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Technology and Applications of Infrared Heating in the Industrial Area

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Abstract: This research describes the technology and applications of infrared heating. The basic principles behind the technology and its important properties are shown. It is shown that the desired transfer of thermal energy is dependant on several factors, like emissivity and shape coefficient. However, in many industrial production processes infrared heating offers advantages with respect to conventional heating techniques such as convection or hot air ovens. Infrared heating is after all characterised by high energy densities, rapid heating and relative ease of installation. All these advantages offer the possibility of higher production speeds, more compact installations and lower investment costs.

Key words: Energy transfer, power dissipation, infrared, electromagnetic spectrum

INTRODUCTION

Infrared radiation is the same kind of radiation as radiation from the sun. A heat source at high temperature emits infrared waves that are subsequently absorbed by a colder object. Thus the heat is transferred in essence by electromagnetic radiation, without the aid of an intermediary.

In high temperature resistance ovens, heat is also transferred to a large extent by radiation. However, for infrared heating it is typical that the heat source irradiates the object to be heated directly. Sometimes reflective surfaces (mirrors) are used to focus or direct the rays. Infrared heating is a typical surface treatment technique and lends itself preferentially to heating products with a simple shape.

THE ELECTROMAGNETIC SPECTRUM

Infrared radiation is a form of electromagnetic radiation. In the electromagnetic frequency spectrum, the area of infrared waves is located between visible light and microwaves that is to say in the area between 0.76 and 1000 μm (wavelength). However, for industrial heating processes only the area between 0.76 and 10 μm is interesting. In this zone 3 regions are traditionally distinguished:

- Short infrared waves 0.76-2 μm
- Medium infrared waves 2-4 μm
- Long infrared waves 4-10 μm

Radiating bodies: The thermal radiation that is transmitted through a surface consists of a continuous spectrum of wavelengths. The spectral distribution and the quantity of radiated energy are dependent upon the temperature of the surface and the condition of the surface (Siegel and Howell, 2002). Properties of radiating bodies are traditionally investigated using the concept of a black radiator or black body. A black body is by definition a body that absorbs all the radiation it receives ($\alpha = 1$). It can be demonstrated that such an object emits more radiation for a given temperature than any other object.

Two important laws describe the radiating phenomena:

The stefan-boltzmann law: The total power density of a radiating surface (i.e., the total emissivity) is proportional to the fourth power of the surface temperature.

$$M = \varepsilon \cdot \sigma \cdot T^4 \; [W\, m^{-2}] \tag{1}$$

σ : Experimental Stefan-Boltzmann constant $5.73.\ 10\text{-}8\ [W\ (m^2K^4)^{-1}]$
T : Absolute surface temperature [K]
ε : Emissivity coefficient

The emission coefficient ε is dependent upon the temperature, the properties of the object that is radiating and the wavelength. For industrial applications ε. will be regarded in most cases as a constant, whose chosen value is representative for the temperature range concerned and the condition of the surface. The body is then known as a grey radiator (constant ε).

Wien's law: It gives an expression for the wavelength at which the monochromatic emissivity is a maximum.

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$$T\,\lambda_{MAX} = C \quad (2)$$

λ_{MAX} : Wavelength [μm]
T : Absolute surface temperature [K]
C : 2898 μm.K

Wien's law is important in practice for the choice of an infrared radiator. After all, the temperature of the radiator will often be chosen in such a way that λ max lies in the vicinity of a maximum in the absorption spectrum of the material that is to be heated. In that manner, efficient heating is obtained.

Absorption of radiation: The success of an infrared application is to a great extent dependent upon the absorptive behaviour of the material to be heated. Only absorbed radiation is converted into heat, after all.

Two important properties of energy transfer by radiation have to be taken into consideration when using infrared heating:

- The relative position of radiator and receiver is important (cos α_1, cos α_2).
- The greater the distance between radiator and receiver, the lower the density of the energy received ($1/R^2$).

In reality, only a fraction of the incident radiation is absorbed and converted into heat. The absorption coefficient α is defined as the ratio of the absorbed to the incident flux. The absorption coefficient α is often dependent upon the wavelength of the incident radiation. In the design of an infrared heating installation, this behaviour is an important factor: It determines the choice of the optimum radiating element (Strack *et al.*, 2005).

