of energy.
4. Get a thermometer with a smaller FOV.

Field of view is described either by its angle or by a distance-to-size ratio (D:S). If D:S = 20:1, and if the distance to the object divided by the diameter of the object is exactly 20, then the object exactly fills the instrument's field of view. A D:S ratio of 60:1 equals a field of view of 1°.

Since most IR thermometers have fixed focus optics, the minimum measurement spot occurs at the specified focal distance. Typically, if an instrument has fixed-focus optics with a 120: 1 D:S ratio and a focal length of 1.5 m the minimum spot (resolution) the instrument can achieve is 1.5 m divided by 120, or 12.5 mm at a distance of 1.5 m from the instrument. This is significant when the size of the object is close to the minimum spot the instrument can measure.

Most general-purpose IR thermometers use a focal distance between 50 cm and 150 cm; special close-focus instruments use a 12.5 mm to 300 mm focal distance, and may be equipped with a light-spot aiming device to ensure that the instrument is measuring the exact spot desired. Some long-range instruments for checking insulators and transformers on pylons use a 15 m focal distance. Sighting scopes are often used at longer distances or for small spot sizes. Some IR thermometers use variable-focus optics, especially high performance fixed-mount types with through-the-lens sighting.

Fibre optics are alternatively used in special applications where there is not enough space to mount a sensing head, or where radio frequency interference (RFI) of high intensity could cause erratic readings.

Emissivity

The ideal surface for IR temperature measurement would have an emissivity of 1.0. Such an object is known as a blackbody, or perfect radiator/absorber. For these objects, R = T = 0. The term "blackbody" is somewhat misleading, in that colour is irrelevant in the IR spectrum because coloured light has much shorter wavelengths. In practice, however, most objects are either graybodies (which have an emissivity of less than 1.0 but the same emissivity at all wavelengths), or non-graybodies (which have emissivities which vary with wavelength and/or temperature). This last type of object can result in serious measurement accuracy problems because most IR thermometers mathematically translate measured IR energy into temperature. As an object with an emissivity of .7 emits only 70% of the available energy, this would cause the indicated temperature to read lower than actual. IR thermometer manufacturers usually address this problem by installing an emissivity compensator, a calibrated gain adjustment which increases the amplification of the detector signal to compensate for the energy lost due to an emissivity less than 1. This same adjustment can be used to correct for transmission losses through viewing ports, smoke, dust, or vapours. For example, setting the compensator to .5 for an object with that emissivity results in a gain increase by a factor of 2. If a viewing port is used to sight the object in a vacuum chamber, and the transmission through the port is 40% (T= .4), the errors are in series, so the net compensator setting is .5 x .4 = .2. The resulting amplification factor of 5 will compensate for all energy losses.

Emissivity Versus Wavelength

For many materials, particularly organics, emissivity does not vary appreciably with wavelength. Other materials, such as glass and thin-film plastics, present severe transmission losses at some wavelengths, particularly the shorter wavelengths. These will be discussed later.

Metals, in almost all cases, tend to be more reflective at long wavelengths, hence their emissivity improves inversely with wavelength. A problem arises with low-temperature metals, where the shortest usable wavelength depends on the point at which insufficient energy exists to produce a detector output. In these cases a compromise is necessary. Further discussion is found in the section on metals applications.

Determination of Emissivity

The emissivity of most organic substances (wood, cloth, plastics, etc.) is approximately 0.95. Metals with smooth, polished surfaces can have emissivities much lower than 1.0. The emissivity of a material can be determined in one of the following ways:

1. Heat a sample of the material to a known temperature as determined by a precise sensor in an oven, and measure the temperature of the object with the IR instrument. Use the emissivity compensator adjustment to force the indicator to display the correct temperature. Use this value of emissivity for measurements of this same material in the future.
2. For relatively low temperature (up to about 250°C or 500°F), a piece of masking tape can be placed on the object and the temperature of the masking tape measured with the IR thermometer using an emissivity setting of 0.95. Next, measure the object temperature, and adjust the emissivity compensator until the display shows the correct temperature. Use this emissivity value for future measurements of this object.
3. For very high temperatures, a hole, the depth of which is at least 6 times the diameter can be drilled into the object. This hole acts as a blackbody with an emissivity of approximately 1.0, and the temperature measured looking into the hole will be the correct object temperature. As in example 2, use the emissivity compensator to determine the correct setting for this object's future measurements.
4. When a portion of the surface of the object can be coated, a dull black paint will have an emissivity of about 1.0. Other non-metallic coatings such as mold release, spray baking powder, deodorant, and other coatings may also be used. Measure the known temperature as before, and use the emissivity adjustment to determine the correct emissivity value.
5. Standardised values of emissivity are available for most materials. For a detailed listing of emissivities, refer to "Thermal Radiative Properties", (volumes 7, 8 and 9) by Y.S Touloukian and D.P. DeWitt, published by IFI/ Plenum Data Corporation, Subsidiary of Plenum Publishing Company, 227 West 17th St, New York, New York 10011.

Spectral Response - Wideband, Narrowband, and Ratio IR Thermometers

One means of categorising IR thermometers is by spectral response: the width of the IR spectrum covered. The most common design approach is to select a segment of the IR spectrum, optically filter the units to look only at that segment of the spectrum (Figure 7), and integrate the energy falling on the detector for that segment. Many general-purpose instruments use a wideband (e.g. 8 to 14 µm in Figure 7); because adequate energy is available, only low-gain amplifiers are required. Some inexpensive units cover most of the .7 to 20 µm IR spectrum, at the expense of being "distance-sensitive" because they include some atmospheric absorption bands. A thermometer which excludes these absorption bands (e.g., 8 to 14 µm) avoids these problems.

For special purposes, very narrow bands (2.2 µm in Figure 7) may be chosen. These instruments are costlier because more stable, high-gain amplifiers are needed to amplify the smaller signals which result from reduced energy levels in these narrow bands. However, they can also be used for general-purpose work, as well as special applications. The ability of narrow band instruments to measure low temperatures may be limited somewhat by the low energy levels encountered.

A third type of thermometer is the ratio, or two-colour thermometer. This instrument measures the ratio of energies at two selected narrow bands. If the change in emissivity at the two selected wavelengths is the same, the effect of emissivity is eliminated, with attendant advantages.

Further, the target need not fill the field of view, as is the case with single-colour instruments. If a target which just fills the field of view is cut in half, half the energy will be lost to the detector, and the single-colour instrument will read low. With the two-colour instrument, if the energy at both wavelengths is cut and the ratio stays the same, the temperature reading will not change (Figure 8). The benefit resulting from this feature is that if a cloud of dust or smoke obscures the target, the radiation reaching the thermometer may be reduced, but the reading will not change as long as the ratio of energies does not vary.

