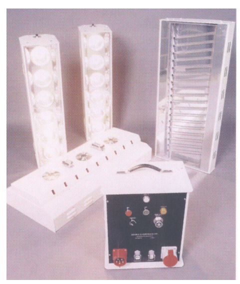
DOUBLE R CONTROLS LTD

TECHNICAL INFORMATION ON THE PRINCIPLES OF INFRA RED



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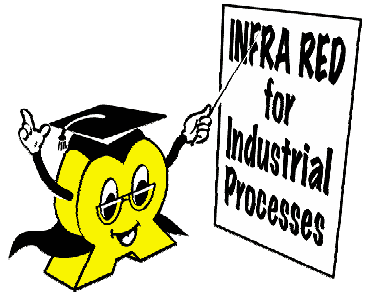

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Updates To Infra Red Document

1. Original Document, date July 2001
2. Original Text Updates, July 2007
3. Additional Information, Added September 2007

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AN INTRODUCTION TO ELECTRIC INFRA RED

The potential for electric Infra Red technology in industry is enormous. It can be used for a wide range of heating, drying and curing applications. Because of its compact size it is easy to fit to existing process lines to achieve increased output in conjunction with or as a replacement for more conventional heating methods. Electric Infra Red is well suited to both continuous and batch production processes.

Double R Controls Ltd. manufacture a full range of robustly constructed Infra Red heater modules suitable for industrial use. From a basic design, these enclosures can be readily tailored to meet the specific requirements of the customer and their process. Associated control systems form part of a typical system, using Double R Controls Ltd.` PHAB controller, which provides all necessary soft start facilities with selectable manual or automatic power output control.

A large selection of equipment is available, the choice of which will depend on the material to be processed and the process conditions. For example, some materials will absorb more energy at one wavelength than at another because of their colour, texture or chemical structure. Double R Controls Ltd. therefore offers a full range of test equipment to any prospective customer to undertake trials in their production environment.

It is important that anyone wishing to use electric Infra Red has a basic understanding of Infra Red and its terminology. To this end, Double R Controls Ltd. attach herewith information, which can be downloaded and printed by individuals for use by them to ensure that everyone has a full understanding of this technology. This document will be continually updated and shows the revision number so that anyone printing this document is fully aware of which version he or she has.

When understood and correctly applied electric Infra Red process heating will provide wide-ranging benefits to industry.

Double R Controls Ltd. have a range of test equipment which can be loaned/hired to undertake basic tests on samples of material to determine the optimum wavelength of Infra Red. Please consult our sales department for further information relating to the test equipment available.

There is a section showing the use of Infra Red when drying water-based materials. This section also includes practical examples where Infra Red equipment has been incorporated into process to remove the water after its application. From this the benefits can be seen of the use of Infra Red.

Heat Transfer

Materials can be heated by any of three familiar methods:

- Conduction – by contact with a heat source.
- Convection – by the movement of a hot fluid or gas, such as air, over the material.
- Radiant Energy – by the use of Infra Red, but also by microwaves and radio frequency energy (in the case of non-metallic materials) or by induction (in the case of metallic materials).

Conduction

Conductive heating is achieved by placing an article into touch contact with a heat source, Figure 1. The rate of heat transfer is determined by several factors, not just the thermal properties and difference in temperature of the two bodies. The surface conditions over the contact area, the pressure of contact and the nature of any gas, liquid or solid films at the interface all play a part in the conductive process.

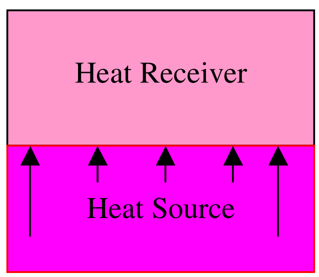


Figure 1

Convection

Convective heating relies on the movement of hot fluid or gas, such as air, which acts as a carrier of heat from one body to another, Figure 2. In industry forced convection is commonly used, that is, the gas or liquid is directed towards the article by a fan or pump. Natural convection occurs because gas or liquid at different temperatures have different densities. An ordinary central heating radiator emits heat mainly through " natural convection. "

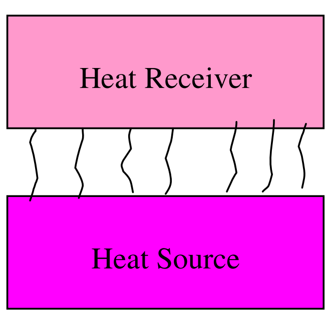


Figure 2

Radiant Energy

The use of radiant energy provides certain advantages over conductive and convective heat transfer:

- NO contact is necessary with the material to be heated, Figure 3.
- High heating power densities can be used (if required by the process).
- Much shorter heating times.
- Infra Red systems usually have fast response.

With radiant techniques, it is energy that is transferred not heat. The material converts the radiated energy into heat by absorption. It is therefore imperative that there is no contamination in the air between the heat source and the product being heated, otherwise the radiated energy will be absorbed by this contamination. Moisture vapour is a particular problem (i.e. clouds) and, therefore, if the process is evaporating moisture it is essential that this extracted so that it does not cause a barrier between the energy source and the product.

