Industrial Applications of Electric Infrared Heating

Advanced ENERGY

The cover:

Electric infrared curing of powder coated engine blocks.
Photograph courtesy of BGK Finishing Systems.

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Chapter 1 – Introduction

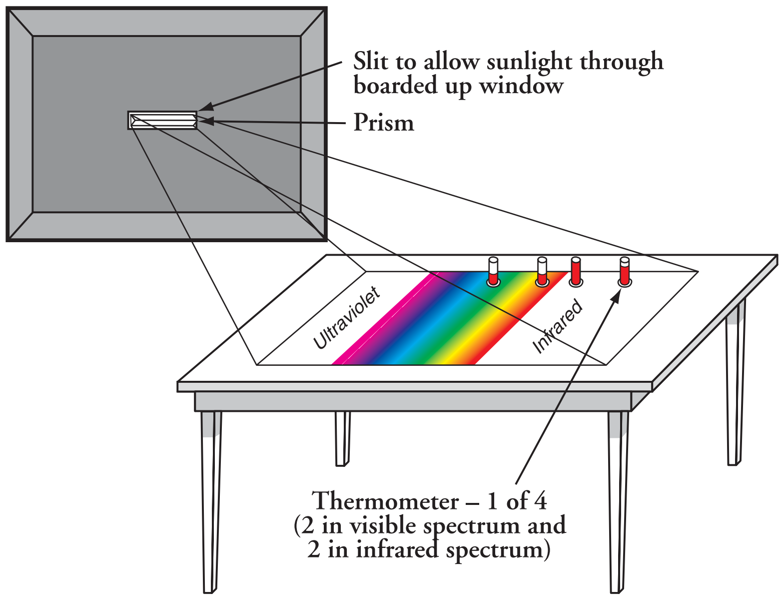


Fig. 1-1: Herschel Discovers Infrared Light

This book is designed to help educate its readers about the principles, methods, and industrial applications of infrared heating.

Sir Frederik William Herschel was excited nearly 200 years ago when he first experienced the discovery of infrared light. We hope readers will be stimulated to consider the possibilities of applying Herschel's discoveries in new and inventive ways.

The young German military musician, while on temporary duty with his regiment in England, left the army and remained in England. Supporting himself as a concert musician, he seriously pursued astronomy as a hobby. His dedication resulted in discovery of the planet Uranus in 1781. King George III, perhaps gladdened by this scientific diversion from his troubles with the American colonies, rewarded him with a civil list pension. Now free to pursue his scientific interests full time, Frederik William Herschel experimented with solar spectroscopy.

In a darkened laboratory, Herschel covered the window with a wood panel which had a small slit to admit light. In that opening he positioned a prism to separate sun light into the colors of the spectrum. His interest was in measuring the heat content of each color of the spectrum. He positioned thermometers, perhaps with blackened bulbs, in the various light bands. To account for differences in temperature around the room he had positioned several control thermometers. To his surprise, the thermometer beyond the last light band had a much higher temperature than any other one in the room! Thus, Herschel accidentally discovered infrared radiation. On March 2, 1800, he addressed the Royal Society of London and stated, ". . . the radiant heat from the sun will at least partly consist – if I may be permitted the expression – of invisible light. . ." [15, 16]

The first use of electric infrared heating in industry was by Ford Motor Company for curing paint on auto bodies in the 1930s. Adoption of infrared heating by industry was slow because early control methods were crude, the early emitters were unreliable, and early advocates often oversold the technology.

The development of computerized controls and highly reliable infrared emitters has led to the successful application of infrared heating for many manufacturing processes.

Chapter 2 – Electric Infrared Heating

Electric infrared (IR) heating can play a key role in improving the competitiveness of manufacturing. Electric IR offers fast heating rates, no physical contact, precise control, high efficiency, and minimal environmental impact. These characteristics result in the potential for improved productivity with enhanced product quality. This chapter will provide the principles of infrared heating, the characteristics of electric infrared heating equipment, plus advantages and difficulties associated with this method of thermal processing.

2.1 Principles of Infrared Heating

The three major methods of heat transfer are:

Conduction – requires physical contact between a hot material and a cool material.

Convection – is a special case of conduction. Convection takes place when a gas or liquid is heated (by conduction) and then the hot gas or liquid moves to a low temperature region and gives up its heat (by conduction).

Radiation – requires no physical contact between the hot and cold regions.

Infrared (IR) radiation, also called thermal radiation, is the transfer of energy between two objects at different temperatures. Infrared radiation is an electromagnetic phenomenon, and it is a form of wave motion.

All bodies with a temperature above absolute zero emit infrared radiation. The heat loss or gain by infrared radiation can be significantly more than that from other modes of heat transfer such as convection and conduction. This characteristic accounts for the fact that a person may feel cold in a room with a relatively warm air temperature. For example, if one sits in a room with a large window, he may feel cold because of radiant exchange between his body and the cold window. Conversely, a small infrared space heater can make one feel warm in a room with cold air temperatures.

IR is transmitted by line-of-sight, and, like visible light, can be focused (concentrated) or reflected.

The energy received at a surface from IR is a function of the distance from the source (emitter) and the angle of radiation incidence. Just as one would move closer to a light bulb to read more clearly (receive more light on the page), the energy transferred by IR is stronger if the object to be heated is closer to the IR emitter. Also, the energy transferred will be greater if the object to be heated is perpendicular to the IR emitter (i.e., the IR waves strike the object "straight on," rather than at an angle).

Our sun, which emits the form of radiation most familiar to all of us, has an estimated temperature of 10,240°F. The sun radiates energy at wavelengths of 0.1 to 3 µm. Most of the energy from the sun is in the range of 0.4 to 0.8 µm, which is the range of visible radiation.[9]

Reference to Fig. 2-1 reveals that the sun's (solar) radiation includes elements of ultraviolet, visible, and infrared radiation. Ultraviolet (invisible radiation) from the sun will cause burning of human tissue, without a thermal effect. Thus, one can become sunburned on an overcast day when one does not feel warmed by the sun. The visible and infrared radiation from the sun provides a thermal effect that we feel as "warmth." Visible and infrared radiation does not cause photochemical effects, as does ultraviolet radiation. The effect of infrared radiation is purely thermal, and thus is very safe.

Infrared, like other forms of electromagnetic radiation such as light, travels in a direct line at the speed of light through a vacuum as well as through a medium such as air. The infrared portion of the electromagnetic spectrum starts at a wavelength of 0.76 µm and extends 1000 µm as shown in Fig. 2-1. This characteristic places infrared at wavelengths just longer than the longest wavelength in the visible spectrum,

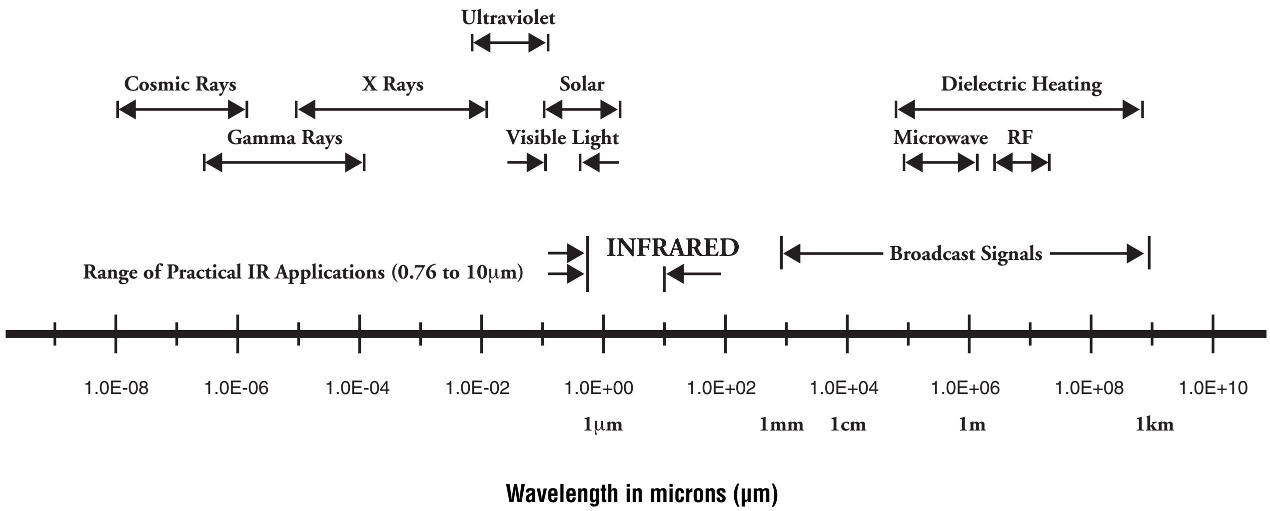


Fig. 2-1: Electromagnetic Spectrum

which is that of the color red, hence the name infrared. The range of infrared wavelengths of interest for industrial heating applications is limited to less than 10 µm. See also Fig. 2-6.

The maximum amount of infrared radiation is emitted by an ideal radiator, called a *black body*, and is proportional to its surface area and the fourth power of its surface temperature rendered in absolute units. This has been expressed as the Stefan-Boltzmann law of radiation:

$$E = k\,(T^4 - T_0^4) \qquad \text{(Stefan-Boltzmann law)}$$

Where E is radiated energy, T is the absolute temperature of the black body, T_0 is the absolute temperature of the surroundings, and k is a constant.

Determining the infrared emission from real bodies, or *gray bodies* as they are referred to, requires the introduction of another proportionality factor called *emissivity*. Emissivity is a property of the material surface and, though it generally depends on temperature, is usually taken to be a constant. The value of emissivity varies from zero for an ideal reflector, to 1.0 for a black body. For real, or gray bodies, the Stefan-Boltzmann law becomes:

$$E = \varepsilon k\,(T^4 - T_0^4)$$ ("ε", is the emissivity for a real body, at system temperature)

Typical emissivity values for some common materials are shown in Table 2-1. Values may be as low as 0.02 for polished gold and as much as 0.98 for specially prepared black surfaces.

***Table 2-1A: Approximate Emissivity of Metals* [5]**

Metal	Polished	Oxidized
Aluminum	0.05	0.15
Brass	0.09	0.60
Cast Iron	0.21	0.70
Copper	0.02	0.60
Galvanized Steel	0.02	0.76
Gold	0.018	----
Lead	0.08	0.70
Nickel	0.06	0.90
Silver	0.03	0.80
Stainless Steel	0.17	0.85
Steel	0.11	0.75
Tin	0.18	0.60
Zinc	0.03	0.50

Table 2-1B: Approximate Emissivity of Liquid Paints, Lacquers and Varnishes [5]

Coating	Emissivity
Aluminum paint	0.27 to 0.67
Enamel (any color)	0.85 to 0.91
Lacquer (any color)	0.80 to 0.95
Varnish	0.89 to 0.93

Table 2-1C: Approximate Emissivity of Miscellaneous Materials [5]

Material	Emissivity
Air	0.057
Brick, masonry	0.83
Carbon	0.96
Glass	0.94
Gypsum	0.90
Ice	0.97
Leather, dry	0.90
Marble	0.90
Meat	0.95
Paper	0.85
Porcelain	0.92
Quartz glass	0.94
Rubber	0.86 -0.95
Wood	0.95

The wavelength of infrared radiation depends on the temperature of the emitter as shown in Figure 2-2. These plots show that the peak wavelength gets shorter with increasing emitter temperature. At surface temperatures below 1200°F (650°C), virtually all of the emitted radiation is in the infrared region of the electromagnetic spectrum. Above this value, more of the radiation emitted by the surface is in the visible spectrum (0.38 μm to 0.76 μm). This behavior may be observed, for example, when a piece of steel is heated electrically or in a flame. Initially, the steel emits no light but with further heating glows a dull red. With increase in temperature it becomes brighter and the color shifts from red to orange to yellow and finally to white.

Visible light is produced by higher temperature, shortwave emitters. Also radiant efficiency is highest for short-wavelength sources. This behavior results because the heat transfer by the convection and conduction modes increases only in direct proportion with temperature increase, while heat transfer by infrared increases as the fourth power of temperature as governed by the Stefan-Boltzmann law [$E = k(T^4 - T_0^4)$]. Therefore, with increase in emitter temperature, the heat transfer by infrared increases at a dramatically faster rate than by the other two modes.

The plots in Figure 2-2 show *radiant intensity*, also called *spectral intensity*, as a function of wavelength. Spectral intensity is the radiant heating rate per unit of wavelength of an infrared source. The total infrared heating rate, or *radiant power*, may be found by integrating the spectral intensity over all of the wavelengths.

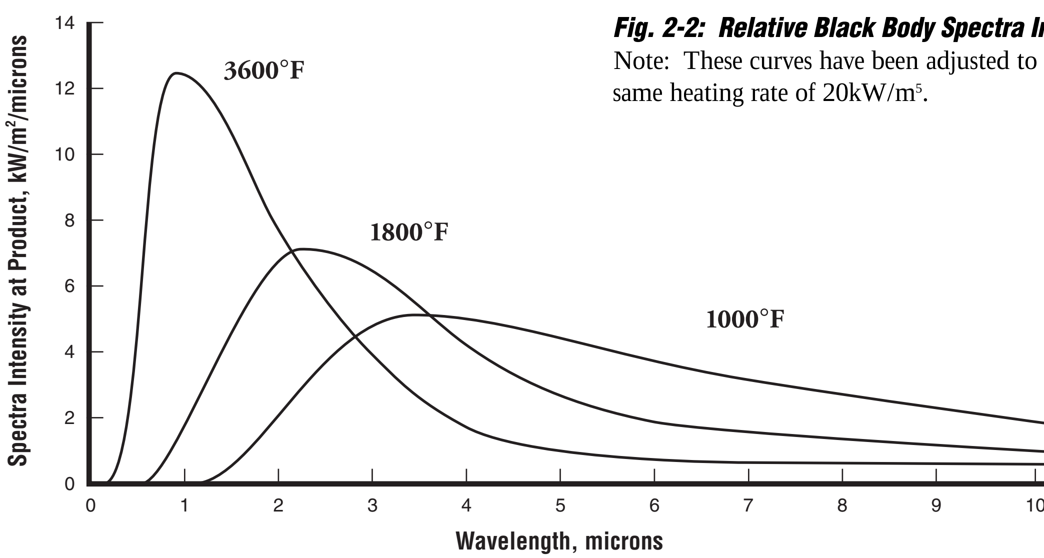


Fig. 2-2: Relative Black Body Spectra Intensity [5]
Note: These curves have been adjusted to correspond to the same heating rate of 20kW/m[5].

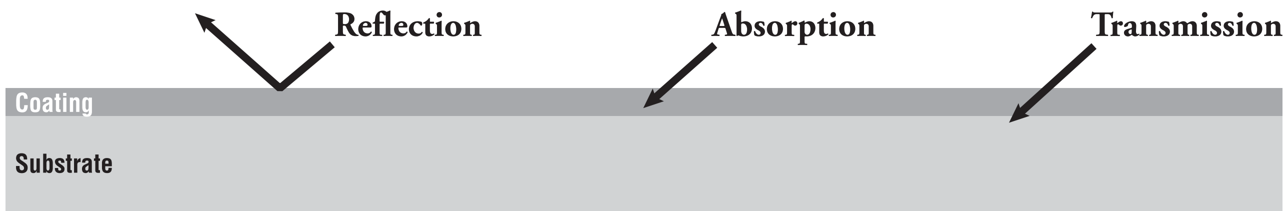


Fig. 2-3: Infrared Behavior

The exchange of infrared energy between adjacent objects occurs continually. This exchange depends not only on the amount of infrared emitted from each surface but also on the geometric relationship between the two surfaces. The parameter that determines how much of the radiation leaving one surface that will strike another surface is called the *shape factor*. This parameter depends directly on the orientation and areas of the two emitting surfaces and inversely on the distance between them. For this reason, the amount of infrared heating received by a surface from an emitter increases as the distance between them decreases.