In practice, the emissivities at the two wavelengths may not vary in a similar manner. Two-colour thermometer manufacturers address this problem with a ratio calibrator adjustment, similar to the emissivity compensator adjustment of single colour instruments. This adjustment is used to calibrate the unit in much the same

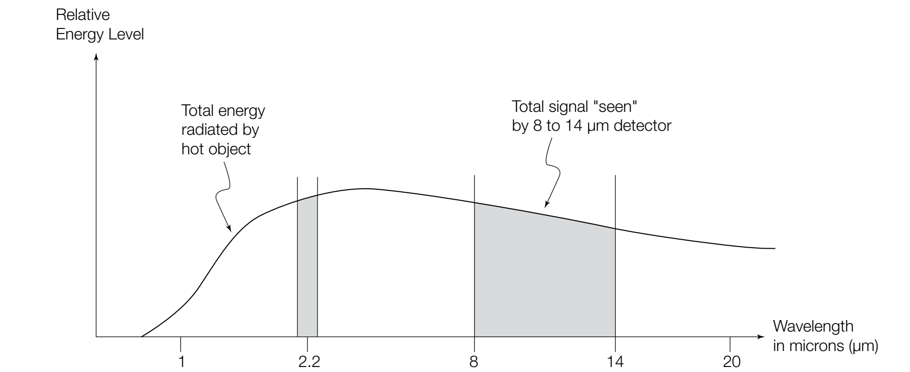


Figure 7: Distribution of energy as received by filtered IR detectors

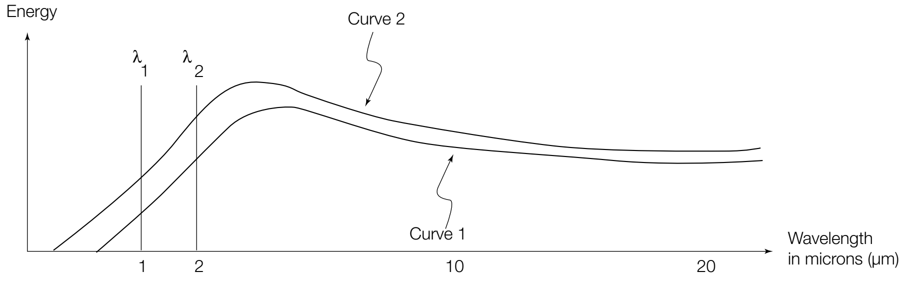


Figure 8: Two temperatures as interpreted by ratio (two-colour) pyrometer

manner described earlier for the emissivity compensator. However, this works only for that particular material, and often only around a given temperature. Therefore, unless the target is a true graybody, the ratio thermometer has questionable advantage over a single-colour unit.

In the event of reduced target area (by a target not filling the field of view, or being obscured by dust or smoke), a single colour unit can read properly by adjusting the emissivity compensator to make up for the loss. This adjustment can make up for any kind of loss in the system, provided the loss is constant. The ratio thermometer has an advantage only when the loss varies during the process, or in a situation where changing the emissivity adjustment is not feasible. If the adjustment needs to be made only once, the user need not spend the extra cost of a two-colour instrument.

To summarise, a two-colour thermometer is beneficial in measuring (1) graybodies of varying or unknown emissivity and (2) targets with a varying field of view due to changing size or distance, varying concentrations of dust or smoke or sight-window coating. Use of a two-colour instrument is justified economically only when special circumstances require it. Further, in some applications, performance can be less accurate than single-colour instruments if there are inconsistent emissivity ratios.

Spectrum For Low Temperatures (Below 500°C/1000°F)

The most popular band for general purpose measurements up to 500°C is 8 to 14 µm. This is a wide band, yielding sufficient energy even at sub-freezing temperature, and free from atmospheric absorption. Uses include maintenance diagnostics, all organic processes (paper, wood, rubber, textiles, agricultural), thick plastics, glass surfaces (if reflection from strong heat sources is not a problem), well-oxidised metals, and metals near ambient (if reflections don't interfere). This is the only type of IR thermometer suitable for measurements below ambient temperature.

Spectrum for Mid-Range Temperatures (100-800°C /200-1500°F)

One of the preferred shorter wavelength bands for penetration of atmosphere, flames and gases is 3.8 µm. This is the best compromise for low-temperature metals because shorter wavelength instruments are limited to high temperatures.

Spectrum for High Temperatures (Above 300°C /600°F)

Another window in the atmosphere and flame-absorption bands ideal for temperature measurement is 2.2 µm. This narrow band is especially well-suited for high temperature measurements.

Special Purpose Instruments

METALS: Metals present some unique IR temperature-measurement problems.

Foremost is the fact that most metals tend to be very reflective (unless well oxidised) and thus have low emissivities. Some of these emissivities are so low that a large portion of the sensed energy is reflected radiation (usually from heaters, flames, refractory walls, etc.). This can result in varying and unreliable readings. For most metals, the problem increases at the longer wavelengths.

The shortest possible measurement wavelength should be used. As shown in Figure 9, the emissivities of most metals improve as wavelength decreases.

Also, as illustrated by Figure 10, a smaller change in indicated temperature results from the same change in emissivity at shorter wavelengths, producing more accurate measurements when emissivity variations are present.

Two factors limit how short the wavelength can be: (1) the lowest temperature which must be measured; as can be seen from blackbody radiation curves, the shorter the wavelength, the less energy is available at that wavelength, and (2) the width of the temperature range desired. As wavelength decreases, the energy level difference between two given temperatures increases, and an amplifier with wider dynamic range capabilities is required. At some point, the gain required to do this becomes unattainable. For these reasons, a compromise must be made; the shortest wavelength which allows the required temperature range should be used.

Other considerations in making this choice may be: instrument price and availability, presence of gases or flames in the line of sight, ability to see through vacuum chamber windows, etc. The optimum wavelength for high-temperature metals is the near infrared, around .8 µm. Other choices are 1.6 µm (where some metals have the same emissivity at different temperatures), 2.2 µm and 3.8 µm (both of which are recommended for reading through clean flames). If the metals are coated, well oxidised, or can be temporarily improved by adding a high-emissivity coating, 8 to 14 µm instruments can be used. Other compromises for low temperature metals are 3.43 µm and 5.1 µm.

Spectrum for Plastics

In general, plastics thicker than 2.5 mm can be measured using 8 to 14 µm instruments. In the case of thin films, however, plastic is partially transparent in the 8 to 14 µm band. Heat sources on the other side of the film and variations in the thickness will result in variations in the IR temperature reading.

Fortunately, there are certain resonant points in the IR spectrum at which thin films appear opaque to an IR thermometer due to characteristics of molecular bonding, eliminating the transmitted energy completely at certain wavelengths. Some plastics (polyethylene,

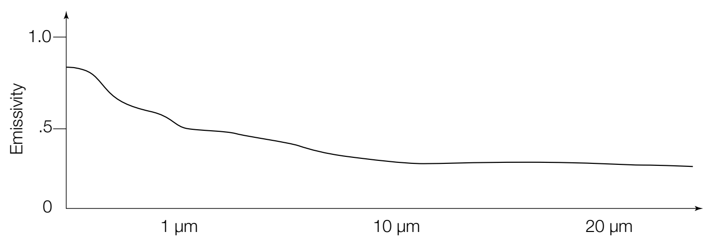


Figure 9: Typical metal: variation of emissivity with wavelength

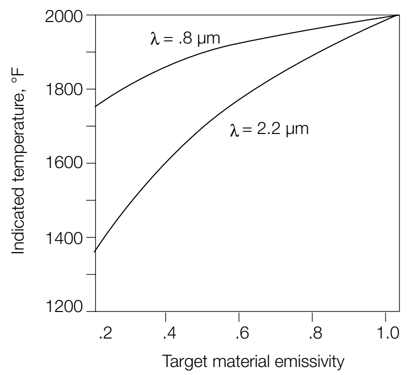


Figure 10. Readings obtained on IR pyrometers with centre wavelengths of .8 µm and 2.2 µm as actual emissivity of target material varies; target temperature is 1100°C, emissivity is 1.0.