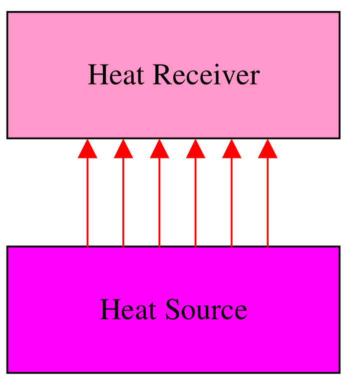


Figure 3

With conductive or convective heat transfer, doubling the source temperature approximately doubles the heat transferred. With radiant heat transfer, doubling the temperature of the source, increases the radiant energy density by a factor of 16.

It is important to remember that a combination in the same process of radiant and conductive or convective heating techniques is widely used and often provides answers to difficult problems (for example, drying processes where hot air is essential to remove the evaporating water).

Electric Infra Red

What Is Infra Red?

As indicated above, Infra Red is radiant energy. More accurately it is electromagnetic radiation and like X-rays, UV, visible light, microwaves, dielectric and induction is part of the electromagnetic spectrum. The difference between these radiations is simply their frequency and wavelength (frequency x wavelength = a constant [the speed of light] so that as frequency increases, wavelength decreases).

Infra Red is energy emitted by any object, which has a temperature above absolute zero (that is °K or minus 273°C). Infra Red is produced as a continuous band of wavelength in the range 0.8 microns to 1mm. As temperature is increased, the intensity of Infra Red radiation increases considerably (proportional to absolute temperature to the power 4, that is T^4, so if the absolute temperature of an Infra Red emitter is doubled it will emit 16 times as much Infra Red per unit area of surface). For effective heating of products with Infra Red it is important that the temperature of the Infra Red emitter is significantly higher than that of the product, so that there is a net energy flow to the product.

Another consequence of increase in temperature on Infra Red radiation is that its wavelength decreases, and more of the energy is radiated at shorter Infra Red wavelengths. We divide Infra Red for process heating into 3 bands – short, medium and long wavelength. Although, for example a medium wave emitter will produce most of its energy in the medium Infra Red band, it will also emit some energy in short and long wave bands, and also some visible light (it will appear 'red hot').

Most lasers, particularly those used for cutting and surface heat treatment, are in effect Infra Red emitters. The difference between lasers and convectional Infra Red emitters is that lasers are essentially monochromatic radiation (that is, a single wavelength, for example 10.6 microns for a CO_2 laser) and are restricted to a very small cross-sectional area heating i.e. high power density.

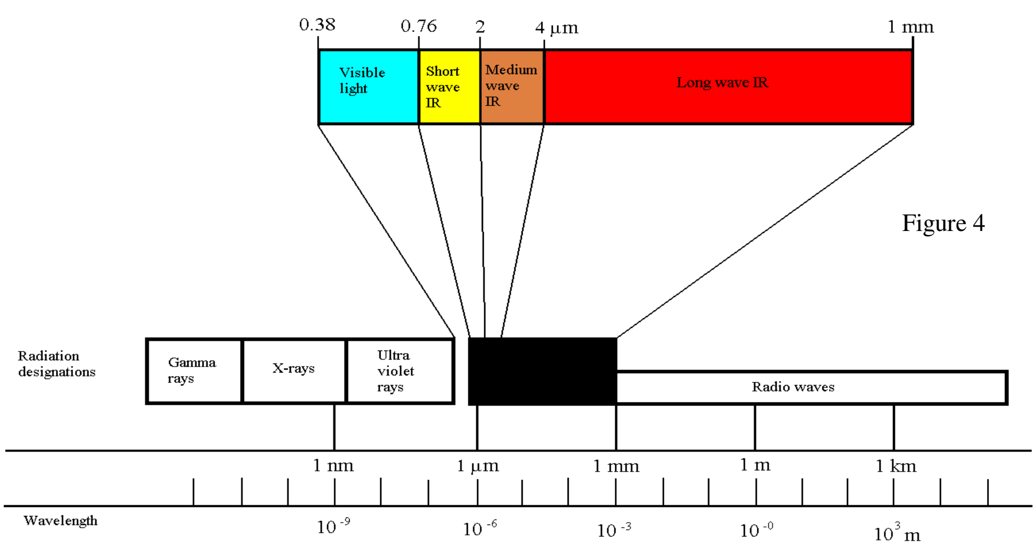


Figure 4

Infra Red is produced as a continuous band of wavelengths in the range of 0.8 microns to 1mm. As temperature is increased the intensity of Infra Red radiant energy increases considerably (proportional to absolute temperature to the power 4, that is T^4, so if the absolute temperature of an Infra Red emitter is doubled, it will give out 16 times as much Infra Red per unit area of surface – The Stefan-Boltzmann Law).

For simplicity Infra Red is divided into 3 wavebands:

- Short wave - less than 2 microns
- Medium wave - between 2 and 4 microns
- Long wave - above 4 microns.

A micron or micrometer is one millionth of a metre.

There is a relationship between temperature and wavelength. As the temperature from an emitter increases then the peak wavelength becomes shorter and vice versa, Figure 5.