The infrared radiation striking a surface is either *reflected, absorbed, or transmitted*. The radiation transmitted through a thin material, such as plastic film, is significant.

Figure 2-3 demonstrates the three possibilities for infrared radiation striking a thin coating. For a thin film of only several thousandths of an inch thick, the radiation which passes through it, or is transmitted, is significant. For thick materials, all radiation which is not reflected is absorbed.

The *penetration ability* of infrared radiation also varies with wavelength. Generally, the shorter the wavelength the more penetrating power the radiation has. However, the depth of penetration observed for infrared radiation, even that of very short wavelength, is relatively low, with observed depths being seldom greater than a few thousandths of an inch. For thick plastic sheet greater than 0.040 inches, heating to the center of the sheet must depend upon conduction. Notable exceptions for IR penetration are snow, which IR will penetrate several inches, and quartz glass.

The property that determines the amount of infrared that is absorbed by a surface is referred to as *absorbance*. For all practical purposes, the absorbance and emissivity of a surface are the same. If a surface is a good emitter of infrared radiation, it will also be a good absorber. Conversely, if a surface is a poor emitter, it will be a poor absorber or, in other words, a good reflector.

The absorbance of solids is complex, depending on the surface characteristics as well as the wavelength of the incident radiation. For example, materials such as water and glass exhibit behavior for short-wave infrared radiation that is very similar to that observed for visible radiation. Virtually all of this type of radiation is transmitted; i.e., water and glass are transparent to light and short-wave radiation. However, infrared radiation above 2 µm is strongly absorbed by both water and glass. Quartz glass is again an exception to this general rule. Quartz has high IR emissivity, but low absorbance.

In order to further illustrate the complexity of the absorptive characteristics of materials, the absorption spectra for water and polypropylene are shown in Figures 2-4 and 2-5. For water, very low absorption values are seen at wavelengths below around 2.5 µm, but large absorption values are observed at longer wavelengths to about 3.3 microns. This behavior suggests that infrared radiation emitted between 2.5 to 3.3 microns will be readily absorbed and thus be effective in drying.

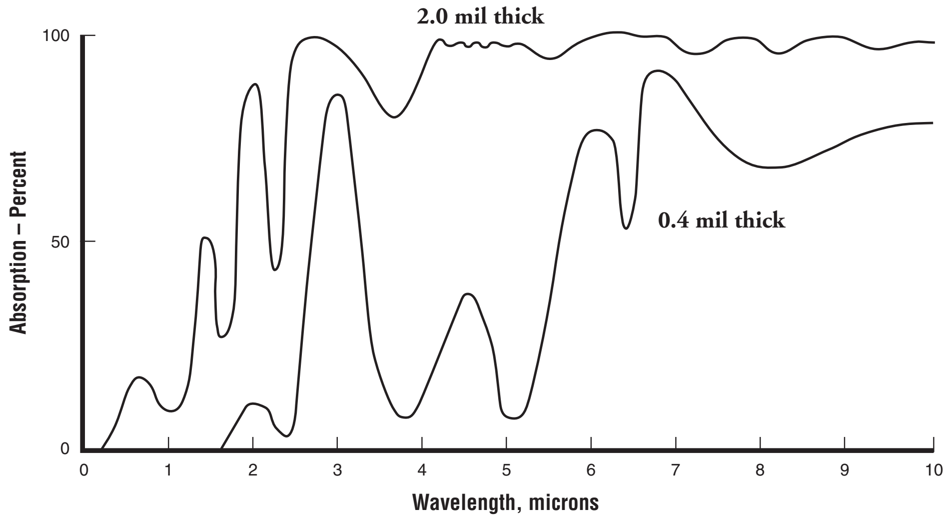


Fig. 2-4: Infrared Absorption vs. Wavelength for Water [2]

In fact, much has been made of the need to match the emission spectra of the infrared heater with the absorption spectra of the material to be heated. However, such matching is rarely important in practice for the heating of coatings and plastics. These materials typically absorb strongly over several broad wavelength ranges between 2.5 µm to 6 µm. These wavelength ranges are included in the emission bands of medium-wavelength and long-wavelength emitters.

The color of the absorbing surface is another factor that can be important in infrared heating. Dark colors, such as black, typically absorb infrared more readily than white or light colors. This behavior is observed more strongly at higher source temperatures. Thus, short-wavelength sources are more color sensitive than lower temperature sources, such as medium- and long-wavelength emitters. There is no such thing as a color blind infrared source. Sources vary in their color sensitivity by degree only.

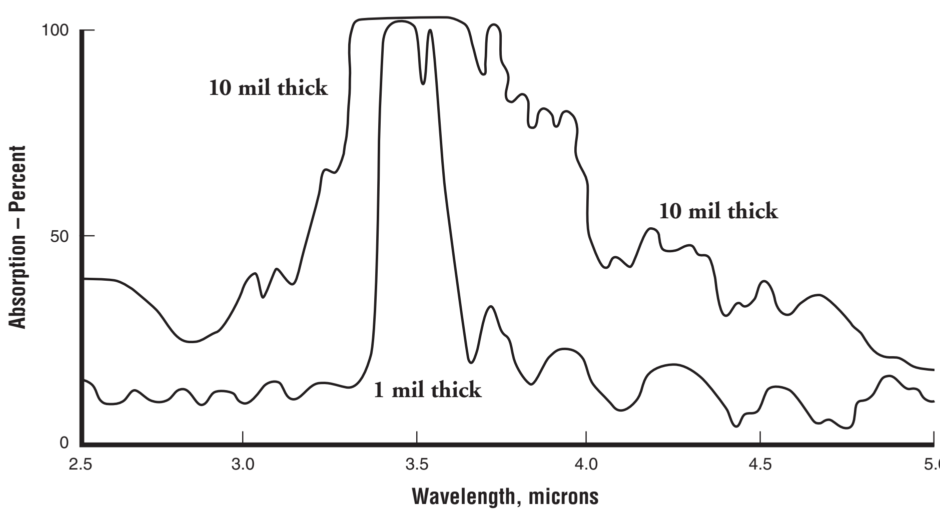


Fig. 2-5: Infrared Absorption vs. Wavelength for Polypropylene [10]

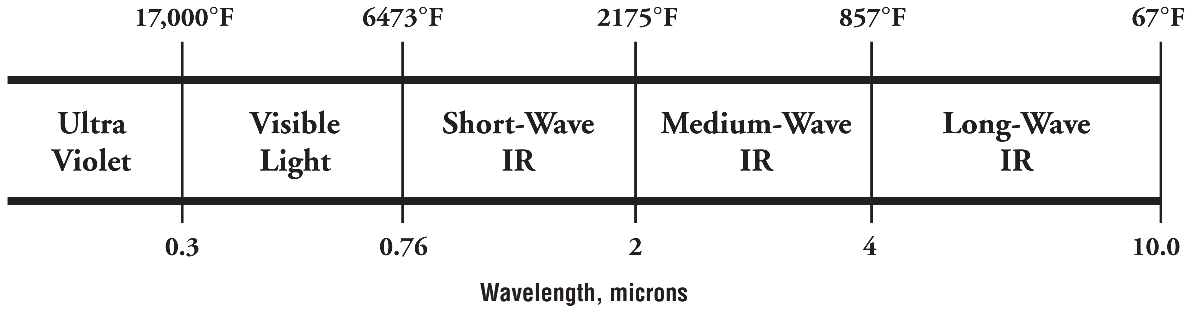


Fig. 2-6: Temperature of Peak Radiated Energy

Wien's Displacement Law:

$$\text{Peak Energy Wavelength (microns)} = \frac{5269 \text{ (microns) (°R)}}{[\text{Temp °F} + 460] \text{ (°R)}}$$

Figure 2-6 displays the surface temperature that a source must have to emit ultraviolet, visible, short-wave infrared, medium-wave infrared, long-wave infrared, or far infrared radiation. The peak energy wavelength for a given heater temperature can be calculated using Wien's displacement law.[2]

For industrial applications, infrared radiation is useable within the range of 0.76 to 10 µm. IR is usually divided by convention into three classifications:

- *short-wave* infrared, from 0.76 to 2 µm
- *medium-wave* infrared, from 2 to 4 µm
- *long-wave* infrared, from 4 to 10 µm

A practical explanation for the 10 micron limit for industrial infrared applications is that an object at room temperature has a peak radiated energy at 10 microns. Objects at room temperature radiate heat, but they are not practical industrial heating sources! Table 2-2: Summarizes the characteristics of infrared heating sources.

	Short-Wave High-Intensity	Medium-Wave Medium-Intensity	Long-Wave Low-Intensity
Radiant Source Temperature	4000 - 2175°F	2175 - 857°F	857 - 400°F
Peak Wavelength Range, µm	1.2 – 2.0	2.0 - 4.0	4.0 - 6.0
Watt Density, W/in^2	Typical - 60 Max. - 1200	Typical - 30 Max. - 80	Typical - 15 Max. - 40
Direct Radiation as Percent of Input Energy*	86 – 72%	60 – 40%	50 – 20%
Relative heat-up Cool-down time	seconds	seconds to minutes	minutes
Mechanical Shock Resistance	Poor	Good to excellent (for metal sheath)	Varies with design

Table 2-2: Characteristics of IR Radiant Heating

Note : * Balance of energy input goes to convection or is re-radiated as secondary radiation at a longer wavelength. Note that for all emitters the percentage direct radiant energy increases as the temperature of the emitter increases.

It is important to note that there is considerable duplication in the actual thermal behavior of the different types of emitters. This characteristic is particularly apparent when it comes to consideration of the distribution of wavelengths emitted, as shown for the idealized sources in Figure 2-2. This situation becomes even more obvious when the emission spectra of real emitters, which are equally as complex as the absorbance spectra shown in Figures 2-4 and 2-5, are compared. Therefore, one must be very careful when generalizing about the wavelength effects and, indeed, the overall thermal performance of one emitter type versus another.

For most thermal processing applications, it is sufficient to note the following:

- Short-wavelength sources provide high radiant efficiency and fast rate of response with some amount of surface penetration.
- Medium and long-wavelength sources penetrate less, but provide good surface heating.
- Medium and long-wavelength emitters operate at lower radiant efficiencies (more heat energy goes to convective heating) and slower response times. However, these deficiencies are offset by lower capital costs and improved ruggedness.

2.2 Infrared Heating Equipment

The basic components of an electric infrared oven typically include an *emitter*, a *reflector system* and *controls*. An electric infrared heating unit is generally classified by the type of emitter used. When considering infrared for a manufacturing thermal process, certain tradeoffs must be considered in making a final selection. For example, short-wave infrared emitters offer the fastest response, greatest heating rates and best efficiency in conversion of electric power to infrared radiation, but have the lowest resistance to mechanical shock and shortest element life. On the other hand, long-wave infrared emitters are very durable, but slow to respond to process changes, deliver heat at lower rates and are generally less efficient in converting electrical energy to infrared radiation. Table 2-3 provides a summary of common infrared emitter types.

	G-30 Bulbs	T3 Quartz Lamp	Quartz Tubes	Metal Radiant Tube	Panel Heaters	Ceramic Element
Heated Element	Tungsten filament	Tungsten filament	Nichrome wire	Nichrome wire or Fe-Cr-Al wire	Fe-Cr-Al wire	Fe-Cr-Al wire
Intensity	Short-Wave High-Intensity	Short-Wave High-Intensity	Medium-Wave Medium-Intensity	Medium-Wave Medium-Intensity	Medium or Long-Wave Medium to Low-Intensity	Medium or Long-Wave Medium to Low-Intensity
Temperature	4000-2900°F	4000-2900°F	1800-1400°F	1400-1000°F	1300-400°F	1300-400°F
Brightness	Bright White	Bright White	Cherry Red	Dull Red	No Visible Light	No Visible Light
Usual Range of Peak Energy Wavelength	1.15 - 1.6 μm	1.15-1.6 μm	2.3-2.8 μm	2.8-3.6 μm	3.2-6 μm	3.2-6 μm
Percent Radiant	72-86%	72-86%	40-60%	45-53%	20-50%	20-50%
Percent Convective	28-14%	28-14%	60-40%	55-47%	80-50%	80-50%
Response to Heat-up/Cool-down	1 second	1 second	30 seconds	2 minutes	5 minutes	5 minutes
Watt density (W/sq. in.)	10 to 15	50 to 1200	10 to 80	10 to 35	10 to 30	10 to 40

Table 2-3: Characteristics of Commonly Used Electric Infrared Emitters

2.2.1 Short-Wavelength Emitters

Tungsten filament lamps, called G-30 lamps, and T-3 quartz lamps are typical of short-wave emitters. Tungsten filament lamps consist of a resistance heated tungsten filament sealed in a bulb. T-3 lamps utilize a 3/8" diameter quartz tube as the enclosure. Quartz glass is very transparent to ultraviolet, the visible, and infrared spectrum to 7.0 µm. Conversely, silica glass, in general, allows the transmission of visible light, but is opaque to both ultraviolet and infrared radiation.

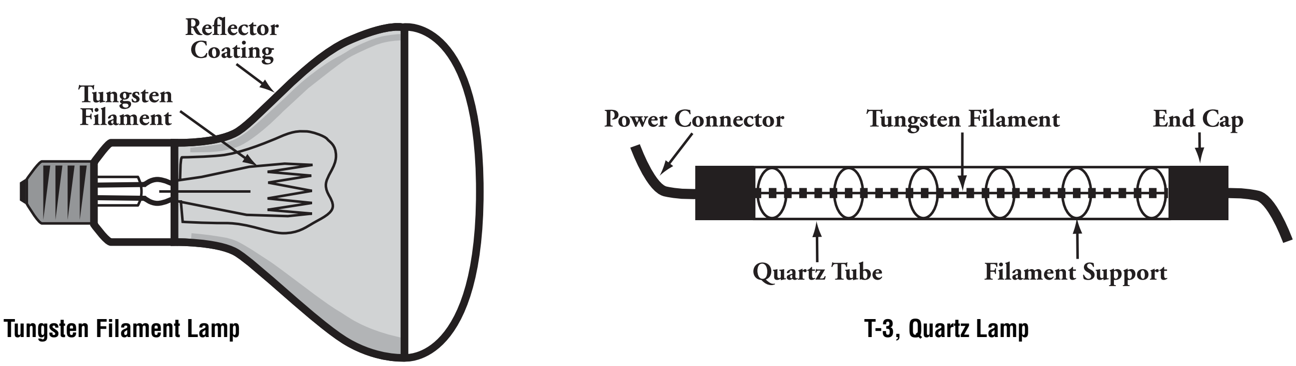
For both G-30 lamps and T-3 quartz lamp, an inert gas such as argon is used to prevent oxidation of the tungsten filament. Typical operating temperatures for these emitters is around 3500°F, which can be achieved in a matter of seconds, and life expectancy is on the order of 5000 hours. The radiant efficiency for short-wavelength lamps is in the range of 72-86%. Figure 2-7 shows sketches of G-30 and T-3 short-wavelength emitters.

G-30 lamps are used in spot heating applications such as for commercial food warming. T-3 lamps are more often seen in industrial settings. They are commonly used for booster ovens for paint drying. When combined with a focusing reflector, T-3 lamps can provide very high-intensity spot heating useful for stress relieving wire, re-flowing solder, etc.