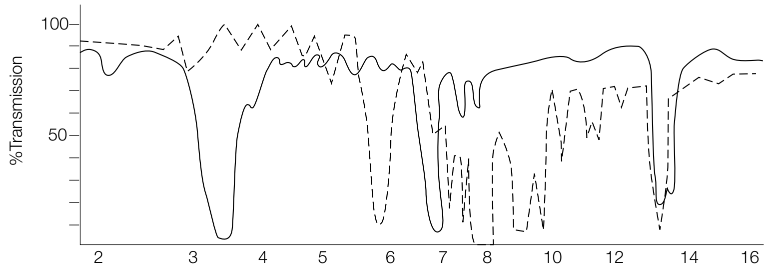


Figure 11: Solid line represents transmission characteristics of 25 μm polyethylene film (typical of plastics wtih strong 3.43 μm absorption) while dashed line illustrates 7.9 μm absorption of polyester film

polypropylene, nylon, polystyrene) are opaque at 3.43 μm; other plastics (polyester, polyurethane, Teflon, FEP, cellulose, polyamide) are opaque at 7.9 μm (Figure 11). Some films are opaque at both. In the latter case, a choice may be based on spectral reflectivity, instrument price and availability, or whether quartz heaters are used in the process (because these heaters may cause severe interference at wavelengths shorter than 5 μm). For plastics opaque only at 3.43 μm it may be possible to use the weaker, secondary 6.86 μm wavelength to avoid quartz heater interference.

Spectrum for Glass

The glass industry is one in which the different factors involved in IR measurement, particularly reflection and transmission, must be well understood for optimum results. Figure 12 shows the relationship of transmission to wavelength. In general, pane glass is opaque beyond 5 μm, and becomes progressively transparent at shorter wavelengths (as evidenced by the human eye). The .8 μm instrument measures several centimetres into molten glass, 2.2 μm about 75 to 100 mm. Instruments using 3.8 μm will measure no further than 25 or 50 mm, depending on the type of glass, so this wavelength is excellent for averaging "gob" temperatures. (These figures are for non-pigmented glass, and it must be remembered that glass nearest the surface will contribute the most to the temperature reading; pigmented glass will be more opaque, even at short wavelengths.) For panes, bottles, and other thin-wall glass, the longer wavelengths must be used. Reflection becomes critical at 8 to 14 μm; reflectivity averages 15%. This band can be used with emissivity settings of .85 with good results. Reflectivity is negligible between 5 to 8 μm but 5.1 μm is preferred as most of the temperature sensed is from a few mils beneath the surface, reducing the cooling effect of surface convection currents. The 5 to 7 μm band is discouraged unless the absence of steam and water vapour can be guaranteed (due to the 5.5 to 7.5 μm absorption band); 7.9 μm is ideal for surface measurement, with no reflectance.

Spectrum for Flame Measurement/ Combustion Optimising

While most IR instruments can be used to measure "dirty" flame temperatures, a clean flame (one with no particulate or smoke) can be measured at 4.5 μm where CO_2 and NOx are opaque, provided these by-products are present and the IR pathlength through the flame exceeds 25 cm. The same instrument can also assist in combustion optimising, even for smaller flames, because relative readings can be used (absolute readings are not required).

Fixed Mount and Portable IR Thermometers

Fixed mount instruments are generally installed in one location to continuously monitor or control a given process. They operate from the local power source (110/220 V AC or 24 V DC), are aimed at a single point or scan an area by a mechanical aiming device. Often they are supplied with a portable case and can be moved from one location to another. In manufacturing, a process can be studied by monitoring several points at different intervals. The sensing head can be mounted on a tripod, and the signal output fed to a chart recorder or data logger for later analysis.

If a truly portable unit is needed, battery-operated IR thermometers are available to match the features of nearly all fixed-mount instruments except control functions. One of the limitations of these units is the need for periodic battery replacement. Generally, their uses have been maintenance diagnostics, quality control functions, periodic spot measurements of temperature critical processes, and energy surveys.

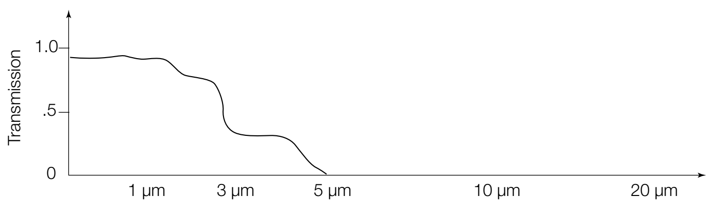


Figure 12: Transmission spectrum of glass (typical 3 mm pane glass)

Critical Specifications

In addition to optics, spectral response, emissivity, temperature range, and mounting (fixed-mount vs portable), the following list of items should be considered in selecting an infrared thermometer:

1. *Response time:* The instrument must respond quickly enough to process changes for proper recording or control of temperature. IR thermometers are usually faster than most other temperature measurement devices, with typical response times in the 100 ms to 1 s range.
2. *Environment:* The instrument must function within the range of ambient temperatures to which it will be exposed. Special provisions must be made to protect the instrument from dirt, dust, flames, and vapours. Intrinsically safe or explosion-proof instruments may be required.
3. *Physical mounting limitations:* The sensing head must fit in the space available to sight the object. If this is a hazardous location, risk can be minimised by using a head which contains the fewest parts (i.e., detector and ambient sensor only) so that a catastrophic loss does not require replacement of the entire instrument. This type of instrument typically uses a remotely located electronics box containing most of the circuitry, which can be mounted a safe distance away from a hazardous location. Alternatives include use of fibre optics, sight tubes, or front-surface mirrors to direct IR energy to the detector.
4. *Viewing port or window applications:* If a vacuum chamber, special atmosphere, or other process requires measuring temperatures through windows into vessels, care must be taken to ensure that the window will pass energy at wavelengths measured by the instrument. Glass will pass wavelengths shorter than 3 μm, quartz .5 to 4.5 μm, zinc selenide from 2 to 15 μm, germanium 4 to 14 μm. Irtran, a series of materials manufactured by Kodak, is available in several different band pass wavelengths from .5 to 20 μm.

   If visible sighting is required as well as infrared, a window material which transmits visible energy as well as infrared must be used. The temperature range of measurement dictates the longest wavelength to be passed, since peak energy wavelengths increase as temperature decreases.
5. *Signal processing:* Various signal processing devices are integrated to produce outputs to interface with displays, recorders, controllers, data loggers, and computers. Displays, alarm set points, and PC Interfces are commonly an integral part of the IR thermometer.

Signal processing features include:

Maximum reading: a stored value for the highest temperature measured.

Minimum reading: a stored value for the lowest temperature measured.

Difference: maximum minus minimum.

Average temperature: the mean of all temperatures measured in a given time period.

Variable time constant: enables smoothing displayed temperature or output in rapidly changing temperature measurements.

Integration of reflected energy compensation: allows calculation based on discrete input for unwanted energy received by instrument.

Output formats:

- mV linear or nonlinear
- mA linear
- Thermocouple equivalents
- RS-485
- USB
- Contact closures for preset alarm points
- Self-test or diagnostic outputs.

Various accessories are available to make IR thermometers convenient to use and reduce installation costs. For portable instruments, accessories include: carrying case, wrist strap and calibration source. Fixed instrument accessories include: sight tube, air purge collar, water-cooled housing, mounting bracket, swivel bracket and alignment light spots.

Emissivity Table

When using infrared pyrometers such as the Calex Pyropen, a knowledge of emissivity setting for various materials will permit optimisation of the measurement.