Furthermore, the absorption coefficient is also influenced by the properties of the irradiated surface: surface roughness, chemical properties, colour, thickness of the material, temperature etc (Fig. 1).

Transfer of energy by radiation: The transfer of energy is completely determined by the temperature of the two bodies, their geometry and their position with respect to one another. The formula for the incident power is the following (radiating surface A_1 and irradiated surface A_2).

$$P = \sigma \cdot \varepsilon' \cdot A_1 \cdot F_{12} \cdot (T_1^4 - T_2^4) \quad [W] \quad (3)$$

σ : Experimental Stefan-Boltzmann constant equal 5.73 10-8 [W $(m^2K^4)^{-1}$]
ε′ : Generalised emission coefficient
A_1 : Radiating surface [m^2]

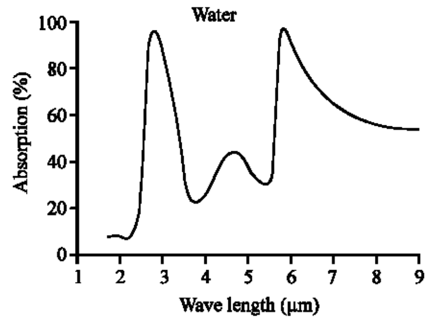

Fig 1: Absorption spectrum of water

F_{12} : View factor (A_2 seen from A_1)
T_1 : Temperature of the radiating surface [K]
T_2 : Temperature of the irradiated surface [K]

The shape coefficient F_{12} is dimensionless and is determined by the geometry, distance and position of the two surfaces with respect to one another. For viable configurations, shape coefficients are available in the form of diagrams.

ELECTRICAL INFRARED INSTALLATIONS

Radiators: Electrical infrared radiators exist in a multiplicity of designs. The design is primarily determined by the type of infrared radiation that one wishes to elicit. The most common designs are lamps, tubes and panels.

Short wave radiators have a high temperature (2000°C and over) and an extremely high power density (cf. the Stefan-Boltzmann law). The temperature of medium-wavelength radiators is situated in the region 900-1500°C. Long-wavelength infrared is obtained with temperatures of 400-800°C.

All electrical infrared radiators make use of the Joule effect: a resistance element is heated by passing an electric current.

Reflectors: As does visible light, the light from infrared radiation devices propagates in straight lines. Reflectors are required to focus the infrared beams optimally on the product that is being heated.

In general, aluminium or polished stainless steel is used as the reflective material. Periodic cleaning is necessary to prevent a loss of efficiency. When the power density is high, the necessary cooling must be provided on the back of the reflector (Fig. 2).

Insulation: In medium and long wave infrared heating, the proportion of convective heat transfer can amount to 50% and more. This is of course not negligible and the whole oven must be insulated accordingly. In the case of short

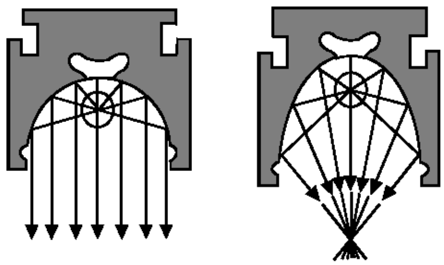

Fig 2: Some reflector designs

wave infrared, the proportion of convection transfer is not significant. However, the oven wall will often be covered with reflective Al plates that (certainly if they get dirty) absorb a proportion of the radiation and so reduce the performance. Insulating them will increase their surface temperature. A proportion of the absorbed heat is then recovered in the form of secondary, long wave radiation. In many infrared applications, vapour (water, solvents) has to be removed. This extraction must be limited to the absolute minimum. Here, infrared heating has a substantial advantage from the energy point of view with respect to conventional convection ovens. Because the radiation heats the product directly, the temperature of the air in the oven will be appreciably lower. If you want to heat a product to, for example, 150-200°C, then the temperature of the air will have to be about 100°C. In convection ovens that is approximately 350-400°C.

Regulating the power: The power can be regulated in different ways (Fig. 3).

Each of these techniques has its advantages and drawbacks, as shown in the following:

Switching in units
Advantages: No harmonics (PF = 1) and unalterable radiated IR spectrum

Drawbacks: Non-uniform power density

Series/parallel switching: Star/delta switching

Advantages: No harmonics (PF = 1)

Drawbacks: Non-uniform power distribution, variation in the radiated IR spectrum.