2.2.2 Medium-Wavelength Emitters

Medium-wavelength infrared is typically produced by the resistance heating of a high-temperature resistance alloy coil of nickel-chromium (nichrome) or iron-chromium-aluminum. Medium-wavelength quartz tube emitters are similar to T-3 sources except that operating temperatures are lower and the tube is unsealed. Medium-wavelength emitters can operate at temperatures up to 2175°F with radiant efficiencies on the order of 40-60%. The balance of the input energy is converted primarily to convective heat, which is also used in the process. Heat-up times are typically in the range of 20 to 30 seconds, but can be as much as 1 minute. Medium-wavelength emitters are more durable than quartz lamp, short-wavelength emitters. Figure 2-8 is a sketch of a medium-wavelength, quartz tube emitter.

Metal radiant tubes (often called "calrods") provide both medium and long-wavelength infrared radiation. These emitters typically consist of a metal resistance coil surrounded by an insulating material (usually MgO) that is sheathed in a sealed metal tube of stainless steel or "Incoloy." Metal radiant tubes are the most durable design infrared emitters and are usually mounted in front of a reflector.



G-30, Tungsten Filament Lamp

T-3, Quartz Lamp

Fig. 2-7: G-30 and T-3 Tungsten Filament, Short-Wave Lamps

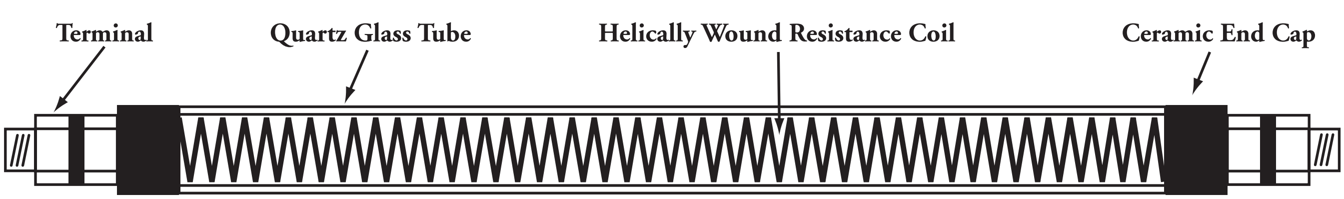


Fig. 2-8: Quartz Tube, Medium-Wave IR Emitter

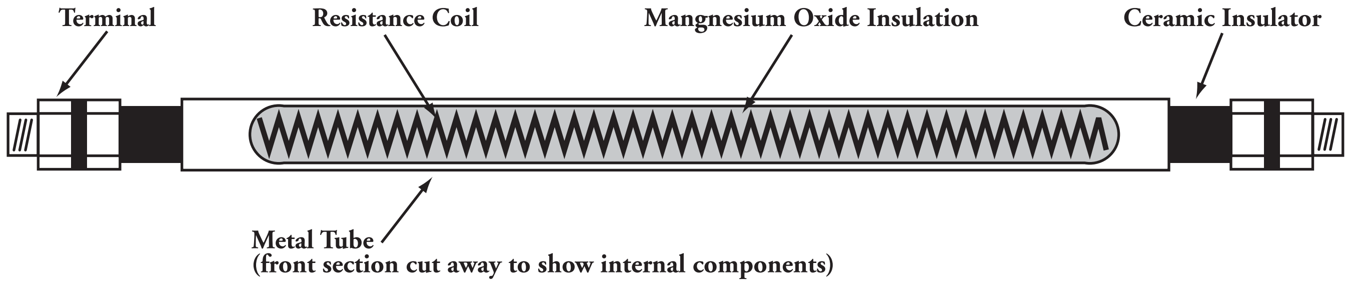


Fig. 2-9: Metal Tubular (Calrod), Medium-Wave IR Emitter

Panel heaters are so named because they contain a surface, usually flat, that is heated and provides a uniform radiating temperature across its face. They allow the placing of the IR emitter to as close as two inches from the product to be heated. The emitter surface may be a quartz glass plate, woven quartz cloth, or metal. If metal, there will be an insulating sheet between the metal panel and the electric resistance elements. The surface is often coated with a black, high emissivity coating. Figure 2-10 is a sketch of a quartz plate panel emitter that uses a grooved refractory board to support and position the resistance coil elements. Panel heaters are often operated as long-wave heaters.

Another design of medium to long-wavelength emitters uses metal coils, ribbons, or foils embedded in ceramic fiber insulation. This design allows custom molded shapes to be easily produced. The ceramic fiber is of low mass, therefore it becomes a panel that can come to operating temperature quickly and provide a uniform radiating surface. Such ceramic fiber heaters are commonly used in electric furnaces for metal heat treatment. Non-metallic elements such as silicon carbide are also widely used for metal heat treating. A full discussion of metal heat treating furnaces is beyond the scope of this book.

Medium-wavelength emitters are a frequent choice for manufacturing heating applications. This is especially true where drying is involved because the range of wavelengths emitted by these sources corresponds relatively well with the major absorption bands for water. The thermal response of medium-wavelength emitters is short enough to allow good process control. They are sufficiently durable to perform well in a manufacturing environment.

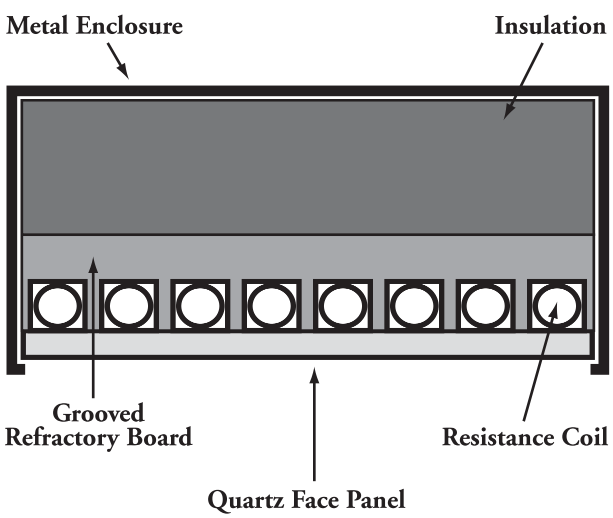


Fig. 2-10: Quartz Panel, Medium-Wave IR Emitter (simplified cross section view)

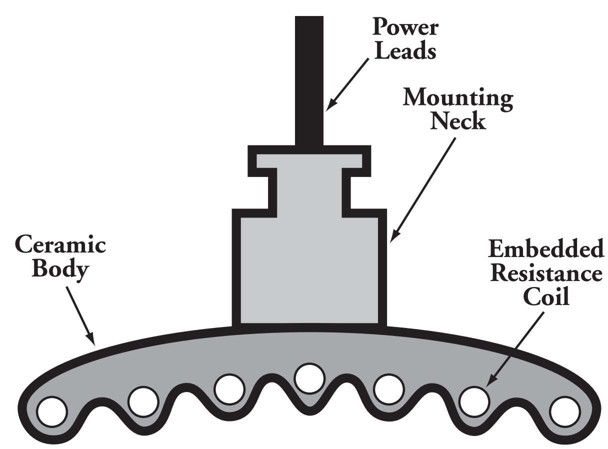
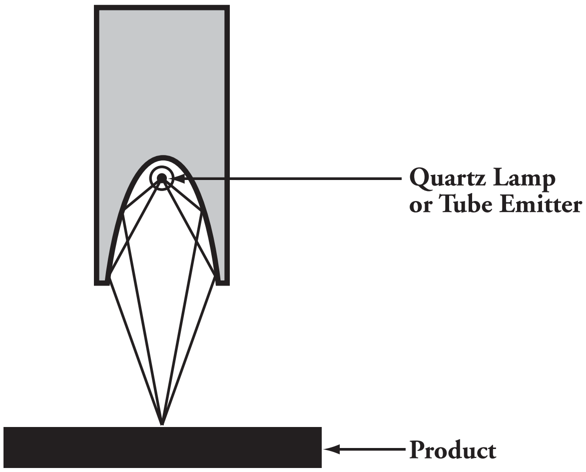
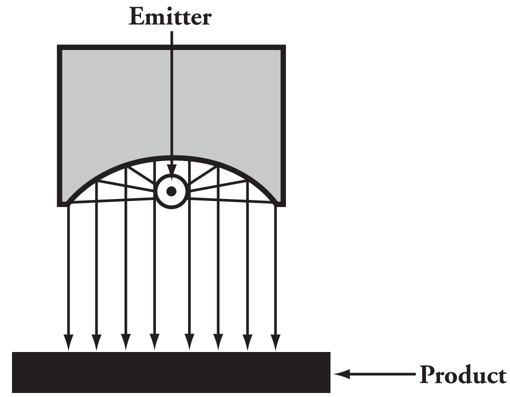


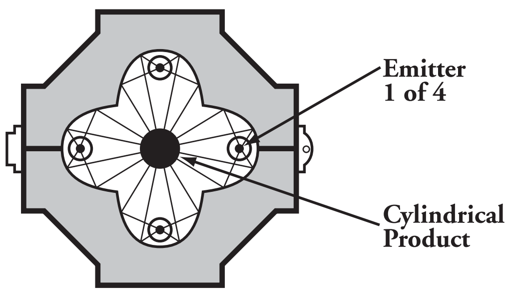
Fig. 2-11: Long-Wave, Ceramic IR Emitter



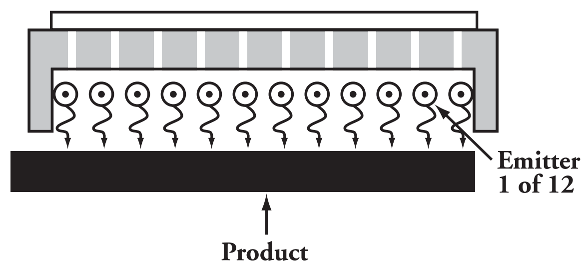
A: Focused Elliptical Reflector



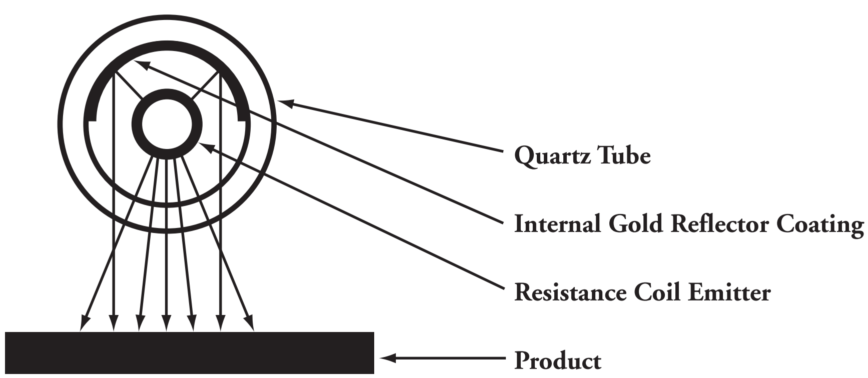
B: Focused Parabolic Reflector



C: Chamber Heater
(Has multiple emitters and elliptical reflectors)



D: Non-Focused, Flat Ceramic Reflector
(Shown with passages for air flow)



E: Quartz Tube with Internal Gold Reflector

Fig. 2-12: Infrared Emitter Reflector Designs (cross section views)

2.2.3 Long-Wavelength Emitters

Many of the previously described medium-wavelength design emitters are commonly operated in the long-wavelength temperature range.

Ceramic heaters are a common form of long-wavelength emitters and consist of resistance elements embedded in a ceramic body. They are sometimes called, "buried ceramic element" emitters. Operating temperatures for these infrared sources are generally limited to less than 1300°F and radiant efficiencies are typically less than 50%. The balance of the input energy goes primarily to convection heat which is also used in the thermal process. As these heaters radiate above the visible range, some manufacturers supply them with a glaze coating that changes color when the heater reaches operating temperature, thus allowing visual determination that a heater is functioning. Long-wavelength panels have relatively high thermal inertia which results in heat-up times as great as 4 to 5 minutes and also causes them to exhibit slow control response. On the positive side, these emitters are very rugged, typically lasting for several years with low maintenance.

2.2.4 Reflectors

Most short and medium-wavelength infrared heating systems utilize specular reflectors to direct energy to the product and to minimize thermal losses. The shape of the specular reflector determines whether it will focus the infrared for high heating rates or diffuse it to produce a uniform heating rate over a large area. See Figure 2-12. Specular reflectors are generally made of a highly polished metal such as stainless steel, aluminum, silver or gold. Reflectors may be external or, for quartz lamps and tubes, internal. The use of silver or gold is typically as an electroplated coating. Ceramic "reflectors" are used with some designs, and are non-focusing. Ceramic "reflectors" heat up from the resistance element's radiation, then re-radiate long-wave infrared. Thus, they are more properly considered "re-radiators," rather than reflectors.

Cleanliness is extremely important for external specular reflectors to function properly. The accumulation of dirt and oxidation from overheating must be avoided for maximum emitter efficiency. When less energy is reflected because of dirt accumulation or oxidation, then more energy is absorbed; which leads to higher temperatures and greater amounts of oxidation and even greater reduction in reflectivity.

Internal reflectors seek to avoid the problems of dirt accumulation and oxidation. This type of reflector is typically made of gold, aluminum or ceramic coatings applied to the back side of the emitter enclosure. One design uses a gold coating on the inside of a quartz tube. See Figure 2-12e.

Another approach to maintaining reflector effectiveness in short-wavelength infrared systems is to make them of a ceramic material. In addition to reflecting a portion of the incident radiation, these devices absorb part of the radiant energy and heat up enough to burn off any contaminants. Thus, they are self-cleaning. The energy absorbed by the reflector is re-radiated as longer wavelength infrared, thus yielding a more versatile system that combines somewhat the advantages of both short-wavelength and medium-wavelength infrared. This design has been successfully used for solvent paint drying systems, such as on automobiles and engine blocks. See the case study "Infrared Tackles the Heavyweights" in Chapter 4.

2.2.5 Controls

An important advantage of electric infrared heating is the ease and precision with which it can be controlled. This characteristic is in contrast to convection heating, which is inherently non-uniform and offers little opportunity for process control. In fact, long exposure times are generally the rule for convection processes, simply to assure that all parts of the product reach a minimum temperature or, in the case of drying, a minimum moisture level.

The direct heating characteristic of electric infrared along with the high energy densities that are possible dictate that automatic control be used. Over-heating can easily occur, leading to product damage and, in the worst case, fire.

Electric infrared heating systems are generally controlled by varying either the product exposure time or radiation intensity. The longer the exposure time and the higher the intensity, the more energy the product absorbs. Exposure time may be controlled by the process speed or the oven length. The infrared output may be controlled by turning the power on and off or through the use of a silicon controlled rectifier (SCR) power supply. In theory, the distance between the emitter and the product can also be used as a control parameter and may be on a manual basis. It is not typically used in automatic control systems.

The simplest method of infrared intensity control is to switch the power on and off. This switching is done very rapidly so that the emitter does not have time to cool down completely. In this manner, the emitter elements will average the power input to reach a steady output and temperature somewhere below the maximum power level. By varying the amount of time the power is on, the emitter can be adjusted from zero to full power output. This control method works best with medium- and long-wavelength emitters whose large thermal inertia enables them to better average the voltage changes.

The on/off control method described above cannot be used with low-mass tungsten emitters characteristic of short-wavelength, high-intensity infrared ovens. This method results in unacceptable voltage spikes when the emitter is turned on because the highly-responsive tungsten element cools so much when it is off that its resistance drops to very low levels. A modification of the on/off approach can work effectively, however. In this method, the emitter is switched from full voltage to half voltage in rapid cycles. When at half voltage, the radiant output is reduced significantly, but the element temperature remains high enough to keep its resistance from falling too low. Thus this method produces the same control result for short-wavelength emitters as the on/off method does for medium- and long-wavelength emitters without the attendant voltage spiking problems.

By far the most preferable control method for electric infrared is through the use of a silicon controlled rectifier (SCR) power supply. Though more costly than the other two methods described above, this method offers more precise control. In this method the line voltage to the emitter is reconfigured electronically to an infinite variety of voltages ranging from zero to a maximum equal to the line voltage. In this way, an infinitely variable output from the emitter can be obtained.