Emissivity is a function of temperature, and is also subject to variations due to the surface condition of the material, and these tables should therefore be used as a guide.

Where accuracy or measurement is critical it is recommended that the notes on “Understanding and using the Infrared Thermometer” be read.

FERROUS AND NON FERROUS METALS

Material	Temp (°C)	Temp (°F)	∊-Emissivity
Alloys			
20-Ni, 24-CR, 55-FE, Oxidized	200	392	0.90
20-Ni, 24-CR, 55-FE, Oxidized	500	932	0.97
60-Ni, 12-CR, 28-FE, Oxidized	270	518	0.89
60-Ni, 12-CR, 28-FE, Oxidized	560	1040	0.82
80-Ni, 20-CR, Oxidized	100	212	0.87
80-Ni, 20-CR, Oxidized	600	1112	0.87
80-Ni, 20-CR, Oxidized	1300	2372	0.89
Aluminium			
Unoxidized	25	77	0.02
Unoxidized	100	212	0.03
Unoxidized	500	932	0.06
Oxidized	199	390	0.11
Oxidized	599	1110	0.19
Oxidized at 599°C	199	390	0.11
Oxidized at 599°C	599	1110	0.19
Heavily Oxidized	93	200	0.20
Heavily Oxidized	504	940	0.31
Highly Polished	100	212	0.09
Roughly Polished	100	212	0.18
Commercial Sheet	100	212	0.09
Highly Polished Plate	227	440	0.04
Highly Polished Plate	577	1070	0.06
Bright Rolled Plate	170	338	0.04
Bright Rolled Plate	500	932	0.05
Alloy A3003, Oxidized	316	600	0.40
Alloy A3003, Oxidized	482	900	0.40
Alloy 1100-0	93-427	200-800	0.05
Alloy 24ST	24	75	0.09
Alloy 24ST Polished	24	75	0.09
Alloy 75ST	24	75	0.11
Alloy 75ST Polished	24	75	0.08
Bismuth, Bright	80	176	0.34
Bismuth, Unoxidized	25	77	0.05
Bismuth, Unoxidized	100	212	0.06
Brass			
73%Cu.27%Zn. Polished	247	476	0.03
73%Cu.27%Zn. Polished	357	674	0.03
62%Cu.37%Zn. Polished	257	494	0.03
62%Cu.37%Zn. Polished	377	710	0.04
83%Cu.17%Zn. Polished	277	530	0.03
Matte	20	68	0.07
Burnished to Brown Colour	20	68	0.40

Material	Temp (°C)	Temp (°F)	∊-Emissivity
Cu-Zn, Brass Oxidized	200	392	0.61
Cu-Zn, Brass Oxidized	400	752	0.60
Cu-Zn, Brass Oxidized	600	1112	0.61
Unoxidized	25	77	0.04
Unoxidized	100	212	0.04
Cadmium	25	77	0.02
Carbon			
Lampblack	25	77	0.95
Unoxidized	25	77	0.81
Unoxidized	100	212	0.81
Unoxidized	500	932	0.79
Candle Soot	121	250	0.95
Filament	260	500	0.95
Graphitized	100	212	0.76
Graphitized	300	572	0.75
Graphitized	500	932	0.71
Chromium	38	100	0.08
Chromium	538	1000	0.26
Chromium Polished	150	302	0.06
Cobalt, Unoxidized	500	932	0.13
Cobalt, Unoxidized	1000	1832	0.23
Columbium,Unoxidized	816	1500	0.19
Columbium,Unoxidized	1093	2000	0.24
Copper			
Cuprous Oxide	38	100	0.87
Cuprous Oxide	260	500	0.83
Cuprous Oxide	538	1000	0.77
Black, Oxidized	38	100	0.78
Etched	38	100	0.09
Matte	38	100	0.22
Roughly Polished	38	100	0.07
Polished	38	100	0.03
Highly Polished	38	100	0.02
Rolled	38	100	0.64
Rough	38	100	0.74
Molten	538	1000	0.15
Molten	1077	1970	0.16
Molten	1221	2230	0.13
Nickel Plated	38-260	100-500	0.37
Dow Metal	(18)-316	0-600	0.15

Material	Temp (°C)	Temp (°F)	∊-Emissivity
Gold			
Enamel	100	212	0.37
Plate (.0001)			
on .0005 Silver	93-399	200-750	.11-.14
on .0005 Nickel	93-399	200-750	.07-.09
Polished	38-260	100-500	0.02
Polished	538-1093	1000-2000	0.03
Haynes Alloy C, Oxidized	316-1093	600-2000	.90-.96
Haynes Alloy 25, Oxidized	316-1093	600-2000	.86-.89
Haynes Alloy X, Oxidized	316-1093	600-2000	.85-.88
Inconel Sheet	538	1000	0.28
Inconel Sheet	649	1200	0.42
Inconel Sheet	760	1400	0.58
Inconel X, Polished	24	75	0.19
Inconel B, Polished	24	75	0.21
Iron			
Oxidized	100	212	0.74
Oxidized	499	930	0.84
Oxidized	1199	2190	0.89
Unoxidized	100	212	0.05
Red Rust	25	77	0.70
Rusted	25	77	0.65
Liquid	1516-1771	2760-3220	.42-.45
Cast Iron			
Oxidized	199	390	0.64
Oxidized	599	1110	0.78
Unoxidized	100	212	0.21
Stong Oxidation	40	104	0.95
Strong Oxidation	250	482	0.95
Liquid	1535	2795	0.29
Wrought Iron			
Dull	25	77	0.94
Dull	349	660	0.94
Smooth	38	100	0.35
Polished	38	100	0.28
Lead			
Polished	38-260	100-500	.06-.08
Rough	38	100	0.43
Oxidized	38	100	0.43
Oxidized at 593°C	38	100	0.63
Gray Oxidized	38	100	0.28
Magnesium	38-260	100-500	.07-.13
Magnesium Oxide	1027-1727	1880-3140	.16-.20
Mercury	0	32	0.09
Mercury	25	77	0.10
Mercury	38	100	0.10
Mercury	100	212	0.12
Molybdenum	38	100	0.06
Molybdenum	260	500	0.08
Molybdenum	538	1000	0.11
Molybdenum	1093	2000	0.18
Molybdenum Oxidized at 538°C	316	600	0.80
Molybdenum Oxidized at 538°C	371	700	0.84
Molybdenum Oxidized at 538°C	427	800	0.84
Molybdenum Oxidized at 538°C	482	900	0.83
Molybdenum Oxidized at 538°C	538	1000	0.82
Monel, Ni-Cu	200	392	0.41
Monel, Ni-Cu	400	752	0.44