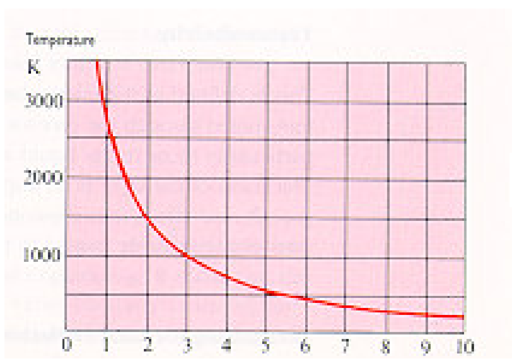


Figure 5

The peak wavelength at which maximum Infra Red emission occurs is expressed according to Wien`s Law which in its simplest interpretation is as follows:

$$\text{Peak Wavelength } (\mu m) = \frac{2898}{\text{Absolute Temperature (K)}}$$

e.g. Emitter operating at 2200 ºC (2473K)

$$\text{Peak Wavelength } (\mu m) = \frac{2898}{2473} = 1.17\ (\mu m)$$

A source of Infra Red will usually produce energy across a continuous spectrum of wavelengths depending on the source temperature, Figure 6. Although, for example, a medium wave emitter will produce most of its energy in the medium Infra Red band, it will also emit some energy in the short and long wave bands, and also some visible light (it will appear "red hot").

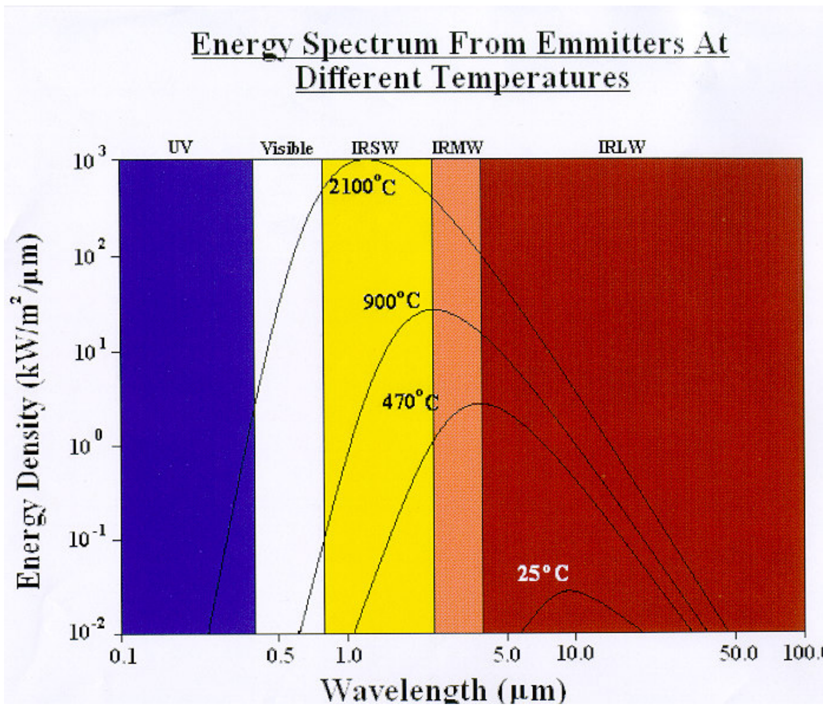


Figure 6

The above data relates to perfect radiators (black bodies). In practice Infra Red emitters have an emissivity of less than 1 so are not perfect emitters, therefore their radiant emission will be lower than that indicated.

Emissivty is defined as a measure of radiant efficiency. If an object has an emissivity factor of 1.0, then it is the perfect radiator and absorber. This is referred to as the perfect black body. If an object has an emissivity of 0, then it is a perfect reflector, and does not absorb any radiant heat.

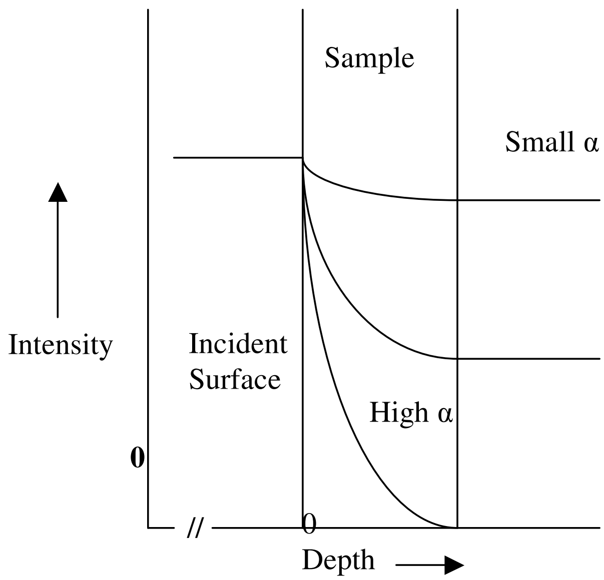
How Does Infra Red Heat Materials?

When electromagnetic radiation encounters a material three things can happen. The radiation can be reflective (like light from a mirror), it can pass through the material (transmitted – like light through a sheet of glass) or it can be absorbed. Only absorption produces an heating effect.

Materials absorb Infra Red radiation in different ways. Most non-metallic materials absorb Infra Red energy because certain parts of their molecular structure are vibrated by particular wavelengths of Infra Red energy. For example, materials containing water (that is what we call 'hydroxyl groups', - OH) absorb Infra Red intensely between 2.5 and 3 microns and to a smaller extent at some other wavelengths. Materials containing CH, NH and other similar chemicals groups (e.g. plastics and textiles) have a number of absorption bands at longer wavelengths (from about 3.5 microns upwards). Silicate glasses absorb beyond 3.5 microns because of the Si-O bond, as well as in the region 2.5 to 3 microns because of the presence of –OH groups. Metals absorb Infra Red due to the interaction of the electro-magnetic energy with the electronic structure of the metal atoms.