The complete SCR control system utilizes measurement of the product temperature feedback loop. This temperature measurement may sometimes be accomplished by direct contact with the product. Where this type of temperature measurement is not possible, the temperature is read using a device such as a non-contact infrared pyrometer. See Figure 2-13.

2.3 Zone Heating

Electric infrared can be “zoned” using multiple emitters with the appropriate reflectors and controls to develop a heating profile across the product and in the machine direction. This characteristic allows the manufacturer to adjust for variations in the product and to address specialized thermal processing needs. Some thermal processes require that the product temperature follow a particular heating profile in the machine direction. For example, an initial heat-up ramp, constant temperature “soak”, and cool-down ramp may be required. A properly zoned electric infrared oven can easily address these processing issues, whereas it is virtually impossible to do so with other heating methods such as with convection ovens.

Electric infrared may also be easily matched with the required thermal processing duty. Because infrared heating is directional, it may be aimed exactly at the area that requires heating while leaving other areas cool. This heating characteristic is almost impossible to achieve with other heating methods, but is easily attained with proper selection and orientation of the electric infrared emitter(s).

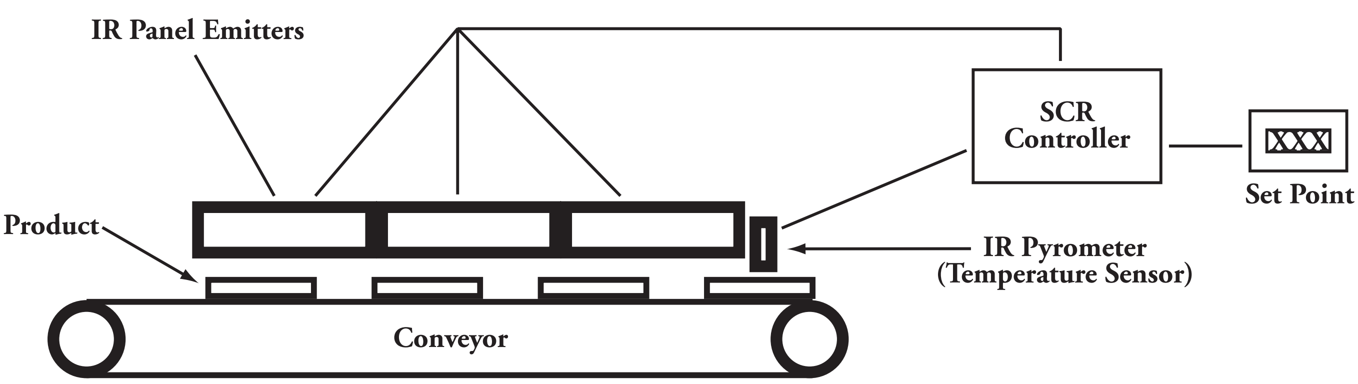


Fig. 2-13: Automatic Control System for IR Heating

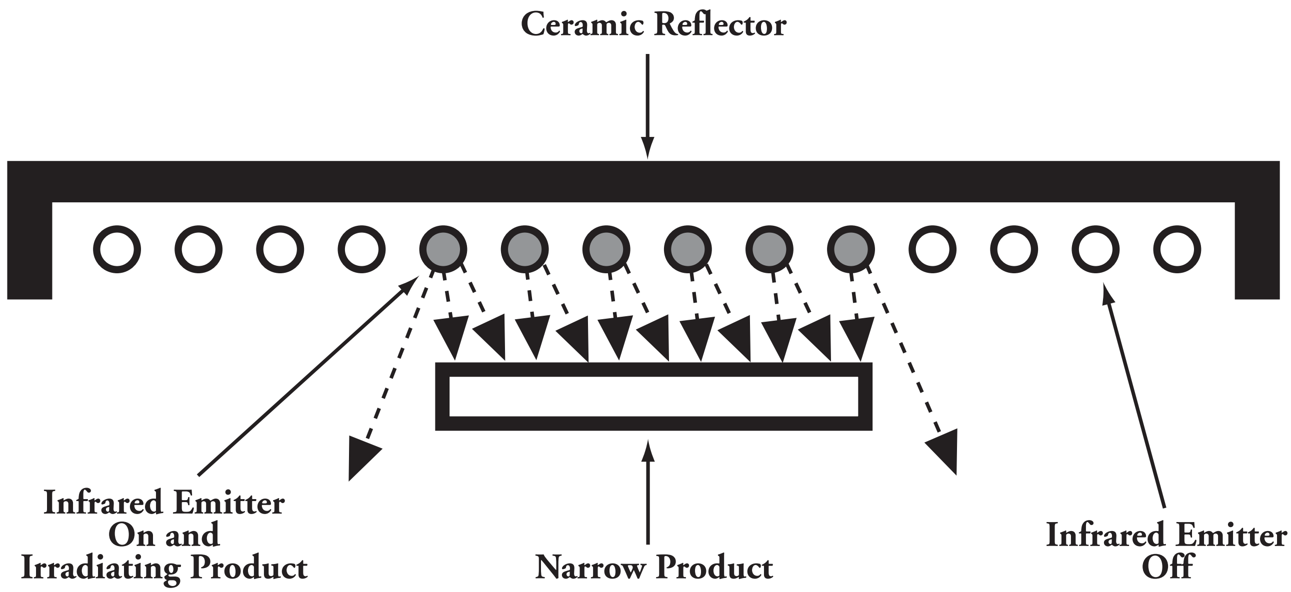


Fig. 2-14: Zoning of IR Emitters to Vary Heat Input

2.4 Advantages of Electric Infrared Heating

There are several significant advantages to the use of electric infrared heating in manufacturing processes. These benefits include:

- Improved productivity
- Consistent, often improved, product quality
- Ease of control
- Precise drying and curing temperature control
- Non-contact drying and curing
- Ability to control temperature by zones
- Compact size and flexibility of configuration
- High energy efficiency
- Low maintenance requirements
- Low environmental impact
- Improved working conditions

Probably the major reason that electric infrared is considered for thermal processing by manufacturers is its ability to improve productivity by increasing line speed. Infrared heats directly without the need for contact or a medium such as air. This characteristic results in the ability to deliver energy to the product at high rates. Thus, infrared can raise the product temperature much more rapidly than conventional heating methods such as with gas convection ovens. This characteristic also allows higher product temperatures to be achieved. Reduction in process heating times by as much as 90% has been observed.

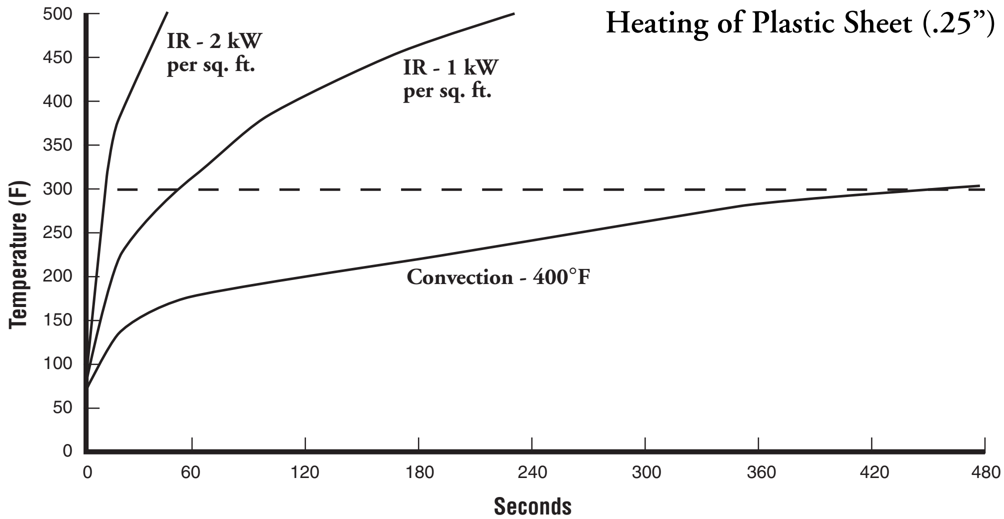


Fig. 2-15: Time to Curing Temperature in Infrared vs. Convection Oven

Electric infrared offers manufacturers a high degree of control in heating processes. Electric infrared heating equipment can be switched off and on in a matter of minutes or, in some cases, seconds. This equipment can be zoned in the machine direction to provide a profile that includes heat-up, constant-temperature and cool-down periods. Zoning across the product width is also possible so that edge effects may be readily treated. With the use of SCR power supplies, the output of electric infrared emitters is infinitely variable from low temperatures to very high temperatures. IR oven heating rates can be as much as 20 times faster than those obtainable in convection ovens. All of these attributes combine to allow the heating process to be custom tailored, while protecting against overheating should there be an operational problem such as a line stoppage.

Inherent in the high degree of controllability of electric infrared is the opportunity to produce consistent, often improved, product quality. More precise temperature control may be achieved than is possible with conventional heating methods. The product may be heated to the target temperature with less likelihood for overheating and resulting damage. With electric infrared, the heat applied can be matched more closely to the required duty without heating the entire product, thus protecting heat sensitive areas. Coatings can be dried or cured by radiant heating of the substrate. This cures a coating from the inside out, and prevents the formation of a surface skin until the entire coating is cured. Electric infrared does not have the problems associated with turbulent air flows. The heated air currents of convection ovens can blow off unmelted powder coatings or deposit dirt particles in liquid coatings, resulting in quality defects.

Since electric infrared ovens deliver heat at higher rates than conventional equipment, they are smaller in size and take up less factory space. Because electric infrared equipment does not rely on convection, the mechanical design is simpler and requires less bulky construction materials. Large air handling equipment is eliminated and less insulation is required. Associated with this reduced size is reduced weight, which also increases the flexibility of electric infrared installations.

Electric infrared systems may be configured many different ways to suit the particular constraints of the manufacturing environment. Because of its compact size and modular nature, electric infrared equipment can be installed in limited space and in unusual geometric configurations. It is not uncommon to see electric infrared equipment suspended from the plant ceiling to save floor space. Electric infrared panels can be configured to direct heat only to the part of the product that requires heating. The compactness and the flexibility in configuration of electric infrared equipment make it very easy to retrofit to existing manufacturing lines. In fact, electric infrared equipment can be made portable and used for localized heating.

Electric infrared equipment has significantly higher energy efficiencies than conventional thermal processing equipment. This characteristic is partially due to the fact that it heats directly without the need of a medium, such as air, so that the losses associated with exhaust and leakage are typically much lower. Furthermore, the smaller equipment size leads to lower housing radiation losses. With proper design, total energy efficiencies in excess of 75% are achievable.

Since no fossil fuels are being burned at the plant site, electric infrared equipment produces no local air pollution. Since emissions produced at the utility power plant are very tightly controlled, overall emissions are reduced when electric IR is utilized. Makeup air rates are low and as mentioned above, heat losses to the surroundings are minimal. No burners or large blowers are required; therefore noise levels are low. These characteristics combine to help manufacturers conform to more stringent environmental and health regulations. In addition, air conditioning costs are lower if the IR heating equipment is installed in a conditioned space.

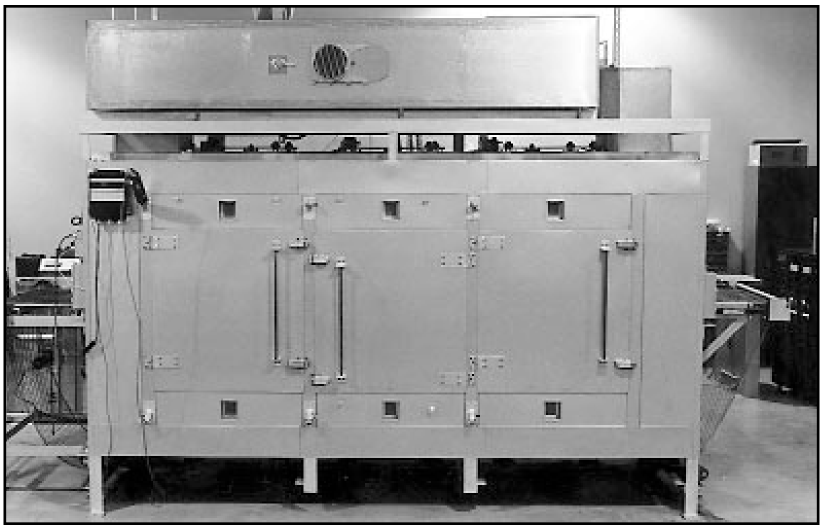


Photo 2-1: Infrared Horizontal Conveyor Oven at Advanced Energy

A metal belt conveyor oven with 120 kW of infrared and 15 kW of convective heating; a maximum of six short, medium, and long-wave emitters arranged in three zones, with individual power and target distance controls for each.

Photo 2-2: A Zone of the Infrared Horizontal Conveyor Oven of Photo 2-1

A short-wave emitter is installed in the bottom position. The metal conveyor belt, top emitter casing, and air ducting to the emitter are visible.

Photo 2-3: Short-Wave IR Emitter

For oven in Photo 2-1. Note air flow holes.

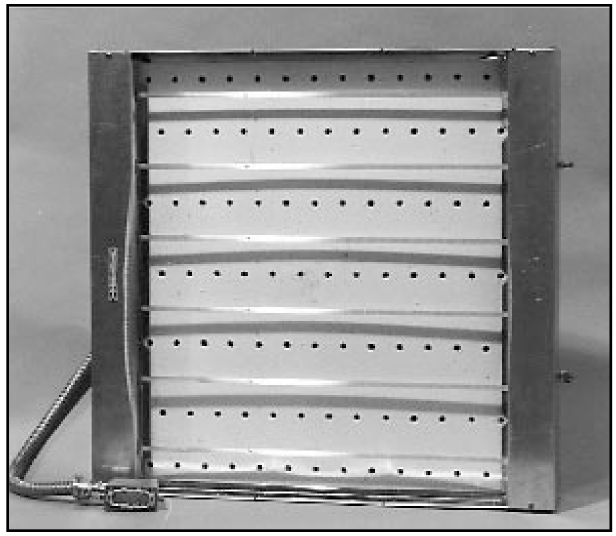


Photo 2-4: Medium-Wave IR Emitter

For oven in Photo 2-1. Note air flow holes.

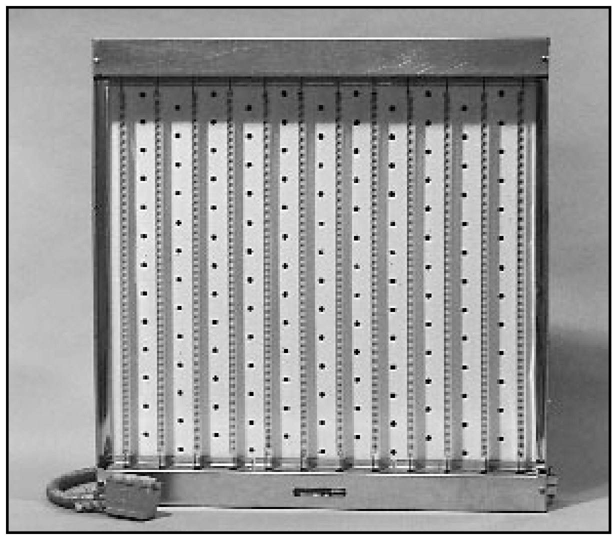


Photo 2-5: Medium to Long-Wave IR Emitter

For oven in Photo 2-1. Note air flow holes.