Material	Temp (°C)	Temp (°F)	∊-Emissivity
Monel, Ni-Cu	600	1112	0.46
Monel, Ni-Cu Oxidized	20	68	0.43
Monel, Ni-Cu Oxidized at 599°C	599	1110	0.46
Nickel			
Polished	38	100	0.05
Oxidized	38-260	100-500	.31-.46
Unoxidized	25	77	0.05
Unoxidized	100	212	0.06
Unoxidized	500	932	0.12
Unoxidized	1000	1832	0.19
Electrolytic	38	100	0.04
Electrolytic	260	500	0.06
Electrolytic	538	1000	0.10
Electrolytic	1093	2000	0.16
Nickel Oxide	538-1093	1000-2000	.59-.86
Palladium Plate			
(.00005 on .0005 silver)	93-399	200-750	.16-.17
Platinum	38	100	0.05
Platinum	260	500	0.05
Platinum	538	1000	0.10
Platinum Black	38	100	0.93
Platinum Black	260	500	0.96
Platinum Black	1093	2000	0.97
Platinum Black Oxidized at 593°C	260	500	0.07
Platinum Black Oxidized at 593°C	538	1000	0.11
Rhodium Flash			
(.0002 on .0005 Ni)	93-371	200-700	.10-.18
Silver			
Plate (.0005 on Ni)	93-371	200-700	.06-.07
Polished	38	100	0.01
Polished	260	500	0.02
Polished	538	1000	0.03
Polished	1093	2000	0.03
Steel			
Cold Rolled	93	200	.75-.85
Ground Sheet	938-1099	1720-2010	.55-.61
Polished Sheet	38	100	0.07
Polished Sheet	260	500	0.10
Polished Sheet	538	1000	0.14
Mild Steel, Polished	24	75	0.10
Mild Steel, Polished Smooth	24	75	0.12
Mild Steel, Liquid	1599-1799	2910-3270	0.28
Steel, Unoxidized	100	212	0.08
Steel Oxidized	25	77	0.80
Steel Alloys			
Type 301, Polished	24	75	0.27
Type 301, Polished	232	450	0.57
Type 301, Polished	949	1740	0.55
Type 303, Oxidized	316-1093	600-2000	.74-.87
Type 310, Rolled	816-1149	1500-2100	.56-.81
Type 316, Polished	24	75	0.28
Type 316, Polished	232	450	0.57
Type 316, Polished	949	1740	0.66
Type 321	93-427	200-800	.27-.32
Type 321 Polished	149-816	300-1500	.18-.49
Type 321 w/BK Oxide	93-427	200-800	.66-.76
Type 347, Oxidized	316-1093	600-2000	.87-.91
Type 350	93-427	200-800	.18-.27
Type 350, Polished	149-982	300-1800	.11-.35
Type 446, Polished	149-816	300-1500	.15-.37
Type 17-7PH	93-316	200-600	.44-.51

Material	Temp (°C)	Temp (°F)	ε-Emissivity
Type 17-7PH Polished	149-816	300-1500	.09-.16
Type C1020, Oxidised	316-1093	600-2000	.87-.91
Type PH-15-7 MO	149-649	300-1200	.07-.19
Stellite, Polished	20	68	0.18
Tantalum			
Unoxidized	727	1340	0.14
Unoxidized	1093	2000	0.19
Unoxidized	1982	3600	0.26
Unoxidized	2930	5306	0.30
Tin, Unoxidized	25	77	0.04
Tin, Unoxidized	100	212	0.05
Tinned Iron, Bright	24	76	0.05
Tinned Iron Bright	100	212	0.08
Titanium			
Alloy C110M, Polished	149-649	300-1200	.08-.19
Alloy C110M, Oxidised at 538°	93-427	200-800	.51-.61
Alloy T1-95A Oxidised at 538°	93-427	200-800	.35-.48
Anodized onto SS	93-316	200-600	.96-.82
Tungsten			
Unoxidized	25	77	0.02
Unoxidized	100	212	0.03
Unoxidized	500	932	0.07
Unoxidized	1000	1832	0.15
Unoxidized	1500	2732	0.23
Unoxidized	2000	3632	0.28
Filament (Aged)	38	100	0.03
Filament (Aged)	538	1000	0.11
Filament (Aged)	2760	5000	0.35
Uranium Oxide	1027	1880	0.79
Zinc			
Bright Galvanized	38	100	0.23
Commercial 99.1%	260	500	0.05
Galvanized	38	100	0.28
Oxidized	260-538	500-1000	0.11
Polished	38	100	0.02
Polished	260	500	0.03
Polished	538	1000	0.04
Polished	1093	2000	0.06

OTHER MATERIALS

Material	Temp (°C)	Temp (°F)	ε-Emissivity
Adobe	20	68	0.90
Asbestos			
Board	38	100	0.96
Cement	0-200	32-392	0.96
Cement Red	1371	2500	0.67
Cement White	1371	2500	0.65
Cloth	93	199	0.90
Paper	38-371	100-700	0.93
Slate	20	68	0.97
Asphalt, pavement	38	100	0.93
Asphalt, tar paper	20	68	0.93
Basalt	20	68	0.72
Brick			
Red, rough	21	70	0.93
Gault Cream	1371-2760	2500-5000	.26-.30
Fire Clay	1371	2500	0.75
Light Buff	538	1000	0.80
Lime Clay	1371	2500	0.43
Fire Brick	1000	1832	.75-.80
Magnesite, Refractory	1000	1832	0.38
Gray Brick	1100	2012	0.75
Silica, Glazed	1093	2000	0.88
Silica, Unglazed	1093	2000	0.80
Sandlime	1371-2760	2500-5000	.59-.63
Carborundum	1010	1850	0.92
Ceramic			
Alumina on Inconel	427-1093	800-2000	.69-.45
Earthenware, Glazed	21	70	0.90
Earthenware, Matte	21	70	0.93
Greens No. 5210-2C	93-399	200-750	.89-.82
Coating No. C20A	93-399	200-750	.73-.87
Porcelain	22	72	0.92
White Aluminium Oxide	93	200	0.90
Zirconia on Inconel	427-1093	800-2000	.62-.45
Clay	20	68	0.39
Clay Fired	70	158	0.91
Clay Shale	20	68	0.69
Clay Tiles, Light Red	1371-2760	2500-5000	.32-.34
Clay Tiles, Red	1371-2760	2500-5000	.40-.51
Clay Tiles, Dark Purple	1371-2760	2500-5000	0.78
Concrete			
Rough	0-1093	32-2000	0.94
Tiles, Natural	1371-2760	2500-5000	.63-.62
Tiles, Brown	1371-2760	2500-5000	.87-.83
Tiles Black	1371-2760	2500-5000	.94-.91
Cotton Cloth	20	68	0.77
Dolomite Lime	20	68	0.41
Emery Corundum	80	176	0.86
Glass			
Convex D	100	212	0.80
Convex D	316	600	0.80
Convex D	500	932	0.76
Nonex	100	212	0.82
Nonex	316	600	0.82
Nonex	500	932	0.78
Smooth	0-93	32-200	.92-.94
Granite	21	70	0.45
Gravel	38	100	0.28
Gypsum	20	68	.80-.90
Ice, Smooth	0	32	0.97
Ice Rough	0	32	0.96
Lacquer			
Black	93	200	0.96
Blue, on Aluminum Foil	38	100	0.78
Clear, on Aluminum Foil (2 coat)	93	200	.08(.09)
Clear, on Bright Copper	93	200	0.66
Clear, on Tarnished Copper	93	200	0.64
Red, on Aluminum Foil (2 coat)	38	100	.61(.74)
White	93	200	0.95
White, on Aluminum Foil (2 coat)	38	100	.69(.88)
Yellow, on Aluminum Foil (2 coat)	38	100	.57(.79)