Voltage regulation with a transformer
Advantages: No harmonics, continuous regulation possible.

Drawbacks: Expensive, difficult solution, variation in the radiated IR spectrum.

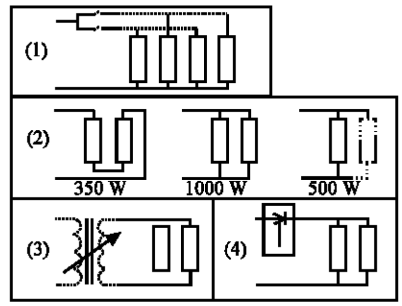

Fig 3: Regulating the power

Current regulation with thyristors: (phase proportioning or pulse trains).

Advantages: Continuous regulation possible, no moving parts.

Drawbacks: Power factor correction is required variation in the radiated IR spectrum.

Measuring the temperature in an infrared installation is less straightforward than in conventional ovens. This is because measuring the air temperature is not very useful. Correct regulation is only possible if you have an idea of the surface temperature of the product.

Choice of radiator: The first step is to decide on the wavelengths required in the process. The most important factor in this is the absorption behaviour of the product to be heated. In most cases it is best for the radiated wavelengths to coincide with maxima in the absorption spectrum. It must be emphasised that the absorption spectrum is dependent upon a number of factors such as temperature, thickness of the material, colour and surface condition of the material (Modest, 2003).

However, other considerations can also play a part in the choice of the electrical radiators:

- Irregular shapes are handled in a more homogeneous way with longer wavelengths (medium wavelength, long wavelength) because a large.
- When surfaces with different colours have to be heated at the same time, long-wavelength infrared can be advantageous; it is less selective (broader spectrum) and the greater proportion of convection heating aids homogeneous temperature treatment.
- High power densities are achieved with short wave infrared (e.g., upgrading of an existing drying installation).
- If production is frequently interrupted, short wave radiators might be required; long wave radiators have

a great thermal inertia and require special measures to prevent overheating or burning of the products.

- Medium-wavelength and long wave radiators are robust and withstand thermal or mechanical shock better.
- Continuous processing of sheets or cloths of different widths requires flexible, separable radiators. Short wave or medium-wavelength quartz tubes are usually needed.

The power required can be estimated by considering the desired production speeds, the required temperature profiles, product properties (density, specific heat, latent heat, heat of reaction, conductivity), thermal losses, opportunities for heat recovery etc.

PROPERTIES OF ELECTRICAL INFRARED HEATING

Space savings: An electrical infrared installation is several times smaller in size than a hot air oven. This is a direct consequence of the high power densities and the good heat transfer from the infrared radiator to the product. The installation itself and the electrical connection are straightforward; it is not necessary to supply fuel or remove exhaust gases. Infrared units have quite a light structure and if the capacity changes the installation, often at minimal expense, can be extended by adding a number of radiators or by adapting the electric power supply. Infrared radiators can in many cases be quite straightforwardly integrated into existing installations. In this manner, it is for example possible to increase the production capacity of an existing installation.

Regulation: Electronic regulation of the power is flexible, rapid and precise. Temperature measurements need to be arranged at a suitable place and the necessary precautions must be taken so that the measurement is representative of the temperature of the product. Temperature-time controls can be included on a number of production lines and can run completely automatically.

Energy consumption: Infrared radiators act mainly to heat the surface layer. In practice there are therefore, few convection losses.

A short wave radiation source converts about 90% of the electricity into infrared radiation. About 70% of this is usefully directed onto the product (Kubin *et al.*, 2004). The latter is naturally strongly dependent upon the reflection and absorption parameters, together with the shape coefficient of the product. In general, it can be assumed that the specific energy consumption in infrared

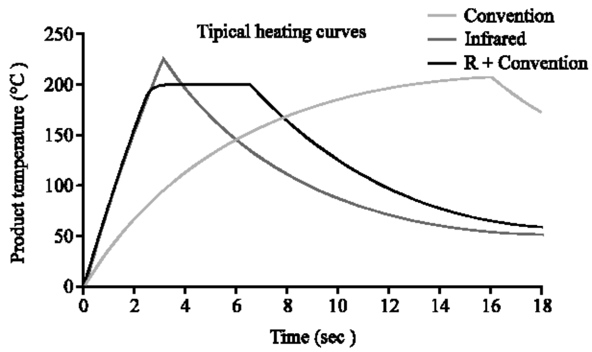

Fig. 4: Typical heating curves when infrared heating and/or hot air heating are used

systems is a few times lower than in hot air systems. An infrared installation is a large resistive user and has a favourable effect on the power factor.