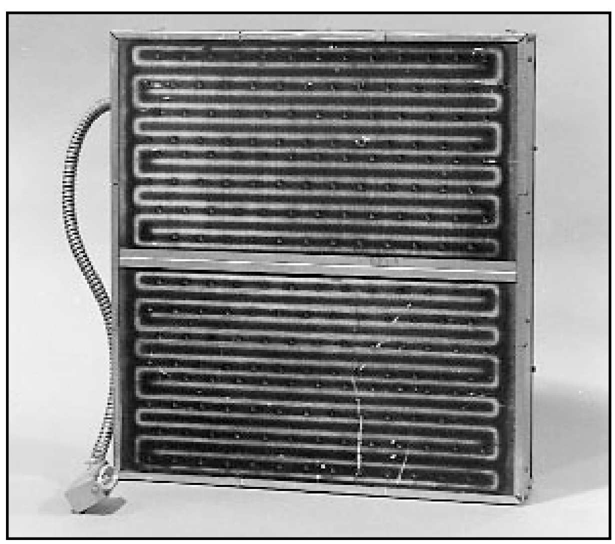


Photo 2-6: Short-Wave Infrared Booster Oven Section

A SW booster section is often used to rapidly melt thermoplastic coatings before they enter the curing oven. Booster IR sections can often be added to drying processes as a pre-dryer to speed up production. This operating booster IR section is heating and displays the visible, bright light characteristic of short-wave emitters.

Photo 2-7: Overhead Conveyor, Infrared Oven at Advanced Energy

An overhead conveyor oven with 85kW of infrared and 36 kW convective heating; three zones of medium / long wave emitters, with power level and emitter distance adjustability. Oven was designed primarily for curing powder coatings. A short wave booster section is positioned to the left of the oven and also shown in Photo 2-6.

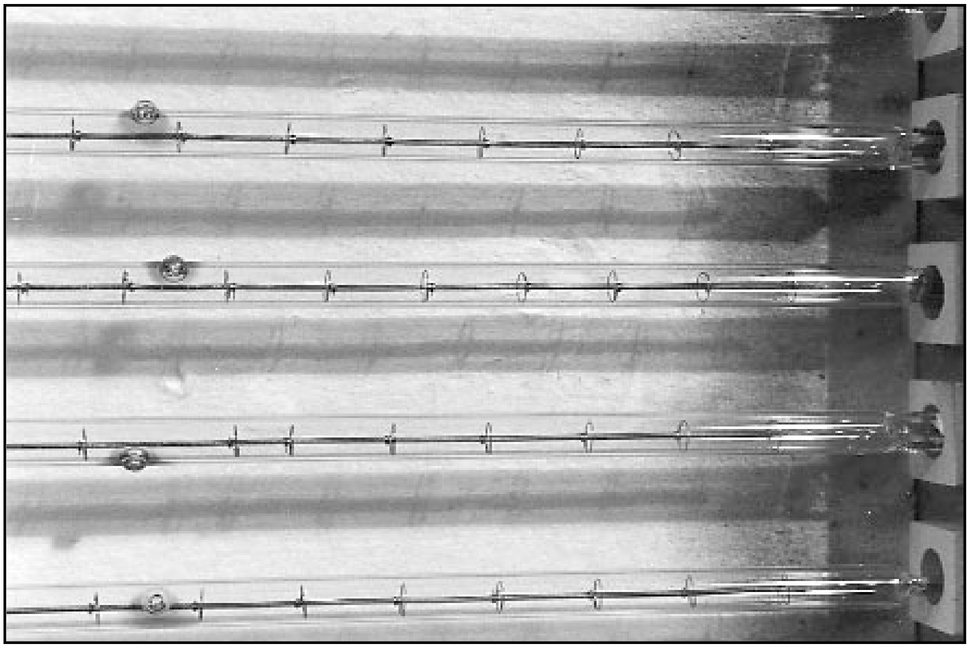


Photo 2-8: Short-Wave Infrared Emitters

See Fig. 2-7. These T-3 lamps are installed in the booster oven section of Photo 2-6. Their "reflector" is a refractory board.

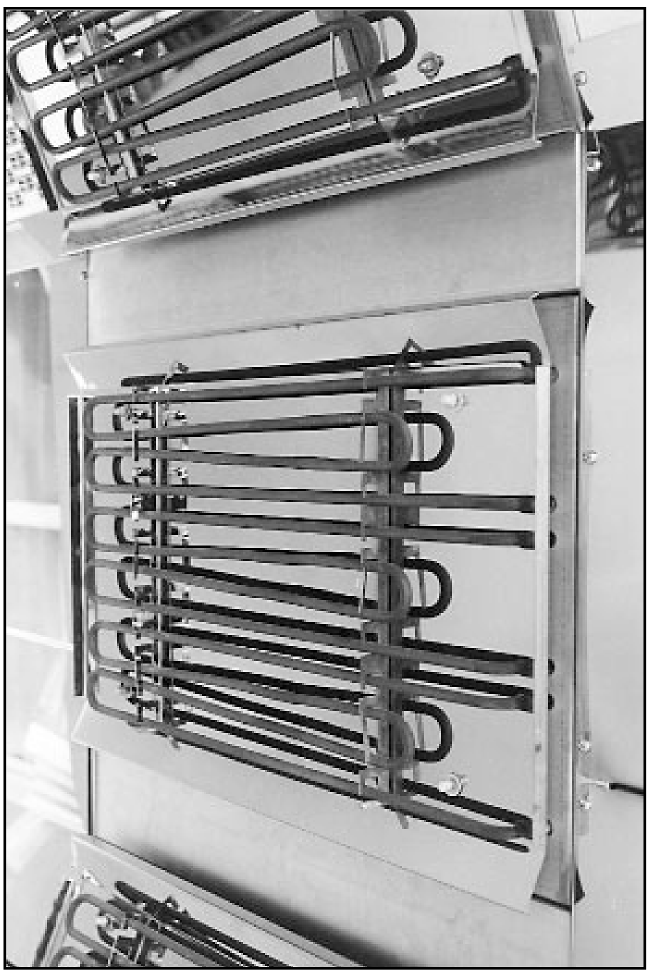


Photo 2-9: Metal Tubular, Medium-Wave Infrared Emitters

See Fig. 2-9. These "calrod" heaters are installed in the IR oven of Photo 2-7. Their specular reflectors are polished stainless steel.

Photo 2-10: Serpentine Metal Ribbon, Medium-Wave IR Emitter

The "reflector" for these ribbon heater elements is a refractory board.

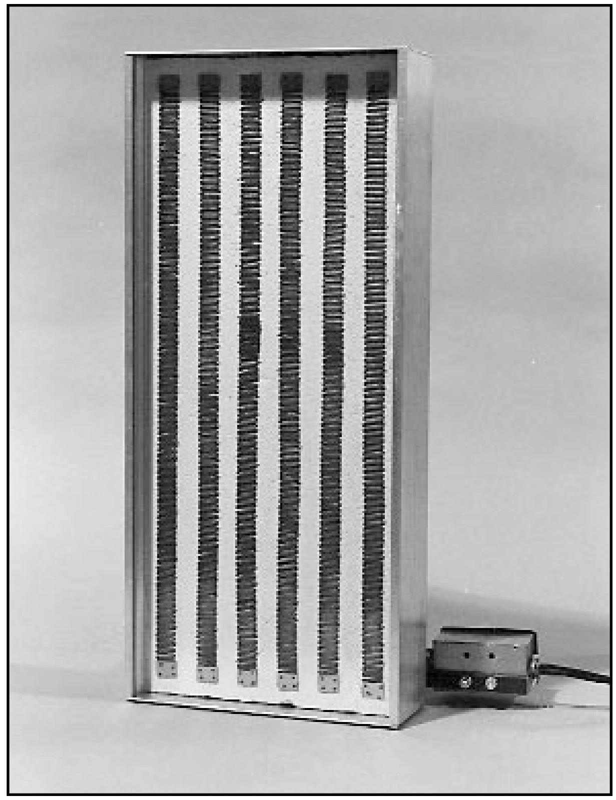


Photo 2-11: Black Quartz Face, Medium-Wave Panel Emitter

See Fig. 2-10. Resistance coils are positioned in a grooved refractory board mounted behind the quartz panel.

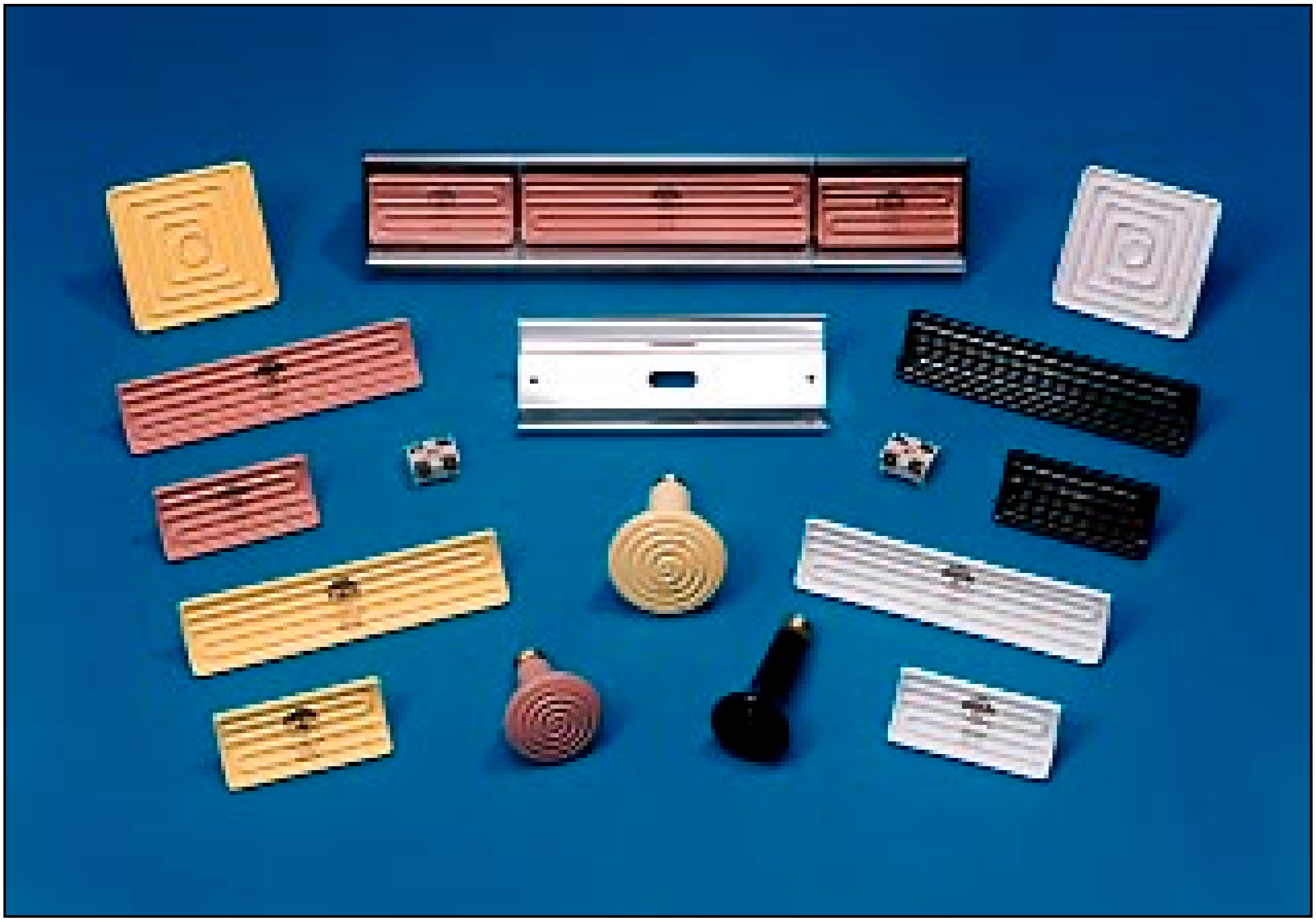


Photo 2-12: Ceramic, Long-Wave Infrared Emitters

See Fig. 2-11. Photograph courtesy of Tempco Electric Heater Corporation, Wood Dale, IL.

Chapter 3 – Common Industrial Applications

3.1 Industrial Applications of Infrared Heating

Adhesives and Coatings
- Activate and cure, or melt adhesives
- Dry inks
- Dry and cure solvent and water-based paints
- Melt and cure powder coating
- Sinter Teflon® coatings

Electronics
- Dry iron oxide on recording tapes
- Fire thick film conductors and resistors
- Rapid heat treatment in MOSFET fabrication (Metal Oxide Semiconductor Field Effect Transistor)
- Reflow soldering of complex circuit boards
- Shrink insulation
- Soldering
- Wafer processing
- Zone-melting recrystallization of silicon-on-insulator structures

Essential Systems
- Heat storage batteries for recharging

Glass and Ceramics
- Bend glass
- Bond double-pane and laminated safety glass
- Dry extruded ceramic shapes in conjunction with microwave
- Temper glass
- Fire glazes

Medical
- Sterilizing glass for drug and pharmaceutical industries
- Shrinking plastic tubes onto metal or glass tubes

Metal Processing
- Annealing
- Brazing and soldering
- Dry after washing
- Expanding for shrink-fit assembly
- Heat processing of fiber reinforced titanium composites
- Stress relief of springs
- Super plastic forming
- Rapid heat treating
- Weld stress relief

Packaging
- Activate adhesives
- Seal plastic foil packages
- Safety seal bottles
- Shrink film

Paper Production
- Corrugated cardboard adhesive curing
- Dry paper sheet

Personnel Comfort
- Spot and area heating

Plastics and Rubber
- Bend and form thermoplastics (Thermoforming)
- Cure silicone rubber extrusions
- Curing thermoset plastics and composites
- Dry and dehydrate pellets for injection molding
- Expanding for shrink-fit assembly
- Heat blow-mold preforms
- Heat thermoset composites
- Heat thermoplastic composites
- Preheat embossing rolls
- Re-glossing
- Shrink packaging film
- Welding

Printing
- Dry inks

Salvage and Disposal Operations
- Heat contaminated soils for thermal destruction of dioxin
- Overbake rubber roll coverings to ease removal
- Overbake adhesives on metal
- Burn fabric coverings off metal braid covered hose

Scientific
- Aerospace re-entry simulations
- Crystal growth precise heating
- Precise temperature control in materials testing

Textiles
- Bond non-woven synthetic fabrics
- Cure coatings
- Dry
- Preheat
- Predry
- Weld join synthetic fiber garments

Wood
- Preliminary drying and redrying of veneers for plywood production

3.2 Drying and Curing

Drying is the process of evaporating a liquid. The largest application for IR heating has been the drying of surface coatings by evaporation. Coating thickness can vary over a wide range. Inks may be applied as a very thin coating; paints as an intermediate thickness coating: and latexes, adhesives, etc., can often be applied as a thick paste. Coatings that require drying may be water-based or solvent based. The first production line application for IR heating was the drying of paint on automobiles at Ford Motor Company in the mid-1930s.

Electric IR has a distinct advantage over gas convection ovens for drying processes, as electric IR can apply heat quicker than can a convection oven. Quicker heating results in shorter processing times and smaller ovens, a significant factor with many established processes that need to expand in their limited space.

Because IR is a surface heating phenomenon, it allows almost instantaneous curing of inks on paper, plastic, elastomer, ceramic and metal surfaces. It is used in high speed printing of text and for product labeling and identification.

When paints are dried in a conventional convection oven, the paint must be dried slowly to prevent the formation of a solid skin on the surface. If a surface film forms, additional solvent or water, as it is heated and vaporizes, can cause blistering of the skin, resulting in a surface defect. IR radiation can penetrate thin coatings and heat the underlying substrate. The substrate then conducts heat into the coating, curing the coating primarily from inside to outside. This mechanism eliminates the problem of surface film blistering and allows much faster curing rates with IR ovens.