Material	Temp (°C)	Temp (°F)	∊-Emissivity
Lime Mortar	38-260	100-500	.90-.92
Limestone	38	100	0.95
Marble, White	38	100	0.95
Marble, Smooth, White	38	100	0.56
Marble, Polished Gray	38	100	0.75
Oil on Nickel			
.001 Film	22	72	0.27
.002 Film	22	72	0.46
.005 Film	22	72	0.72
Thick Film	22	72	0.82
Oil, Linseed			
On Aluminum Foil, uncoated	121	250	0.09
On Aluminum Foil, 1 coat	121	250	0.56
On Aluminum Foil, 2 coats	121	250	0.51
On Polished Iron, .001 Film	38	100	0.22
On Polished Iron, .002 Film	38	100	0.45
On Polished Iron, .004 Film	38	100	0.65
On Polished Iron, Thick Film	38	100	0.83
Paints			
Blue, Cu_2-O_3	24	75	0.94
Black, CuO	24	75	0.96
Green, Cu_2O_3	24	75	0.92
Red, Fe_2O_3	24	75	0.91
White Al_2-O_3	24	75	0.94
White Y_2O_3	24	75	0.90
White ZnO	24	75	0.95
White $MgCO_3$	24	75	0.91
White, ZrO_2	24	75	0.95
White ThO_2	24	75	0.90
White MgO $_2$	4	75	0.91
White $PbCO_3$	24	75	0.93
Yellow, PbO	24	75	0.90
Yellow $PbCrO_4$	24	75	0.93
Paints, Aluminum	38	100	.27-.67
10% Al	38	100	0.52
20% Al	38	100	0.30
Dow XP-310	93	200	0.22
Paints, Bronze	Low	Low	.34-.80
Gum Varnish (2 coats)	21	70	0.53
Gum Varnish (3 coats)	21	70	0.50
Cellulose Binder (2 coats)	21	70	0.34
Paints, Oil			
All colours	93	200	.92-.96
Black	93	200	0.92
Black Gloss	21	70	0.30
Camouflage Green	52	125	0.85
Flat Black	27	80	0.88
Flat White	27	80	0.91
Gray-Green	21	70	0.95
Green	93	200	0.95
Lamp Black	98	209	0.96
Red	93	200	0.95
White	93	200	0.94
Quartz, Rough, Fused	21	70	0.93
Glass, 1.96 mm	282	540	0.90
Glass, 1.96 mm	838	1540	0.41
Glass, 6.88 mm	282	540	0.93
Glass, 6.88 mm	838	1540	0.47
Opaque	299	570	0.92
Opaque	838	1540	0.68

Material	Temp (°C)	Temp (°F)	∊-Emissivity
Red Lead	100	212	0.93
Rubber, Hard	23	74	0.94
Rubber, Soft, Gray	24	76	0.86
Sand	20	68	0.76
Sandstone	38	100	0.67
Sandstone Red	38	100	.60-.83
Sawdust	20	68	0.75
Shale	20	68	0.69
Silica Glazed	1000	1832	0.85
Silica Unglazed	1100	2012	0.75
Silicon Carbide	149-649	300-1200	.83-.96
Silk Cloth	20	68	0.78
Slate	38	100	.67-.80
Snow, Fine Particles	-7	20	0.82
Snow Granular	-8	18	0.89
Soil			
Surface	38	100	0.38
Black Loam	20	68	0.66
Plowed Field	20	68	0.38
Soot			
Acetylene	24	75	0.97
Camphor	24	75	0.94
Candle	121	250	0.95
Coal	20	68	0.95
Stonework	38	100	0.93
Water	38	100	0.67
Waterglass	20	68	0.96
Wood	Low	Low	.80-.90
Beech, Planed	70	158	0.94
Oak, Planed	38	100	0.91
Spruce, Sanded	38	100	0.89

Emissivity

What it is and why it matters

What is emissivity?

All surfaces emit infrared radiation. The amount of energy they emit depends on their temperature and emissivity.

To accurately measure the temperature of a surface, the infrared sensor needs to know how much of the energy it is "seeing" has been emitted from the surface as a result of the object's temperature, and not reflected from the surface, or transmitted through it.

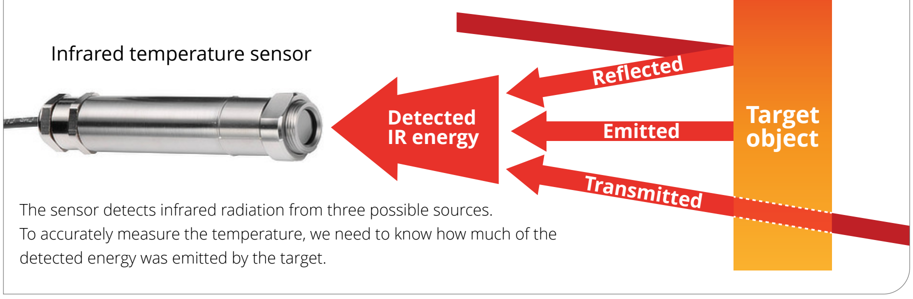
The emissivity of a surface is a measure of how effectively a surface emits infrared radiation.

The sensor's emissivity setting should match the emissivity of the target surface for maximum accuracy.

Transmissive materials

Most materials do not transmit any infrared radiation, so we can assume all the energy the sensor detects has been either emitted or reflected.

Transmissive materials are a special case. See below for more information.



The sensor detects infrared radiation from three possible sources.
To accurately measure the temperature, we need to know how much of the detected energy was emitted by the target.

How to adjust the emissivity setting

If necessary, the emissivity setting can be adjusted in a different way for each type of sensor:

PyroMini	Via the touch screen if fitted, via Modbus if present, or via two rotary switches in the electronics module
PyroEpsilon	Via the 4-20 mA input
PyroUSB	Via USB using the included cable and free software
PyroMiniBus	Via the PM180 or other RS485 Modbus Master
PyroSigma	Via push-buttons on the sensor
ExTemp	Via the optional LCT configuration tools (USB or RS485)
PyroNFC	Via the Android app with an NFC smartphone
PyroCube	Via the PM030 configuration unit, or RS232 Modbus
PyroCouple	The emissivity setting is fixed at 0.95 and cannot be adjusted

High emissivity materials

e.g. painted or very dirty surfaces, food, rubber, thick plastics, paper, glue, asphalt

The emissivity of these materials is often close to 0.95. This is the default emissivity setting of all Calex sensors.

A surface with a high emissivity is easy to measure with a low-cost, general-purpose sensor. In this case, reflections are minimal.

Up to 1000°C: Low-cost 8 to 14 µm sensors such as the PyroCouple, PyroSigma and PyroMini give good results.

It is also possible to use a short-wavelength sensor, such as the PyroUSB PUA2, on high-emissivity materials at high temperatures.

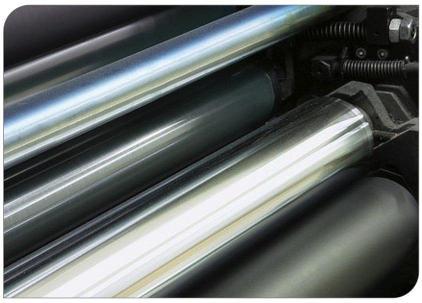
Note: The colour of a surface does not usually affect the emissivity much.

Low emissivity materials

e.g. clean, bare, reflective metal surfaces including iron and steel

Reflective surfaces have a low emissivity and are more difficult to measure accurately.

If the emissivity is known, it is possible to achieve a good reading from a bare metal surface using a short-wavelength sensor.



If it is possible to paint the surface, you can use a low-cost 8 to 14 µm sensor such as the PyroCouple, PyroSigma or PyroMini.

Otherwise, we suggest trying a short-wavelength sensor such as the PyroUSB PUA2 or PyroMini 2.2.