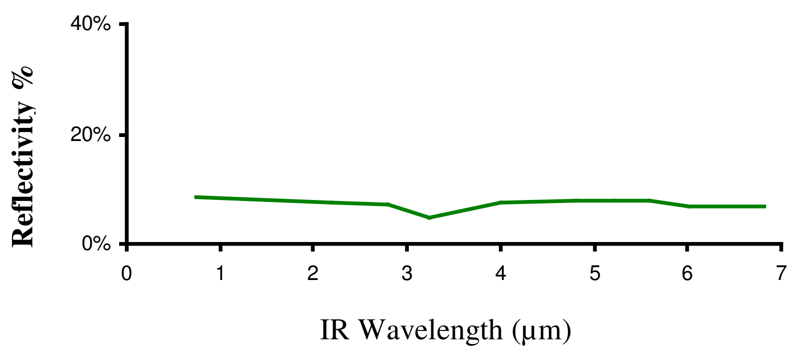
For most materials, Infra Red can be considered as a surface heating technique i.e. a piece of toast. That is the Infra Red energy is absorbed in the surface layer of the material. It therefore has some similarities to conductive and convective heating, but can provide very much more intense heating if that is a process requirement. For some materials, such as transparent plastics, glass, paper and textiles, Infra Red can provide a varying degree of 'through heating', that is the radiant energy will penetrate into the material and produce an **instantaneous** heating effect to some depth. As the Infra Red energy penetrates into the material, its intensity decreases non-linearly with depth (exponentially). As a consequence a temperature gradient can be created, the magnitude of the gradient being dependent on the absorption factor. When the absorption factor is small, the temperature gradient is small (and heating is low); with a high absorption factor, the temperature gradient is high, with most of the energy absorbed in the surface layers. A very high absorption factor essentially produces surface heating.
Because the absorption of some materials to Infra Red varies with wavelength it is possible by choice of the type of Infra Red emitter to obtain either surface heating or different degrees of through or bulk heating as required by the process.

Graphical Illustration Of Attenuation Of Infra Red Through A Sample

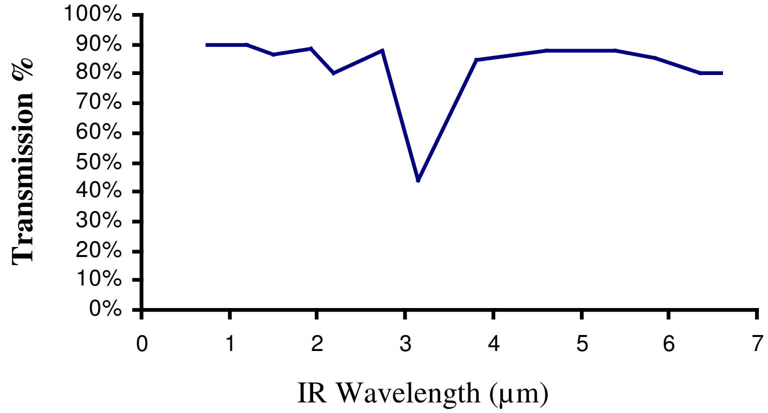


BEER – LAMBERT LAW: $I_x = I_o e^{-\alpha x}$
Were α = attenuation coefficient.

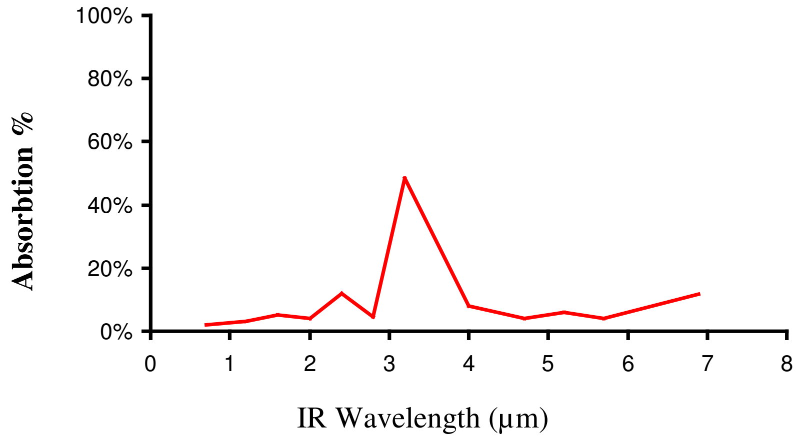
Infra Red Reflectivity Of Non Pigmented Polyethylene



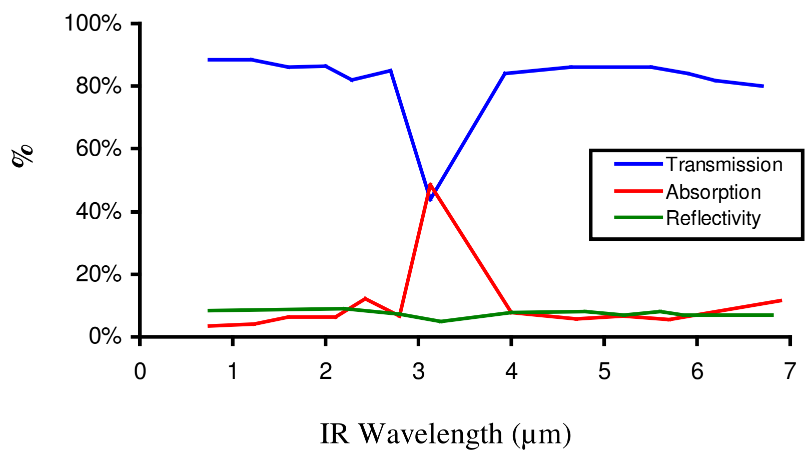
Infra Red Transmission Of Non Pigmented Polyethylene