The solvents from paints and coatings which contain organic solvents can become explosive. Air flow within an IR oven for these drying applications is essential to avoid vapor accumulation. Likewise, the drying of water produces a vapor cloud above the product surface. Short-wave (SW) electric IR can penetrate the moisture vapor cloud and directly heat the product surface, thus driving the moisture out. However, when drying of moisture is the only purpose of heating, ovens with medium-wave (MW) or long-wave (LW) emitters are usually chosen, as the wave lengths of MW and LW emitters are more strongly absorbed by water. See Figure 2-4 and Table 2-2.

With MW emitters, it is necessary to include air flow to disperse the water vapor cloud that forms above the heated, wet product. Without air flow, the vapor cloud will absorb the MW radiation and further heating of the product cannot occur until it is dispersed. An effective method of providing air flow within MW and LW ovens is to provide air passages through the emitters or their reflectors. Air flow through the emitter or reflector heats the air and provides additional convective heating to the product.

IR drying has many applications for web drying of wet and coated metal sheet, textiles, and paper, etc.

For very critical applications, such as electronics, electric IR has another important advantage over convection ovens. Electric IR does not add water vapor to an oven's atmosphere. In contrast, the oxidation (burning) of gas always produces water vapor. One mole of methane, when burned, consumes two moles of oxygen from the oven's atmosphere, but replaces it with one mole of carbon dioxide and two moles of water. One mole of propane, when oxidized, consumes five moles of oxygen and replaces it with three moles of carbon dioxide and four moles of water.

(methane) $CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$

(propane) $C_3H_8 + 5O_2 \longrightarrow 3CO_2 + 4H_2O$

This fact – that burning of fuel gases produces water – explains the rusting problem that occurs with convection oven gas burners when they are not continuously operated.

Curing is the oxidation or polymerization cross-linking chemical reactions which occur in addition to solvent or water removal from coatings. For electrostatically applied powder coatings, IR first melts, or gels, the powder and causes it to flow into a continuous coating. Additional IR heating results in the curing of the powder coating to one that is often superior in hardness and wear resistance to solvent applied coatings.

Each organic coating has an absorption peak where IR radiation of specific wavelengths is strongly absorbed. See Figure 2-5, which is an example for 1 mil and 10 mil thick polypropylene. In theory, it is possible to design an oven system and operate emitters so that the emitters' wave length band peaks within the absorption band for a coating. Reference to Figure 2-2 and Figure 2-5 will show that even if that is done, a majority of the IR radiation will pass through a thin coating and heat the substrate beneath, because IR emitters radiate over a wide band of wave lengths. (Some IR will be reflected from the substrate back through the coating, where it will either be absorbed or transmitted back to the atmosphere of the oven.)

Studies on powder coatings have shown that coatings primarily cure by heating of the substrate and then conduction of heat back through the coating.[22] IR ovens for drying and curing coatings are designed and produced with SW, MW, LW, and a combination of these emitters. For coatings on heavy metals parts, such as engine blocks, SW emitters are usually chosen to provide the high intensity energy required to heat the metal surface rapidly. See "IR Tackles the Heavyweights" in Chapter 4. For drying and curing a variety of coatings on thinner metals, MW or LW emitters are often chosen. See "Fast Cure for Pool Heaters" in Chapter 4. The percent electrical energy that is converted to radiant energy is higher with shorter wave lengths (see Table 2-2). However, for some materials the overall thermal efficiency may be greater if the material's absorption wave length is closely matched with the wave length of the emitter. Howard reports that "… the overall efficiency for heating Teflon® is 8.5 percent for short wave infrared and 48 percent for medium wave infrared."[18]

SW infrared heaters are often used as "booster" oven sections either before or after conventional convection oven sections. Their use can often allow significant line production speed-up due to the high intensity of SW radiation. Examples are as finishing dryers for textile, paper and other web processes, and as entry oven sections for powder paint where they rapidly gel the powder and prevent the coating from being disturbed by convection currents in a convection oven. See Photo 2-6.

IR ovens are widely used for curing adhesives. Applications for bonding fabric, plastics, elastomers and metals with IR are numerous.

Material or process requirements may dictate that combination heating techniques are necessary. Thermovation Engineering reports a case study involving adhesive bonding an assembly of a pulley and bearing to produce idler pulleys for automobile and appliance manufacturers. Test production had involved batch oven curing for one hour. Information from the bearing manufacturer established that any exposure above 250°F could damage the elastomer bearing seal and degrade the permanent lubrication within the bearing. A series of tests was run to determine the effects of infrared heating, convection heating temperature, and convection air velocity on seal and lubricant deterioration. Final oven design involved a combination of IR and convection heating. The oven conveyor was set to run between one and two feet per minute through the eight foot oven, providing a total cure time of four to eight minutes. Parts testing determined breakaway strengths four times greater than the desired standard and two times greater than results with convection curing only.[25]

3.3 Plastic Thermoforming

Thermoforming is a rapid method of producing plastic parts. Flat plastic sheet is first gripped in a clamping frame, heated to a temperature where it becomes soft and pliable, then moved over a mold or die. It is then either vacuum formed by being drawn into the die by vacuum, or pressure formed by both vacuum drawing and forcing into the female die with either air pressure or with hydraulic pressure exerted by a male die.

Heating in a thermoformer occurs when the plastic sheet is moved between two parallel banks of infrared emitters. The top panel may be as close as two inches from the plastic sheet. The bottom panel will be located far enough away that the heated plastic sheet does not sag down onto it. For mass production parts, a thermoformer line may consist of three or four heating stages, rather than a single zone. Production thermoformers exist with all of the following IR emitter types[4]:

- Tubular quartz
- Metal tubular (Calrod)
- Quartz fabric panel
- Metal panel
- Ceramic
- Gas catalytic panel

An early – and continuing – application of thermoforming is for packaging applications where thin sheet is formed over a product, which is, in effect, the forming die. This simple application for plastic thermoforming requires little process control.

The applications for thermoformed plastic parts are endless. Examples are product packaging, containers (margarine tubs, hamburger trays, egg cartons, cups, etc.), picture frames, signs, computer and equipment housings, skylights, machine guards, automobile and aircraft dashes and interiors, luggage, furniture components, sinks, spas and bath tubs, refrigerator liners, camper tops, boat hulls, and storage pallets.

Twin-sheet thermoforming is the most advanced application of plastic thermoforming. It is a process for making plastic structural parts than can compete with injection blow molding and structural foam methods. The process heats and forms two plastic sheets individually, then welds them together by the application of mechanical pressure to the seam lines. Finished parts can be hollow, or can encapsulate wood, plastic or metal, or they can be filled with foamed or cast-in-place materials. An example would be the outer shell and liner for an insulated cooler which has insulating foam injected into the cavity.

A major volume application of twin-sheet thermoforming for a structural part is for shipping pallets of high density polyethylene (HDPE). The U.S. Postal Service tested twin-sheet thermoformed pallets before converting from presswood pallets for First-Class and Third-Class bulk mail use. Catalogues, for example, are printed, stacked on pallets and stretch wrapped by the printer before delivery to the postal service for bulk mailing.

3.4 Glass Manufacturing

Building and vehicle standards require tempered “safety” glass for many applications where breakage could seriously injure people. Examples include vehicle windows, glass doors, shower and tub surrounds, etc. Tempering is accomplished by heating glass to about 1200°F, then rapidly air cooling both sides. This imparts compressive stresses in the outer layers of the glass which increases impact strength by five to six times. Tempered “safety” glass, when broken, fractures into many small pieces without sharp edges, rather than into long, sharp splinters as with common glass. Several IR manufacturers supply standard IR ovens for production tempering of glass.

Laminated “safety” glass is toughened glass that has a layer of polyvinyl butyral (PVB) between two pieces of glass. The PVB functions as an adhesive which tends to hold the glass pieces in place, if struck with sufficient force to fracture the glass. Production is typically first a laminating step in which an infrared heating system heats the glass layers to 100 to 120°F, after which a PVB layer is positioned between two glass layers. Next, the laminate is again IR heated to 150 to 160°F, passed through a bonding layer, reheated to 180-190°F with IR, and again passed through bonding rollers. Once bonding has occurred, the parts are placed into an autoclave for final curing.

Many glass products require bending with complex curvatures. IR heating is utilized for small to large production runs for vehicle, furniture, and architectural glass products.

3.5 Metal Heating

High-intensity SW infrared emitters can operate at up to 4000°F. When focused and concentrated they have the ability to surface melt almost all metals. Common metals applications for infrared heating include reflowing solder on printed circuit boards, and other joining operations requiring soldering or brazing. Accurate temperature control possible with IR heating allows reflow soldering to occur without damaging heat sensitive electronic components.

Whitemetal is an alloy of tin and about 10 percent antimony. When deposited under controlled conditions onto steel backing surfaces, it is useful as a bearing surface for thrust and journal bearings. The use of IR heating, with accurate controls, standardized the production of quality whitemetal deposits and increased production rates over the old, highly skilled, manual casting methods.

The heating of metal surfaces to dry and cure coatings has been previously mentioned. The drying of metal surfaces after washing and prior to subsequent processing bears repeating.

Focused, high-intensity, SW infrared emitters are well suited for rapid heat treatment of thin sections and wire. Chamber or tubular heaters typically consist of focused SW emitters and reflectors arranged around an axial pass. A continuous product, such as wire or hose can be passed through and rapidly heated.

Above about 1000 to 1300°F, radiant heating is the predominant mode of heat transfer in metal heat treat furnaces, whether the furnace is fuel fired or electric heated.

3.6 Product Shrink Wrapping

Faster, better, the packaging industry is continually trying to improve its methods. Flexible plastic films combine strength, high- and low-temperature resistance, crystal clarity, and printability. They may be plain or metallized, formable, provide a barrier to gas and water vapor, and have excellent flex and puncture resistance. Flexible plastic films can maintain their strength at both freezer and oven temperatures, and can be used for leak-resistant wraps and lidding in a wide range of food and nonfood applications. And all of these benefits can be obtained and applied at high speed production rates.

Plastic packaging film may be as simple as clear, heat shrinkable polyethylene film, or as complex as laminate or coextrusion film that consists of seven or more distinct layers. Heat shrinkable films offer manufacturers a simple method of securing their product, whether against pilferage of small items, or against soiling of large items such as large pieces of furniture.

Photo 3-1 demonstrates testing to determine IR oven heating requirements for large textile rolls. This photograph shows a plastic heat shrink film wrapped textile roll suspended by chains from the overhead conveyor of the vertical IR oven at Advanced Energy in Raleigh, North Carolina.

Safe transport of palletized stock is assured by the use of infrared heaters to shrink clear polyethylene film around a pallet. Palletized production can be robotically wrapped and conveyed through an IR oven for almost instantaneous shrinking. Or, a simple single pallet heater could be constructed, as sketched below (Figure 3-1), that could handle 20 or more pallets per hour without requiring blowers or vents.[26]

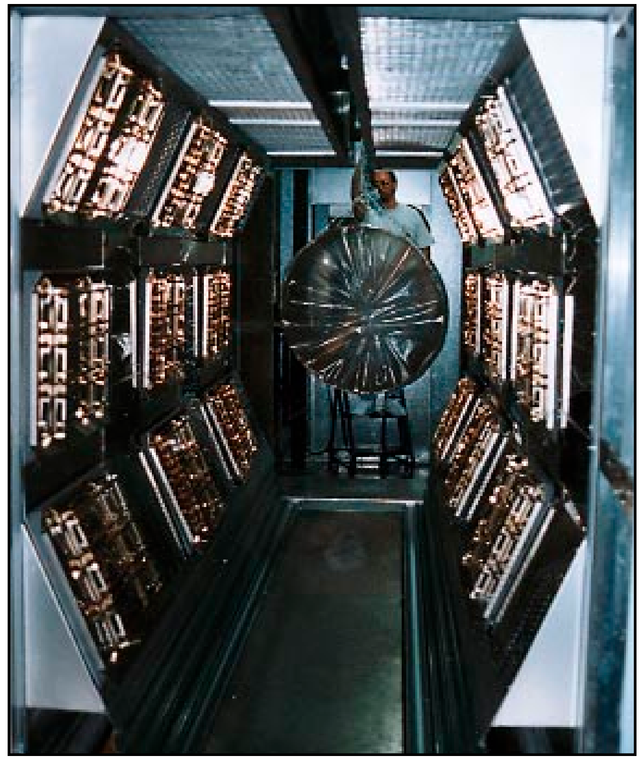


Photo 3-1: Test IR Heat Shrinking of Film Packaging on Large Textile Roll

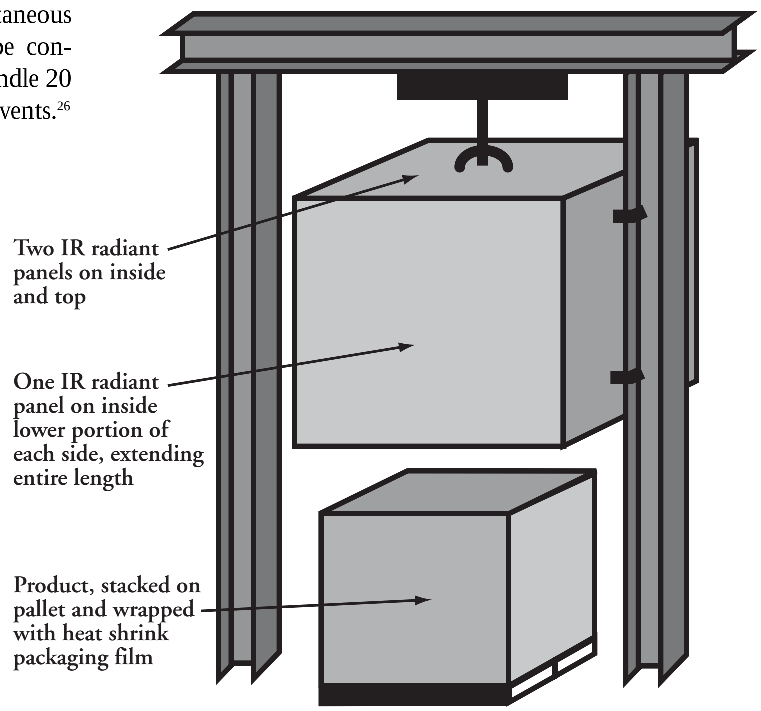


Fig. 3-1. Sketch of Pallet Heater for Heat Shrinking Packaging Film

3.7 Electric Infrared Comfort Heating

Electric infrared heating is an effective method of providing heat and personnel comfort, especially for spot areas, infrequently used areas, and high-bay facilities. Advantages of electric infrared include:

- Heats people and objects – not air
- Zone control flexibility – heat assembly area at 70°F, storage at 50°F, etc.
- Instant Heat – with short-wave emitters
- Negligible maintenance – no moving parts, motors, filters or lubrication required
- Clean – no byproducts of combustion
- Safe – no open flame, moving parts, fuel lines, toxic byproducts
- Efficient – short-wave IR emitters convert electricity to heat at almost 100% total efficiency

Examples of electric infrared comfort heating include airport walkways, building entrances, churches, car washes, hangars and high-bay manufacturing facilities, hospital treatment areas, loading docks, pump houses, smoking areas, and sports facilities. Fostoria Industries heats its entire 130,000 square foot facility in Northwest Ohio with electric infrared comfort heat.

A researcher home-tested a heat pump, baseboard radiant heaters, and surface mounted, ceiling, low mass radiant panels. The ceiling radiant panels produced energy savings of 33 percent compared to the heat pump and 52 percent compared to baseboard heaters.