Some metals, most commonly aluminium and copper, are very difficult to measure. Contact Calex for advice.

Transmissive materials

e.g. thin plastic film, silicon

A small number of materials, such as thin film plastics and silicon, transmit most wavelengths of infrared energy. If the plastic film is thinner than about 1-2 mm, there is a possibility that general- purpose IR sensors could "see" through it.

Transmissive materials are difficult to measure. A specialised sensor such as the PyroCube P may be required to achieve a good reading.

Contact Calex for advice.

For more advice on emissivity, including how to measure the emissivity of a surface, see the Guide to Infrared Thermometry on our website, or contact us for help and guidance on a specific application.

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Reflected Energy Compensation

What it is and when to use it

What is reflected energy compensation?

Some of the infrared energy detected by an infrared temperature sensor is not emitted by the target, but is a reflection of its surroundings.

To ensure an accurate reading, the sensor needs to know the temperature of the source of that reflected energy. In most cases, this is the same as the sensor body temperature, so no compensation is required. However, in some applications, the source of the reflected energy is much hotter or colder than the sensor itself.

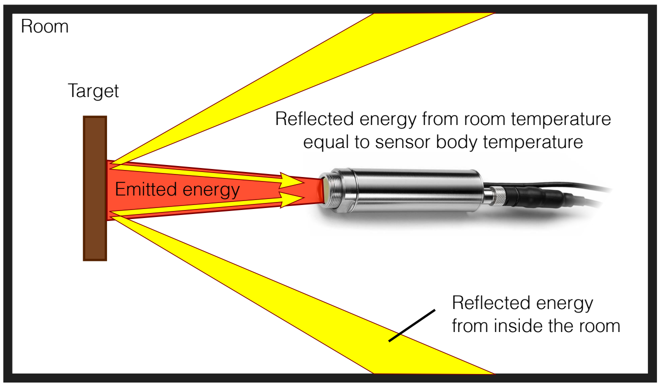
An adjustable setting for reflected energy compensation allows the user to enter the temperature of the surroundings, which in some applications can improve the accuracy of the measurement.

When is reflected energy compensation not required?

In most applications, the surroundings of the target have the same temperature as the sensor itself (e.g. the sensor and target are in the same room).

In this case, the sensor automatically compensates for the reflected energy, so an adjustable setting for reflected energy compensation is not necessary.

Sensor and target are in the same room:
Reflected energy compensation is not required, and should be disabled.

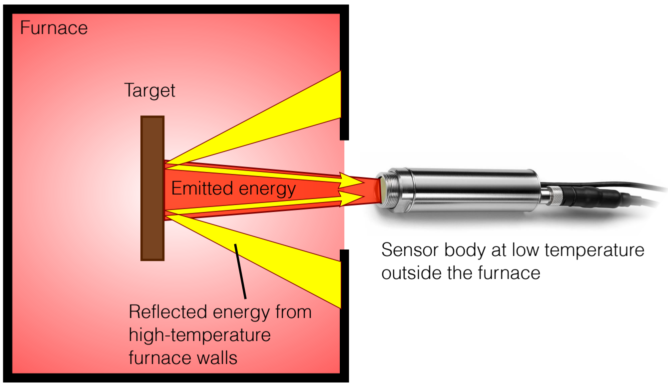


When should reflected energy compensation be used?

If the temperature of the sensor is significantly different from that of the surroundings of the target, then reflected energy compensation should be enabled and set to the temperature of the surroundings of the target.

For example, if the target is inside a furnace and the sensor is outside, the reflected temperature is the temperature inside the furnace.

Target surroundings are significantly hotter or colder than the sensor:
Reflected energy compensation should be enabled.

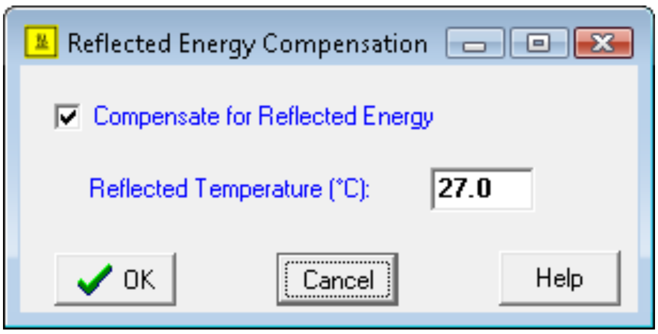


How is reflected energy compensation enabled?

The following sensors have an adjustable reflected energy compensation setting. Here is how to find it on each of them:

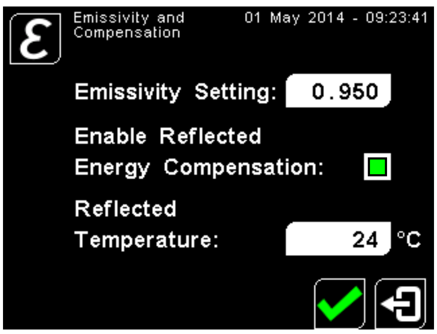
PyroUSB and PyroUSB 2.2 (all models):

In CalexSoft, the Reflected Energy Compensation setting can be found in the Setup menu.



PyroMini models with touch screen interface:

First, unlock the display by entering the password, then go to the Settings screen, and then Emissivity & Compensation.



PyroMini -BB models and all PyroBus models:

The setting can be changed via the Settings menu of a Calex touch screen terminal, or directly via Modbus commands. Please see the sensor operator's guide for details of the Modbus registers to change.

If you have any questions about reflected energy compensation, please do not hesitate to contact Calex.

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Introduction to Using Calex Infrared Temperature Sensors with Third Party Modbus Software

Introduction to Modbus

Modbus is an open communication protocol commonly used in industry. It enables the transmission of data over serial lines between electronic devices such as sensors.

Calex sensors with Modbus use either RS485, RS232 or USB to send and receive data.

A standard RS485 Modbus network consists of 1 Modbus Master, such as a Modbus PLC or software such as a SCADA system, and (depending on the type of device) up to 247 Slave devices such as Calex infrared temperature sensors and output modules. If USB or RS232 is used, typically only one Slave device is connected.

Data Format

The data is sent as binary digits (bits), with a standard data rate of 9600 baud (bits per second). We can also provide other baud rates to suit special requirements – please contact Calex for more information.

Bits are usually interpreted by software in hexadecimal (base 16), with a block of 4 bits being represented by one of 16 characters from 0 to F. A pair of hexadecimal characters represents 8 bits (one byte) of data. Some third-party Modbus software also allows values to be entered in decimal – be sure to check whether this is the case for your software.

Hexadecimal numbers are denoted by the prefix "0x" to distinguish them from decimal numbers. For example, "0x0010" is the hexadecimal number 10 (decimal 16).

The standard data format for Calex sensors is 8 data bits, no parity bits, and 1 stop bit. Most Modbus software can be configured to use this data format, and we can provide special alternative data formats if required.

Storing and Accessing Data in Modbus

Information is stored in the Modbus Slave device in a series of Registers, each with its own address in the device's memory. The size of each Register is 2 bytes (1 Word, 4 hex characters) or more.

Because the Registers are sequential, it is possible to read more than one Register at the same time using a single Modbus command, if required.

To read from or write to a sensor, the Modbus Master (e.g. the SCADA software or the Modbus PLC) sends a command made up of a series of parts, and the Slave device will respond with a message of a corresponding format.