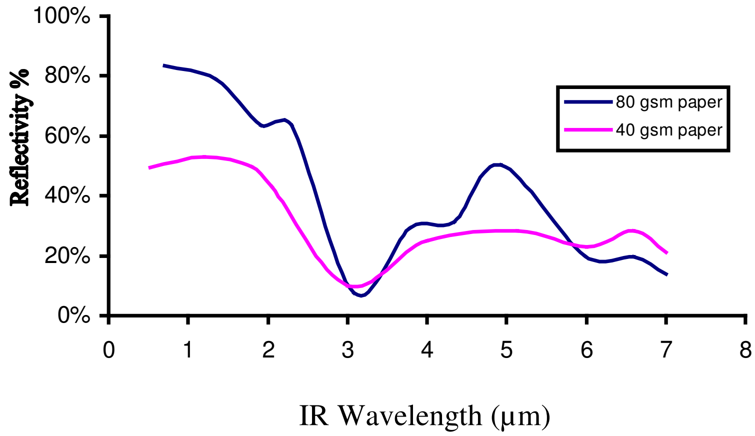
Infra Red Absorption Of Non Pigmented Polyethylene



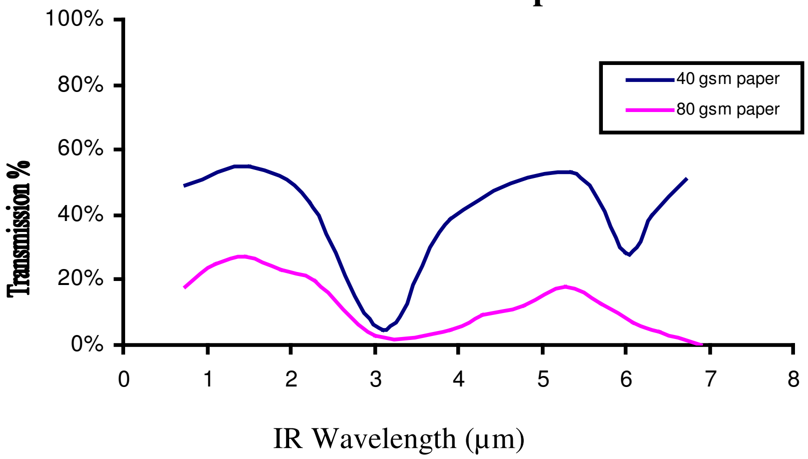
Infra Red Properties Of Non Pigmented Polyethylene



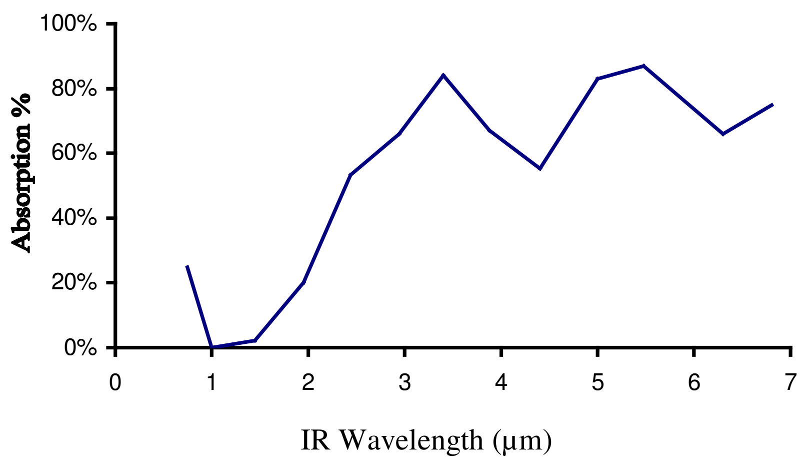
Infra Red Reflectivity Of White Paper



Infra Red Transmission Of White Paper



Absorption Of Clear Perspex 0.55mm Thick



Increasing Temperature Of An Infra Red Emitter Produces The Following:

- Substantially more Infra Red energy at shorter wavelengths; more at ALL wavelengths
- The maximum radiant power density occurs at a shorter wavelengths
- Total amount of Infra Red energy increases considerably (e.g. if absolute temperature of emitter is doubled, Infra Red output is increased by 16 times; the T^4 law)

Typical Power Densities

	INPUT POWER DENSITY	RADIANT OUTPUT DENSITY
	KW/M^2 (Estimated)	
Long wave ceramic	40	30
Metal sheathed elements	40	30
Medium wave tubular (“quartz”)	60	50
Short wave conical bulbs	25	15
Short wave tubes	90	80
Short wave tubes (cooled)	400	350

Lasers

"Light amplification by stimulated emission of radiation"

High intensity emissions at monochromatic wavelengths - coherent radiation.
High power densities and very small areas