Chapter 4 – Case Studies with Electric IR Heating

4.1 Infrared Tackles the Heavyweights

Is infrared a beneficial technology for curing powder coatings on heavy parts? The experiences at Industrial Coating Services (ICS) confirm that the answer is a resounding yes. In August 1994, ICS started operation of a new line installed to finish engine blocks and heads for Navistar International and Ford Motor Company. The technology used for curing black epoxy powder coating was infrared, and the benefits are noteworthy.

First, the time for curing a 375 lb. engine block was 6 minutes in the infrared oven, compared to 75 minutes in the gas fired convection oven. Infrared heats through radiation, hence only the outer layer of the part is heated to the requisite cure temperature. In a gas convection oven, the entire block has to be heated to obtain cure. Infrared therefore heats and cures the coating faster, resulting in efficient energy use and increased production. In fact, ICS needs only 5 kWh to cure the powder coating on a 375 lb. engine block.

Second, cool down time is faster, which allows the conveyor to be shorter and its drive motor to consume less power. Also, parts can be packaged and shipped more expeditiously.

Third, the ICS infrared oven facilitates enhanced controls. Customized control strategies and emitter zoning configurations can be developed for each part. This ensures that curing accords with specifications. The oven can also be allowed to idle on low power during breaks, which further optimizes energy use. Inflexible burner arrangement and high thermal inertia make idling and precise control very difficult in a gas oven.

Fourth, the floor space occupied by the ICS infrared oven was significantly less than conventionally expected. The company had tested curing the engine block in a 380 ft long gas convection oven which occupied 7,200 ft^2., whereas the infrared oven installed is 47 ft. long and occupies 258 ft^2.

Fifth, there are no on-site combustion emissions associated with the infrared oven.

Main Features of the Oven

BGK Finishing Systems, located in Minneapolis, Minnesota, supplied the infrared oven. It came complete with 23 vertical zones and used 544 emitters for a total connected load of 1545 kW.

Each zone can be set up to emit a fixed amount of heat established by the requirements of the part being cured. Characteristics of the part which are considered in establishing a curing setup include recesses, shadows, shape and weight. Oven integrity is maintained since there is no warping or meltdown because of excessive heat. The short wave infrared emitters are equipped with self-cleaning, white ceramic reflectors which are able to withstand temperatures up to 2200°F. Excess powder that lands on the reflector is incinerated and leaves the surface without unduly affecting reflectivity and consequently, the amount of energy getting to the part. Short wave emitters radiate some energy to the ceramic reflectors; and that energy is reflected, absorbed or conducted away. Some of the energy absorbed is re-radiated from the reflector in the form of long wave infrared. Both reflected and re-radiated energy contribute to curing the part in the oven.

The infrared oven has significantly fewer components requiring maintenance attention. Essentially the maintenance list includes emitters, reflectors, temperature monitors, exhaust fans and a control system. A gas oven requires more components for proper operation, and therefore generates a more daunting list of maintenance items.

Photo 4-1: Powder coated engine blocks being cured by the ICS short wave infrared oven.
Photograph courtesy of BGK Finishing Systems

Who is ICS?

Industrial Coating Services, headquartered in Indianapolis, Indiana, has been in business since 1983 and is a job shop finishing parts for the automotive and appliance industry. The company has three plants and employs approximately 225 people. On winning the contract to finish engine blocks and heads, the company explored various options for curing and eventually selected a system that uses infrared technology. This has put ICS in a position to use leading edge technology to succeed against heavyweight challenges.

4.2 Plastic Strapping Produced with Electric IR Heating

Background: Dynaric, Inc., of Virginia Beach, Virginia, produces polypropylene and polyester plastic straps used for a variety of shipping and binding purposes. Although most orders are shipped in the United States, the company serves an increasing international market. To meet the continuous demand for strapping, Dynaric's 60,000 square foot plant has production lines that run 24 hours per day, 365 days a year.

Process: Dynaric uses a process where plastic is melted, extruded and stretched into long straps. Different orders of straps may vary in minimum breaking strength from 100 to 1,250 pounds. To meet the exact specifications of customers, control is of primary importance throughout the process, which involves chilling, pre-heating, stretching, annealing and cooling of straps.

The Problem: For 16 years, Dynaric relied on production lines that used water of varying temperatures for the different stages of the process. While this method produced quality straps, greater control was desired to maintain the company's competitive edge. Dynaric also sought to correct an environ-

Photo 4-2: As a normal part of Dynaric's quality control, technician Karl Schmitt checks the roll speed of straps on the production line in the exit section of an IR oven. The side door has been opened for this test. The three-pass path of the strapping can be seen. Heat and roll speed must be properly maintained throughout the process to meet Dynaric's high standards of consistency.

mental problem brought about by the high level of humidity created by the wet bath production process. Wet floors were everywhere, which presented a threat to employee safety. In addition, the high plant humidity caused a major expense associated with protecting the building structure against corrosion and replacing corroded lighting, pumps, motors, and other mechanical equipment.

The Solution: In 1989, Dynaric began converting its wet production lines to an electric infrared method of heating and curing straps. Each line has three ovens about ten feet long. The strapping takes a double switch-back within each oven, thus the path length within each oven is approximately thirty feet. Ceramic panel electric IR emitters at the top and bottom of the ovens provide the radiant heating. The electric IR ovens perform the tasks of preheat, heat stretching, and annealing. The IR process virtually eliminates the need for water and has dramatically increased Dynaric's ability to control all phases of production. Jim Nelson, Dynaric's vice president of manufacturing, also points out a remarkable improvement in the plant's comfort and safety level. He says, "The plant always used to be damp and humid, with puddles and slick spots on the floor. The damage from steam moisture was so extensive, plant equipment had to be replaced. Now, without the excess moisture, the plant has an entirely different atmosphere, promoting increased morale and productivity."

Production Benefits: The greatest product benefit is the increased quality brought on by precise control. Now, because of accurate temperature settings throughout production, straps can be made that are uniformly equal in durability and elasticity. Along with greater consistency in meeting customers' specifications, production lines can move faster, increasing Dynaric's output capacity and profitability. As Jim Nelson says, "We're simply a much more efficient plant in every way since we switched to infrared heating."

Savings: Since heat is radiated directly to the strapping that is being processed, Dynaric realizes far greater energy efficiency than with wet production lines. Also, the wet production lines produced airborne moisture which had to be removed from the plant. To accomplish this requirement, Dynaric used two 20-hp exhaust fans operating 24 hours a day. With reduced exhaust fan usage due to the elimination of the wet production lines, Dynaric is able to save approximately $20,000 per year. Additionally, Dynaric saves thousands of gallons of water per month, and a significant amount of money in sewage costs.

Conversion Status: Eight of nine production lines at Dynaric had been converted from wet production to electric IR as of July 1997. The final line conversion was scheduled for 4Q97.

Print Drying: Dynaric also uses an IR drying process for printing codes on its plastic strapping with water-based inks.

4.3 Fast Cure for Pool Heaters

Most businesses are interested in cutting costs while maintaining quality and productivity. Pac-Fab Inc., a manufacturer in Sanford, North Carolina, is no different. A maker of swimming pool heaters and filtration systems, Pac-Fab was spending nearly $300,000 a year for powder coating of heater cabinets, not counting the cost of the powder.

Malcolm Reese, electrotechnology engineer at Carolina Power and Light, suggested that Pac-Fab consider in-house powder coating with infrared curing. (Pac-Fab was subcontracting the coating and curing to an outside vendor.) Reese arranged for tests to be performed at Advanced Energy.

Powder coating is an emission free replacement for solvent based paint that requires 350-400°F for curing. Laboratory testing demonstrated that a commercial infrared oven, which uses medium-wave infrared along with convection heating, provides the necessary distribution of heat to properly cure the powder coating on the various shapes of pool heater cabinets in only three to four minutes.

Photo 4-3: Curing powder coating in infrared oven.
(Note: Red lighting is used to illustrate reflective surfaces.)
Photograph by R. A. Flynn

Photo 4-4: Cabinet body after powder spraying and curing. Infrared oven in background.
Photograph by R. A. Flynn

Working with Reese, CP&L account manager Scott Reynolds, and a powder coating consultant, Pac-Fab chose an infrared oven with an electrostatic powder spray booth and a conveyor line to meet both present and projected coating needs. The equipment costs were approximately $100,000. Operating the in-house system will cost about $60,000 a year, saving $240,000 a year and achieving payback of the capital investment in only five months.

In addition to cost savings, the company enjoys other benefits as well. First there is increased quality since the in-house coating and curing allows Pac-Fab to control to high quality coating standards. Finally, there are space savings. According to Pac-Fab's Bill Wheeler, space is a major constraint at the plant. Fortunately, the infrared unit has a footprint about 25% of that required for a conventional gas fired oven. Also, Pac-Fab can now coat, cure, and assemble parts in-house on an as needed basis, reducing inventory space requirements. Wheeler says, "This system allows us to move closer to build-to-order manufacturing."

The Results

Quality: In-house coating and curing allows Pac-Fab to control to high quality coating standards.

Cost Saving: Switching from contract applied to in-house applied powder coating with IR oven curing saved 60 cents per square foot with a project savings of $240,000 per year.

Investment Payback: Achieved in five months.

Income Producing: Only five hours per day are scheduled for in-house use of the powder coating line. Idle time is available for contract painting parts for other manufacturers.

Inventory Reduction: Pac-Fab can now coat, cure, and assemble parts in-house, which allows them to manufacture heaters on an as needed basis and reduce inventory space requirements.

Photo 4-5: Assembled swimming pool heater awaiting final testing.
Photograph by R. A. Flynn

4.4 Auto Body Shop Chooses Infrared

Why did the Norfolk Technical Vocational Center (NTVC) chose electric infrared heating for its auto body shop? The many advantages of IR combined to convince instructor Jerry Wellings that it was the right choice for his new down draft paint booth. Not only does IR provide a superior finish but also it dries waterborne paint much faster than gas. Furthermore, the system is easy and inexpensive to both operate and maintain.

After Virginia Power recommended that the NTVC modify its spray booth to incorporate infrared curing, Wellings contacted RDM Enterprises, Inc., of Greenville, South Carolina, a company that designs and sells down-draft spray booths with infrared curing. RDM installed 18 medium wave, quartz tube IR emitters. These emitters are located around and above a car to provide full-car IR heat coverage. Each emitter has a stainless reflector, housing, cover, and on/off switch. During paint spraying, the emitter cover is closed to seal out paint over spray. The on/off switch is activated by opening the cover. Emitters can be left closed – and off – if not needed, as when only part of a car, such as a fender, is to be painted. Each emitter draws a maximum of 2000 watts.

The control system chosen for IR heating of this spray booth is simple, cheap, and requires that the operator select only the "intensity" and time of heating. An SCR controller varies the voltage supplied to the emitters based upon the intensity setting selected. This varies the emitters' tube temperatures and thus the heat radiated. Wellings' extensive knowledge of painting enables him to correctly choose time and intensity settings for various size and color vehicles. Automatic con-controller systems are available that use IR pyrometers to measure the vehicle surface temperature and automatically control each emitter's power output.

Before the auto body shop started using IR heating, only one car could be painted each day. A freshly painted car had to be left in the spray booth with its filtered air supply and exhaust system for four to five hours, until the paint was dry "to touch." Now the entire process can be accomplished in as little as an hour and a half. Wellings comments on the increased speed and productivity resulting from his new system: "With my IR heaters, I can now paint, bake, and roll out a car during each of my two-hour-and-forty-minute classes."

The following additional comments by Wellings underscore more benefits of the IR curing system.

Photo 4-6: A Paint Job Curing
Note three vertical side emitters, and three horizontal top emitters with their doors open and hanging down.

Quality: From my experience, gas heating had a real problem with "solvent pop." A gas heated booth is just a hot box. With it, the paint must dry from the outside, in. If the drying is too fast, a dry skin forms on the outside of the paint. As the inside of the paint dries, the solvents fight to come out. As they do, they break the dry, top crust, leaving little craters in the paint that we call, "solvent pop." IR heating penetrates the paint, heating up the paint all the way through and also heating the metal underneath the paint. This helps drive the solvents out. IR heating is really a better and faster way to dry a paint job.

Reliability: IR heating is very reliable. I was looking for long, trouble free operation. I'm a firm believer in buying good stuff only once. You can buy a good tool one time, or you can buy a cheap tool five times.

Efficiency: If I want to paint only part of a car, I only open the emitter covers located near that part. There is no need to operate all the emitters.

Safety: IR heating is safe. To change an emitter, I need only to throw one switch and lock it out. There is never any fear of a gas explosion.

Cleanness: IR heating is totally clean. With gas heating, I would expect to have to change my intake air filters at least once a year for school shop use. A commercial shop would be much more often. We've had this spray booth system over two years and the filters are still good.

Quiet: Another thing I like is the quietness of IR curing. Once we stop spraying paint, we can turn off the air supply blower fans, and only the exhaust fan continues running. I can now teach a class next to the booth while a car is being dried.

Ease of maintenance: There is no concern for corrosion of gas burners when not in use, or the need for adjustment after periods of school vacation. With electric infrared medium wave emitters, I can immediately see if an emitter has failed, and it is quick and easy to change. There is almost no maintenance of this IR system.

Low cost: IR heating doesn't cost much. The maximum IR heating cycle I use is 40 minutes. I seldom set the intensity setting for the emitters above 80%. Even if they were set at maximum intensity, 18 emitters would draw only 36 kW. For 40 minutes usage, that's 23 kWh, which only costs less than a dollar and a half at six cents per kWh. That's cheap to dry a car's paint job.

Mac McColm, president of RDM Enterprises, adds another benefit to the list: IR's compatibility with any paint formulation and method of application, whether it be waterborne, high solids, urethane, or powder coating. McColm agrees that medium wave electric IR is an excellent choice for Norfolk Technical Center. He explains, "First, they are in the business of training people for the local job market, and that responsibility requires that their training be on the leading edge of technology. Second, in terms of initial cost, operational cost, and efficiency, IR is the only technology that allows them the best use of funds."

Photo 4-7: Wellings' "Santa's T", a 1927 Ford Model T street rod.

4.5 Outdoor Shipyard Workers Warmed in Winter Weather [27]

The Twin City Shipyard in St. Paul, Minnesota, fabricates river barges. Two motorized buildings, each 60 feet long by 75 feet wide by 45 feet high, and mounted on tracks, can be positioned together to shield workers from rain and snow. During winter months, a large canvas curtain is hung on both ends to function as a wind break. In St. Paul's winter climate, outside working conditions can become miserable to impossible.

Forty-eight short wave, quartz IR lamp units are used to provide comfort heating for this barge fabrication work. Even at an outside temperature of -16°F, they are capable of providing an environment of 55 to 60°F within this moveable building enclosure. Each IR lamp unit consists of a frame, an aluminum reflector, and two IR lamps. Each IR lamp draws 3650 watts on 480 volt power. Twenty-four IR units are mounted around the ceiling perimeter of each building. Twenty-four additional IR units are mounted at the ceiling 45 foot height on 15 foot by 20 foot centers.

Staging control allows the operation of only one of the two IR lamps in each unit during less severe weather. Zone control can restrict heating only to the areas where work is occurring, thereby reducing the power consumed. However, with all emitters operating on full voltage, to heat each 60 foot by 75 foot, high-bay, moveable building, only 350,400 watts are required, which is a heating density of 78 watts per sq. ft.

In contrast, the alternative method of heating was to use a portable, direct-fired propane unit heater. The recommended propane unit heater provided 3 million BTU input, which is equivalent to 195 watts per sq. ft. for propane, versus only 78 watts for electric IR.

Photo 4-8: Welder at Work. Electric IR units mounted below building ceiling provide comfort heating.
Photograph compliments of Fostoria Industries, Inc.

Photo 4-9: Electric IR Heating Provides Open-Air Comfort Heating in Minnesota Shipyard.
Photograph compliments of Fostoria Industries, Inc.