Modbus Commands

The first part of the command is the Modbus Slave address of the sensor (called the Slave ID or Device ID in some software). Each device has its own address from 1 to 247, which must be unique on the network to prevent communication conflicts. Groups of sensors are supplied with sequential Modbus addresses, and they can be changed by the user via the sensor's configuration interface.

The format of the rest of the message depends on the type of command, which is described by a Function Code.

Calex sensors utilise some or all of the following Modbus Function Codes:

Function Code	Action
04 (04 hex)	Read input register(s)
03 (03 hex)	Read holding register(s)
06 (06 hex)	Write single register
16 (10 hex)	Write multiple registers
22 (16 hex)	Mask write register
23 (17 hex)	Read/Write register

For example, to read the measured temperature (a holding register), function code 3 is used.

The Master then tells the Slave which Register address to read from or write to, how much data there is, and (if writing) the value to be written.

At the end of every Modbus command, there are two bytes used for error detection, these are known as the Cyclic Redundancy Check (CRC). The Modbus Slave also calculates the CRC and compares it to the CRC from the Master. If the CRCs are different, an error will result. Modbus software handles CRC calculation automatically.

List of Modbus Registers (Modbus Map)

A Modbus Map is a list of Register addresses that describes what the data is (e.g. the filtered temperature); where the data is stored in the device's memory (the register address), the length of the register, and how the data is stored (for example the emissivity setting 0.95 is stored in Calex sensors as 9500, and the measured temperature 23.5°C is stored as 235).

This list of registers can be found in the instruction manual of each Calex Modbus infrared temperature sensor.

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Examples of Using Modbus with Calex Infrared Temperature Sensors

Example 1 - To Read the Filtered Object Temperature

In this example, a PyroMiniBus sensor with address 17 is the Modbus Slave.

The Modbus Master sends the command 11 03 000E 0001 59E7

11	Slave Address (11 hex is the Modbus address of the sensor i.e. 17 in decimal)
03	Function Code 3 (Read Register)
000E	Data Address of the first register requested (From the PyroMiniBus manual, address 0x000E = Filtered Object Temperature)
0001	Total number of registers requested. (This register has a length of 1 Word, as shown in the PyroMiniBus manual)
59E7	CRC (If possible, let the software automatically calculate this)

The Modbus Slave responds with the requested data. The response is 11 03 02 00E7 CD39

11	Slave Address (11 hex = address 17)
03	Function Code 3 (Read Register)
02	The number of data bytes to follow (1 register x 2 bytes each = 2 bytes total = 4 hex characters)
00E7	The contents of register 000E; the measured temperature (0x00E7 = decimal 231 = 23.1°C) *Note, as stated in the PyroMiniBus manual, the temperature is in tenths of a degree.*
CD39	CRC

Example 2 - To Write the Emissivity Setting

In this example, a PyroMini sensor with address 176 is the Modbus Slave.

The emissivity setting for the sensor is to be set to 0.95.

The Modbus Master sends the command B0 06 0014 251C 76C9

B0	Slave Address (0xB0 is the Modbus address of the sensor i.e. 176 in decimal)
06	Function Code 6 (Write Register)
0014	Data Address of the first register requested (from the Modbus table in the PyroMini instruction manual, address 0x0014 = Emissivity Setting)
251C	Value to write (emissivity setting 0.95) The PyroMini manual states that 1 LSB (Least Significant Bit) = 0.0001. Emissivity setting 0.95 = decimal 9500 = hex 251C
76C9	CRC

The Modbus Slave then sends a response to confirm the data has been written – the response is B0 06 02 251C ECA4

B0	Slave Address (0xB0 is address 176 in decimal)
06	Function Code 6 (Write Register)
02	The number of data bytes to follow (1 register x 2 bytes each = 2 bytes total)
251C	The contents of register 0014; the emissivity value (0x251C = decimal 9500 = emissivity 0.95) *Note: the units of the emissivity value are 0.0001*
ECA4	CRC

More information

For more information on how Modbus works, please use the following links:

http://www.simplymodbus.ca

http://www.modbus.org/specs.php

Protective Windows

for Infrared Temperature Sensors

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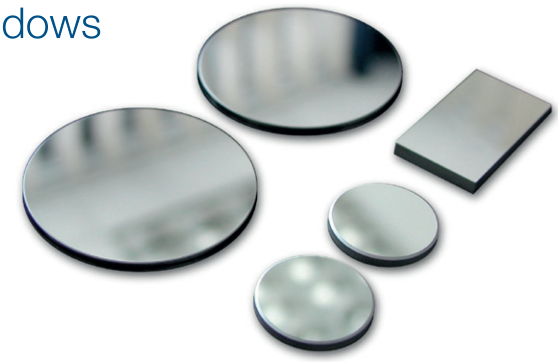
IR Viewport Windows



- Mount the window in a flange on your process
- Protect the sensor from high pressure, high temperature or vacuum
- Choice of materials to suit a range of sensors and applications
- Wide range of standard sizes, or custom-made to suit your requirements

Calex provides IR-transmissive windows in a choice of sizes. Windows are commonly circular, however other shapes are available, and we can provide windows manufactured to suit your requirements.

The material should be chosen to suit the type of sensor and the conditions in the process, such as the pressure and temperature. Short-wavelength sensors, such as the PyroUSB 2.2, PyroMini 2.2 and FibreMini, can view through glass, quartz and calcium fluoride. Other materials, such as zinc selenide and germanium, are required for use with long-wavelength (8 to 14 µm) sensors.

The sensor must have an adjustable emissivity setting to compensate for the small percentage of infrared energy lost to reflection and absorption by the window. Use this formula to ensure maximum accuracy.

Emissivity setting =
actual emissivity of target x transmission of window

MATERIALS

Window Material	Transmission Range	Transmission (approx.)	Maximum Temperature
Zinc selenide (ZnSe)	4 to 14 µm	72%	250°C
Germanium (Ge)	2 to 14 µm	46% uncoated (around 90% if anti-reflective coated)	70°C
Calcium fluoride (CaF2)	0.2 to 7 µm	94%	1200°C
Sapphire (Al2O3)	0.2 to 4.5 µm	85%	2000°C
Quartz Crystal (SiO2)	0.4 to 3 µm	92%	490°C

ORDERING

These windows are inexpensive compared with the cost of replacing the lens of an infrared temperature sensor. Contact Calex for a quotation, or for assistance on choosing a suitable window.

Protective Plastic Window -

ideal for the food and pharmaceutical industries

The protective plastic window models PWS and PWL are designed to help protect the germanium lens of Calex infrared temperature sensors from mechanical damage, and to help retain fragments of the lens if it is damaged.

To use the window, simply screw the stainless steel window holder onto the front of the sensor, tighten with a spanner, adjust the emissivity setting using the formula below, and begin taking measurements.

Emissivity setting = actual emissivity of target x 0.768

SPECIFICATIONS

Model	PWS	PWL
Mounting	M16 x 1 mm	M20 x 1 mm
Compatible With	PyroEpsilon, PyroBus, PyroMini*, PyroMiniBus, PyroMiniUSB	PyroUSB*
Transmission (8 to 14 µm)	76.8%	76.8%
Ambient Temperature Range	0°C to 100°C**	0°C to 100°C**
Window material	IR-transmissive plastic	IR-transmissive plastic
Holder material	Stainless steel	Stainless steel

* Not compatible with PyroUSB 2.2 or PyroMini 2.2 models

** Do not exceed the ambient temperature limits of the sensor.