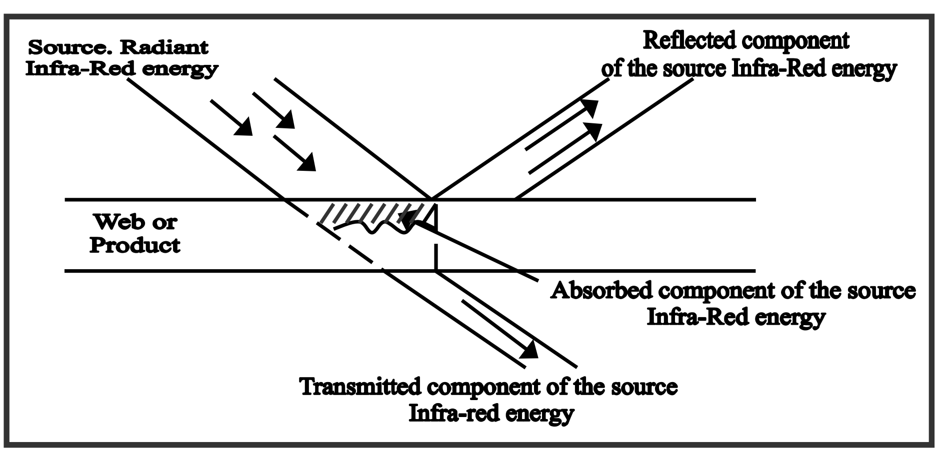
<u>Types</u>: **Ruby**
Helium-neon
Argon (0.351-0.529µm)
Carbon dioxide (10.6µm)
Carbon monoxide (5.4µm)
YAG (1.06µm)
UV laser (Excimer)

<u>Uses</u>: **Cutting**
Machining (micro)
Welding
Surface Treatment

Infra Red Drying Of Water Based Materials

When drying a product that has incorporated water in the process it is essential that the water vapour, when evaporated from the product, be removed, therefore, a combined system provides a much-improved process. By this we mean the use of Infra Red plus convection or air movement within the process. Infra Red would provide the heat input and the convected air provides the removal of the evaporated water as well as surface cooling or in some cases heating as well as temperature equalisation. The design of the total system is of paramount importance for energy efficiency. One of the main advantages of the Infra Red systems is that we can vary the power across the width of the product and therefore assist in equalisation of the temperature across the product and it is an excellent transfer system without making the product itself.

Infra Red Energy Transfer



Calculation Of Energy Input Requirements For A Process
(How Many KW Of Infra Red Energy Do I Need?)

Energy Input Requirements

- Determine process mass through put rate Kg/hour
- If drying, how much water is removed
- Change in temperature required (ΔT)
- Thermal properties of materials (specific heat; if drying, latent heat)

- *Energy Required = Mass x SH (LH) x Temperature Rise (ΔT)*

Energy Input Requirements – 2

- *Energy required = mass x SH (LH) x ΔT*

Attempt to calculate "Energy required" in either joules/second or kilojoules/second or kJ/s = kW

Then: J/s = Watts

Specific Heat Capacity

This is the amount of energy required to raise the temperature of 1 kg of material by I degree K.

Reference books will give the information in:
Joules (J) per kg per degree K (J/kg/°K)

NOTE: BECAUSE WE LOOK AT CHANGE IN TEMPERATURE WE CAN ASSUME DEGREES KELVIN = DEGREES CENTIGRADE.

Specific Latent Heat (lμh)

It is the amount of energy required to convert 1 kg of material from a solid to a liquid without changing its temperature (fusion) or from a liquid to a vapour (vaporization).

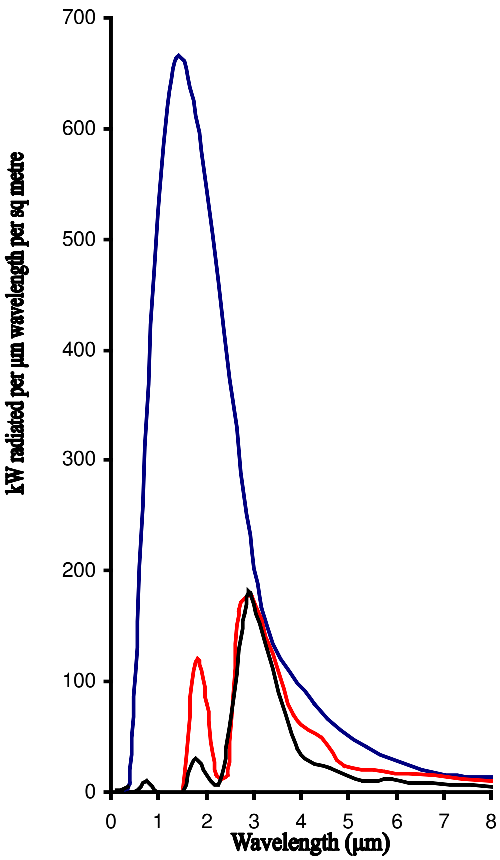
Information is given in:
Joules (J) or kilojoules (kJ) per kg
(J/kg or kJ/kg)