Production capacity: Thanks to the extremely intense energy densities of the radiators, it is possible to obtain noticeably higher production speeds than with hot air. When starting, the entire production capacity is rapidly available for use because the radiating elements have a low thermal inertia. The Fig. 4 shows in a qualitative manner how the process time can be shortened. Reductions with a coefficient 3-4 are realistic.

Maintenance and lifetime: The lifetime is strongly dependent upon the characteristic properties and the operating conditions. In a polluted oven atmosphere, or if solvents are being evaporated, both the radiators and the reflectors can get dirty or even be damaged. Regular cleaning is recommended. If a fan is used with infrared equipment, corrosion and contamination with gases/dust can be reduced.

Working conditions: An infrared oven makes no noise in the workplace. Neither are any hot spots created. Infrared radiators that are used for space heating can have a beneficial effect on the working environment: There is no air circulation, no draughts and no dust blown about. Operation and maintenance are easy.

Quality: Infrared electrical installations enhance the quality of the product. With infrared drying processes, extremely low degrees of humidity can be obtained. With the precise regulation of temperature and power profiles the end result is extremely homogeneous (Metaxas, 1996).

The products do not come into contact with combustion gases. When products have to be extremely clean or pure, electrical infrared can be used in a vacuum oven. Comparison with gas-fired infrared radiators.

In comparison with gas-fired infrared radiators, electrically powered infrared has the following advantages:

- A greater range of radiators; gas-fired radiators are mostly long wavelength
- Great efficiency (>70%)
- Better and more precise regulation
- Rapid start and stop
- Low maintenance cost
- Safer and better working conditions for the staff
- No contamination of the product being heated

INDUSTRIAL APPLICATIONS

Infrared can be applied in various industry branches. In every industry branch where baking, heating or drying is done, where products need to be polymerised or where coatings need to be placed continuously, there are potentially interesting application possibilities.

Metal processing industry: Metal products are mostly finished with one or several layers of paint or coatings. The coating protects the metal against corrosion but also provides a more appealing appearance. Both liquid and powder coatings are baked at temperatures between 150 and 200°C. The applications are legion: car components, bicycle frames, metal furniture, etc.

Compared to traditional installations with hot air, infrared radiation scores well in these applications for a number of reasons:

- Rapid heating
- High production speed (due to high power density)
- Compact installation
- Dust reduction: Almost immediately a protective layer is formed and the air circulation is restricted (only removal of solvents)
- Good energy efficiency.

Infrared is often combined with hot air in industrial tunnel ovens: The infrared zone is followed by a convective region. In this way an equal product temperature can be obtained, even on the places that are not directly irradiated by the infrared. Moreover the risk of overheating the product is lower and the product temperature can be controlled more easily.

Local workplace heating: In large warehouses, in spacious halls with local working posts or even in open hangars and storage rooms, infrared heating is often a cheap and efficient solution. This radiant heating (often ceramic heaters) has a number of great advantages compared to the classic heating techniques:

The radiation is concentrated where needed. Hot air, on the contrary, climbs to the ceiling.

The radiation heats the surface and not the volume. The air is not heated directly, but indirectly by calorie losses from objects already heated with radiation. There is therefore also no heat loss by air renewal (i.e., air conditioning). Heating is immediate and comfort is rapidly felt from the heat. Normally 95% of the radiated power is felt within 5 min of the radiating elements being switched on. The heating installation is also compact, silent and free of dust.

CONCLUSION

This research describes the technology and applications of infrared heating. The basic principles behind the technology and its important properties are shown. It is shown that the desired transfer of thermal energy is dependant on several factors, like emissivity and shape coefficient.

However, in many industrial production processes infrared heating offers advantages with respect to conventional heating techniques such as convection or hot air ovens. Infrared heating is after all characterised by high energy densities, rapid heating and relative ease of installation. All these advantages offer the possibility of higher production speeds, more compact installations and lower investment costs.

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