NOTE: 1 KILOJOULE = 1000 JOULES

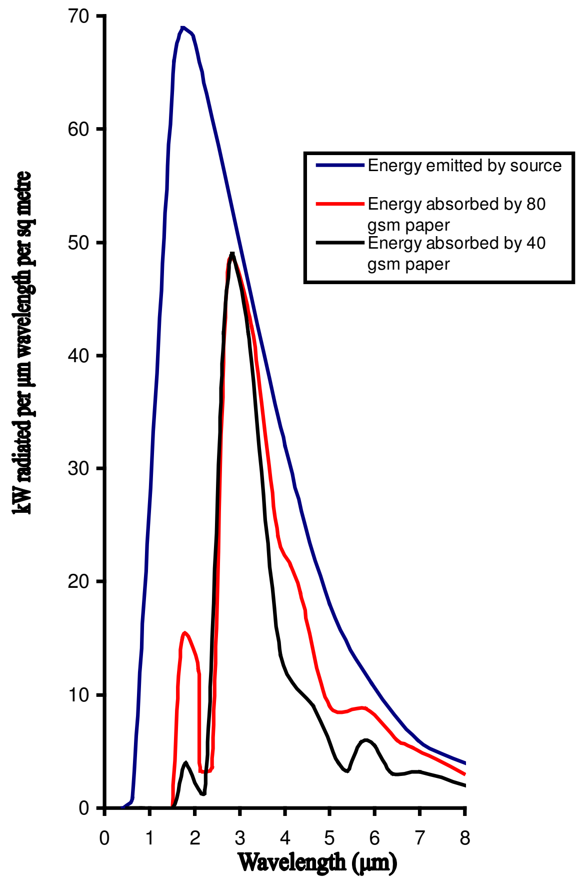
Temperature And Wavelength Of Typical Infra Red Emitters

	Wavelength (Microns)	Typical Emitter Temperature (°C)	Visible Appearance
Short Wave (Near IR)	0.76 - 2	2100	Very Bright, White Hot
Medium Wave	2 - 4	750 - 1200	Red To Light Orange
Long Wave (Far IR)	Beyond 4	Below 600	No Visible Colour

Typical Paper Absorption From Different Infra Red Emitters

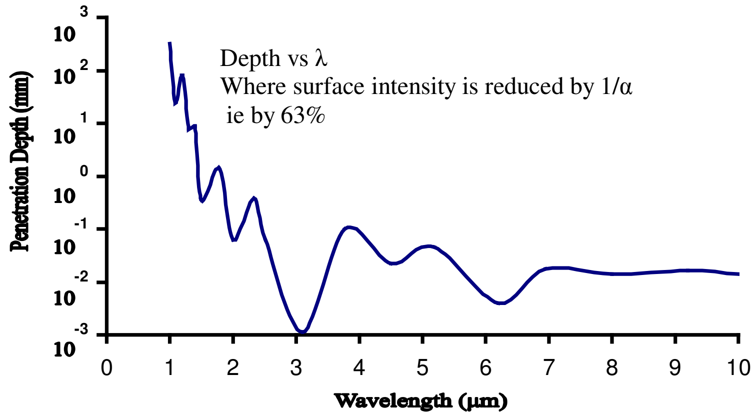


SOURCE TEMP 2400K (SHORT WAVE)



SOURCE TEMP 1400K (MEDIUM WAVE)

Penetration Of Infra Red Energy Into Water



Heating And Evaporation Of Water Using Infra Red In A Industrial Process

The conversion of raw materials to finished products and components involves many processes. A large proportion of these processes require heating. It is useful when investigating how Infra Red can be used to provide the heat input for a process to have a general appreciation of the heating processes, which are available, and how Infra Red fits into this picture.

Heat can be transferred to materials by three processes:

1. By contact with a hot surface ('conductive' heat transfer)
2. By using hot air (often called 'convective heat transfer)
3. By using radiant energy (for example, Infra Red, but can also be by microwaves, by radio frequency [dielectric] or by induction)

The use of radiant energy provides certain advantages over conductive and convective heat transfer in that NO contact is necessary with the material to be heated from the heater energy source. High heating power densities can be used (if required by the process) giving much shorter heating times. Infra Red systems usually have fast response. For some material combinations selective heating of one material component is possible. Strictly, with radiant techniques, it is energy that is transferred, NOT heat – the material converts the radiated energy to heat by absorption.

It is important to remember that a combination in the same process of radiant and conductive or convective heating techniques is widely used and often provides answers to difficult problems (for example a drying processes where hot air is essential to remove the evaporated water).

Combined Heating With Infra Red

Although infra red is used alone as a heating technique, there are many processes where it can be used more effectively in combination with other heating techniques, particularly convection (hot air).

The introduction of moving air stream into an heating installation can provide a means of temperature control. For example, in a heating application in which components of variable cross section are heated, Infra Red will provide a means for rapid heating but without very sophisticated sensing and control systems overheating of the thinner sections can result. The use of an air stream at the desired maximum temperature helps heat transfer in two ways, namely providing extra heat for the thicker sections and potential cooling for the thinner sections. If the process requires the removal of water, the introduction of an air stream is important to remove the evaporated water.

Estimation Of Amount Of Infra Red Required For A Process

In order to estimate the amount of Infra Red required for a particular heating process, several parameters must be known, namely:

- Amount of material to be processed in a given time (if this is a variable, use the highest throughput)
- The temperature increase to be achieved (again if a variable, use the largest increase)
- The specific heat of the material(s) to be heated
- Is it a drying application, if so how much water is to be removed?

The basic equation for calculating the heat requirements is:

Heat required = mass throughout x specific heat of material x increase in temperature.

$$\mathbf{Q = m \times C_p \times \Delta T}$$

Units: It is easiest to work in metric units! Preferably, kilograms per second for mass throughput and degrees Celsius for temperature change. Reference books will give specific heats for most common materials, alternatively your customer might be able to provide this data. It is essential that the specific heat data be given in joules (J) or kilojoules (kJ) per kg per degree C or K. If drying is taking place, you will also need to know the latent heat of vaporisation of the liquid (usually water) and this will be in J or kJ per kg. Using this information, the equation above will provide the energy required in units of joules per second, and conveniently, 1 J/s is 1 watt, so1000 J/s (or 1kJ/s) is 1 kW.

[For those who still work in BTU's, etc, you will need specific heat data in BTU/Lb/ºF and then need to convert your BTU's (per second) to joules (per second) by: 1 BTU = 1055 joules, ***but*** *it is preferable to work in metric units because at the end of the day your Infra Red emitters are rated in kW!!].*

Sample Calculation 1

A manufacturer wishes to heat 300 kg an hour of metal components (mild steel) from ambient to 70ºC. How much Infra Red will be required to carry out this progress?

From reference books, the specific heat of mild steel is given as 420 J/kg/°K [For this calculation we can take this as the same as temperature is in ºC]

Step 1: Calculate mass through put (m) per second:

300 kg per hour = 300/60x60 kg/sec

Step 2: Establish the temperature increase (ΔT) required:

Ambient to 70ºC, assume for a factory of 15ºC, so the temperature change is 70 – 15 = 55 degrees

Step 3: Calculate heat input requirement:

$$Q = m \times Cp \times \Delta T$$

$$Q = (300 / 60 \times 60) \times 420 \times 55 \text{ Joules/second}$$

$$= 1925 \text{ Joules/second}$$

$$= 1925/1000 \text{ kJ/sec } (= \text{kW})$$

$$= 1.925 \text{ kW}$$

Comments: *This value is* ***energy*** *input requirement; the amount of Infra Red we will need will be larger because the heating systems will not be 100% efficient. There are some losses in converting electrical power to Infra Red; there will be losses in transferring the Infra Red energy from the emitter to the product that will be very dependant on design of the heating enclosure and materials used in its construction. Consequently the installed power of Infra Red will be greater than the calculated heat requirement.*

Sample Calculation 2

A textile manufacture wishes to dry his product (a synthetic woven textile web) after a washing operation. The products he wishes to dry vary in weight from 75 to 150 grammes/metre^2 dry and will have a moisture content of 20% on a dry weight basis. The webs will vary in width from 1 to 1.5 metres and pass through the drying section (which is part of a processing line) at 20 to 50 metres per minute.

How much Infra Red is required to carry out the drying process? Is it necessary to include any other factors?

Comments: *This example illustrates a production line that has a variable throughput and hence will have a variable heat input requirement. If more information is not available on throughputs, for example, if the heavier fabrics are put through at the slower speeds, then calculate the heat requirement based on the maximum throughput, that is, heaviest fabric, maximum width and highest speed.*

The synthetic textile web will have a specific heat of 2000 J/kg/K.
Water has a specific heat of 4200 J/kg/K and a latent heat of evaporation of 2260 **kJ**/k

Step 1: Calculate mass throughput: 'worst' case:

[Two parts: textile and water]

Textile: 150 $g/m^{2,}$ 1.5m wide, 50m/min

Area passed through = 1.5 x 50 m2/min

= 1.5 x 50 / 60 m2/sec

Weight passed through = 1.5 x 50 / 60 x 0.15 kg/sec

Water: 20% dry weight basis is 20% of the dry weight of textile hence weight of water going into Infra Red dying section is 20% of weight of

Textile = 1.5 x 50 / 60 x 0.15 x 20/100 kg/sec

Step 2: Establish temperature change required.

No information given on inlet temperature, so assume 20°C.

Outlet temperature: In a dryer removing water, assume outlet temperature of 100°C unless manufacture specifies otherwise (although water will evaporate at a temperature below 100°C, taking the boiling point maximises the calculation of heat input requirements).

Hence, temperature change is 20 to 100, that is 80°C (or K)

Step 3: Calculate heat input requirement.

[Three parts: textile, water and evaporation of water]

Energy input textile web:

Q (web) $= m \times C_p \times \Delta T$

= (1.5x50/60x0.15) x 2000x 80 = 37500 J/sec

= 37.5 kJ/sec

Energy into liquid water:

Q (water) $= m \times C_p \times \Delta T$

= 1.5x50/60x0.15x0.2) x 4200 x 80 = 12600 J/sec

= 12.6 kJ/sec

Energy required to evaporate water:

Q (evap water) = mass x latent heat of evaporation

= (1.5x50/60x0.15x0.2) x 2260 = 84.75 kJ/sec

[NOTE: latent heat is in kJ/kg because it is such a large number]

Therefore, total heat required is: 37.5 + 12.6 + 84.75 = 134.85 kJ/sec

= 134.85 kW

Comments: *As can be seen in this example, almost double the energy is required to evaporate water as to heat liquid water and the textile fabric to the evaporation temperature. The same comments apply as for example 1 in connection with estimating the Infra Red power required for this application.*

In addition, the secondary question of what else should be considered needs to be answered and its implications on the heat input requirements. Answers on a post card please.

Disclaimer.

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