Chapter 5 – Frequently Asked Questions

There are a number of concerns that industry has about electric infrared (IR) heating which this handbook has tried to answer. Each electric IR application tends to be unique unto itself. The design and size of the unit to be used, whether it will be a stand-alone application or in conjunction with some existing drying methods, must be specified in the beginning of the decision making process. Some of the following questions and answers will cover the unknowns and the misconceptions about electric IR heating.

Q. *Are IR heaters (emitters) hot?*
A. The IR emitters are at a much higher temperature than the parts being heated.

Q. *Is IR heating rapid?*
A. The direct transfer of energy, via infrared electro-magnetic radiation, allows IR heating to be very rapid. Reductions in process heating times by up to 90% over gas convection ovens have been documented.

Q. *Can my part be over heated in an IR oven?*
A. Yes. The final part temperature is determined by the dwell time in an IR oven and the temperature of the IR emitters.

Q. *How can I prevent my part from being damaged by over-heating if the oven's conveyor stops?*
A. An electric IR oven can be programmed to immediately turn the emitters off if a process line stops for any reason. Also, air jets directed across the product can be programmed to turn on at line stoppage to prevent product damage.

Q. *When I start my process in the morning, must I wait for an IR oven to heat up?*
A. Electric IR oven emitters come to full temperature within seconds for short wave emitters, to within minutes for long wave emitters.

Q. *Can I shut an IR oven off for line stoppages and the lunch break?*
A. Unlike convection ovens, electric IR ovens can be shut down for short stoppages and require only seconds to a few minutes for the emitters to return to operating temperatures.

Q. *Is there a size limitation for electric infrared heating applications?*
A. The application can require as little as a light bulb sized emitter of about 50 watts or a large drying or curing oven of 800 kW. There is not a constraint on the physical size of an electric IR oven. Usually the limiting factors are space related or process equipment capabilities. The size becomes more of an economic evaluation of cost versus savings.

Q. *Is there uniform heating across the width of an electric IR heater?*
A. There is more uniformity with electric infrared as compared with a gas infrared due to the valving and pressure control problems of gas IR. With the ability to easily zone IR ovens, it is easy to focus heat on a specific area. With web products, for example, it may be desirable to apply additional heating to the edges. This is easily accomplished with proper IR oven design.

Q. *Are electric IR ovens much more expensive than gas convection ovens?*
A. The individual components of an electric IR oven may be more expensive than those of a gas convection oven. For example, IR emitters may cost more than a gas burner. However, the overall size of the IR oven will be several times smaller than a comparable capability gas convection oven, resulting in savings in materials and fabrication costs, and savings in factory space. In many cases, the cost of an IR oven will be comparable to a gas convection oven, and in some cases it will be less.

Q. *Do electric IR ovens cost more to operate than gas convection ovens?*

A. On the average, electric IR ovens are three times more efficient in delivering energy to the product than are gas convection ovens. If the cost of gas consumed, on a BTU basis, is 1/3 the cost of electric energy, the cost of energy delivered to the product will be the same in each oven.

Q. *If gas is much cheaper, per Btu, than electricity, how can electric IR be more economical?*

A. The thermal efficiency of properly designed IR ovens are much greater than gas fired convection ovens. Much of the heat from the gas combustion process is wasted as exhaust gases. Additionally, IR heating can be directed and need heat only the product. A gas oven heats everything (walls, conveyor, etc.) within the oven. Also, an electric IR oven can be zoned. When processing small parts, only those IR emitters which are directed toward the part need operate.

Q. *Do electric IR ovens require more maintenance than gas convection ovens?*

A. Electric IR ovens require periodic maintenance to check and replace any emitters that have burned out, and to clean metallic reflectors if they are used. Gas convection ovens require periodic maintenance to clean and adjust burners, clean oven surfaces, clean the flue, and check the flue for proper draft. A gas convection oven may be more forgiving if maintenance is skipped, since it will still work if it is dirty, if the flue is leaking, or if the controls are out of adjustment. However, this may result in an unsafe operation. An electric IR oven is less forgiving of skipped maintenance because a burned out emitter or dirty reflec tor may significantly affect the oven's performance. It is important also to remember that a gas system, if out of proper adjustment, wastes fuel. An electric IR oven's emitters either heat, or do not heat. When an electric IR emitter heats, all of the energy consumed is converted either to radiant or convective heat in the oven; when an electric IR does not heat, no energy is used.

Q. *Does IR radiation work better with little or no air moving?*

A. Air is virtually transparent to IR radiation. IR radiation is neither absorbed nor scattered by air. For water drying applications, a water vapor cloud may form above the product, blocking medium and long wave radiation. For water drying, air flow is often desirable to break up and remove the water vapor from the product surface.

Q. *What do SW, MW, and LW mean?*

A. Short-wave, medium-wave and long-wave are arbitrary divisions of the practical band of electromagnetic radiation that is useful for industrial applications. A common division is 0.76 micro meters (µm) to 2 µm for SW, 2 to 4 µm for MW, and 4 to 10 µm for LW.

Q. *Are there any performance differences between SW, MW, or LW?*

A. Short-wave penetrates more than the other two in most cases. However, this does not hold true in every situation. Different materials have peak absorbability at different wavelengths, thus it is important to know the absorption characteristics of the material being heated over the entire spectrum when selecting the most appropriate type of emitter. See the quote in Section 3.2 concerning sintering Teflon for a good example where wave length is critical.

Q. *Is a specific wave length necessary for each item heated with IR?*

A. For most applications, the most important factor is the total heating rate applied to the product surface. In this regard, short-wave emitters emit the most energy, i.e., are capable of the highest power density of watts per sq. in. Also, the shorter the wave length, the higher the percent total energy that is radiated and the less which goes to convective heating. Wave length may matter for heating glass or for drying water. Those substances transmit SW, but are highly absorbent of MW. Thus for heating glass or drying water, medium-wavelength IR is often chosen. If one desires to heat a coating on a metal substrate, SW may be chosen so that the IR radiation will pass through the coating and heat the substrate, which then heats and cures the coating from its inside surface, out.

Q. *Does color have any affect upon IR performance?*

A. Short-wavelength IR is somewhat color sensitive, since about five percent of the radiation from a 4000°F SW emitter falls in the visible spectrum (0.39 to 0.76 µm). At 3600°F the visible radiation drops to less than three percent. The difference in product temperature from a black to a white object in an IR oven should be no greater than 10 to 15°F. Using MW or LW emitters can control it even more closely.

Q. *Is infrared radiation harmful to oven operators?*

A. There is no immediate danger associated with the use of IR radiation compared with ultraviolet radiation (less than 0.39 µm). Medium-wave emitters emit a visible dull red glow. This presents no hazard to the eye when viewed at a normal viewing distance.20 Short-wave IR emitters do emit wave lengths in the visible range. Studies have shown that the brightness and heat of a quartz SW lamp is sufficient to produce an aversion response that will prevent retinal thermal damage from inadvertent viewing. Repeated long-term IR radiation may cause cataracts in some individuals. As a precaution, for someone whose work requires viewing into a bright IR oven, the protection of dark glasses is recommended. Generally, the shielding around an IR oven eliminates any health risk.

Q. *Is the heat generated by electric IR different from heat generated by gas IR?*

A. Electric IR may be short, medium, or long wave. Gas IR is only long wave.

Chapter 6 – Electric Infrared Vendor Information

This vendor resource chapter presents information about IR equipment vendors who are believed to be significant manufacturers of IR emitters, heaters, ovens, and/or systems. With one exception, it does not list manufacturers that specialize in textile applications or that produce conventional electric furnaces for metal heat treat applications. An attempt was made to identify those firms that market materials fabrication firms in the Southeast. Several firms contacted did not respond to our survey and are not included. There may be some unintentional omissions of competent firms. We welcome information from any competent manufacturer of IR equipment and will inform the responsible people at the electric utilities sponsoring this handbook of future information that we receive. A representative of each company contacted supplied the information on primary markets. Companies are listed in alphabetical order.

Company	Aztec Machinery Ivyland PA, Tel. # 215-672-2600 John O'Leary, Tel. # 215-672-2600
Primary Markets:	Textiles, Chemical, General Industry
IR Equipment Type:	MW ovens, provide material handling equipment.

Company	BGK Finishing Systems Minneapolis MN, Tel. # 612-784-0466, 800-663-5498 Ed Eckhart, Tel. # 419-891-8201
S.E. Distributor:	John Deere Precision Equipment Sales Co., Tel. # 704-845-0990
Primary Markets:	Auto Components, Steel and Aluminum Coil Coatings, Powder Coating Systems.
IR Equipment Type:	SW convection ovens, produce turn key oven systems

Company	Blasdell Enterprises Greensburg IN, Tel. # 800-661-3213 Jill Blasdell, Tel. # 812-663-3213
Primary Markets:	Powder Coating, Liquid Paint on Plastics, Thermoforming
IR Equipment Type:	MW ovens, often with convection. Produce complete oven systems.

Company	Casso Solar Corp. Pomona NY, Tel. # 914-354-2500
S.E. Distributor:	W.K. Hile Co., Inc., Tel. # 704-847-9125
Primary Markets:	Textiles, Curing/Finishing of Liquid and Powder Coatings, Glass
IR Equipment Type:	Produce SW and MW emiters. Provide SW and MW ovens with and without convection, provide turnkey oven systems.

Company	Chromalox Pittsburgh PA, Tel. # 412-967-3800, 800-443-2640
S.E. Distributor:	Russ Holder, Tel. # 704-841-8727
Primary Markets:	All industries. Producer of IR emitters.
IR Equipment Type:	SW, MW, and LW emitters and heaters for OEM applications. Do not produce systems.

Company	Conversion Processes Corporation St. Charles MO, Tel. # 314-939-1069 Jim Farmer, Tel. # 314-939-1069
S.E. Distributor:	Dick Gates, Tel. # 704-532-7520
Primary Markets:	Curing Coatings, Adhesives, Printing
IR Equipment Type:	Custom ovens with MW flat panel emitters, with and without convection.
Internet Site:	http://www.cpcorp.com

Company	DriQuik Greensberg IN, Tel. # 812-663-4141, 800-473-2402 David Boyle, Tel. # 812-663-4141
S.E. Distributor:	John Painter, High Point Pneumatics, Tel. # 910-889-8416
Primary Markets:	Furniture, Powder Coating, Automotive
IR Equipment Type:	Produce SW, MW and LW ovens with or without convection. Provide turnkey oven systems.

Company	Fostoria Industries, Inc., Process Heat Div. Fostoria OH, Tel. # 419-435-9201 X249 Bob Simonis, Tel. # 419-435-9201 X221
S.E. Distributor:	Jim Faber, Tel. # 864-287-0571
Primary Markets:	Automotive, Coatings, Paper
IR Equipment Type:	Produce SW, MW, and LW ovens with and without convection. Provide turnkey oven systems.

Company	Glen-Ro Inc. Patterson NJ, Tel. # 201-279-5900 Jim Alimena, Tel. # 201-279-5900
S.E. Distributor:	Tom Van Denand, Tel. # 704-437-8400
Primary Markets:	Paper converting, Plastics, Textiles
IR Equipment Type:	Produce SW, MW, and LW ovens with and without convection. Provide turn key oven systems.

Company	Heraeus Amersil Inc. Duluth GA, Tel. # 770-623-6000, 800-311-8527
S.E. Distributor:	Jeff Williams, Tel. # 770-623-5630 X261
Primary Markets:	Powder Coating, Automotive, Textiles
IR Equipment Type:	Imports SW and MW emitters from parent company in Europe. Produce turnkey oven systems.

Company	Infrared International of North America Comstock Park MI, Tel. # 800-442-2581 Deitz Kracker, Pres., Tel. # 800-442-2581
Primary Markets:	Plastics Thermoforming, Food, Packaging
IR Equipment Type:	Import LW ceramic emitters from Wales.

Company	Infratech Covina CA, Tel. # 818-331-9400 Bob Petro, Tel. # 818-331-9400
S.E. Distributor:	Bud Porter, Tel. # 770-992-3321
Primary Markets:	Automotive, Powder Coating, Furniture
IR Equipment Type:	Produce MW quartz tube emitters, SW, MW, and LW electric ovens, and UV ovens. Provide turnkey oven systems.

Company	Innovative Industries Cleveland OH, Tel. # 216-468-2601, 800-843-7647 Tom Shiveley, Tel. # 216-468-2601
Primary Markets:	Paper and Cardboard, Industrial including Powder and Paint, Tubular Product Heaters
IR Equipment Type:	SW, MW, LW ovens with convection. Provide complete systems. Stress use of SW which can be operated as SW, MW or LW.

Company	IRT Systems North America Concord Ontario, Tel. # 800-387-3639 Mike Bertrand, Tel. # 905-669-5816
S.E. Distributor:	Hutchins Auto Supply, Durham, Tel. # 919-682-9101
Primary Markets:	Auto Aftermarket (body shops), Auto OEMs, Pulp and Paper
IR Equipment Type:	SW ovens which include convection. Import Swedish IR emitters.

Company	Maytag, Inc. Clarence MO, Tel. # 816-699-2158, 800-255-6635
Primary Markets:	Food, Spa, Industrial
IR Equipment Type:	MW calrod elements

Company	Ogden Manufacturing Co. Arlington Heights IL, Tel. # 847-593-8050 Gordon Hollander, Tel. # 847-593-8050
S.E. Distributor:	George Coyazo, Tel. # 704-399-4248
Primary Markets:	Plastics Thermoforming, Ink Drying, Powder Coating
IR Equipment Type:	MW and LW infrared panels. Ceramic LW panels have embedded thermocouples. Provides complete, custom oven systems with and without convection.

Company	Osram Sylvania Inc. Exter NH, Tel. # 603-772-4331, 800-258-8290
S.E. Distributor:	NC and SC: Sloan Carolina Inc., Tel. # 704-357-6800 VA: Sloan Associates, Tel. # 804-973-6662
Primary Markets:	Plastics Thermoforming, Paint Curing, Printing
IR Equipment Type:	Produce ceramic IR emitters.

Company	PED Technologies, Inc Erlanger KY, Tel. # 606-282-2750 Bruce Kazich, Tel. # 606-282-2750
S.E. Regional Sales	Todd Trenkamp, Tel. # 606-282-2750
Primary Markets:	Industrial Paint and Powder, Shoe and Leather Goods, Automotive
IR Equipment Type:	SW, MW, LW electric and LW gas IR ovens with convection. Provide some materials handling associated with ovens.

Company	Process Thermal Dynamics, Inc. Brandon MN, Tel. # 320-834-3370 Terry Scott, Tel. # 800-793-2077
S.E. Distributor:	Kevin Mitchell, Tel. # 864-271-8202 or 800-402-0832
Primary Markets:	Curing Coatings, Plastics Processing, Web Drying
IR Equipment Type:	Produce MW emitters. Also complete oven systems, some including convection.

Company	Radiant Energy Systems, Inc. Wayne NJ, Tel. # 201-942-7767, Bob Narang, Tel. # 201-942-7767
S.E. Distributor:	Bill Durland, Tel. # 704-283-9699
Primary Markets:	Converting (paper, film, foil), Textiles, Powder Coating
IR Equipment Type:	SW, MW, LW ovens with convection. Provide turnkey oven systems.

Company	Radiant Heat Coventry RI, Tel. # 401-822-0360, 800-295-9524 Bob Singleton, Tel. # 401-822-0360
Primary Markets:	Textiles, Powder coating, Non-wovens
IR Equipment Type:	SW, MW, LW ovens with and without convection. Provide turnkey oven systems.

Company	Radiation Systems Wyckoff NJ, Tel. # 201-891-7515 J. Wm.(Bill) Van Dyke, Tel. # 201-891-7515
S.E. Distributor:	Bruce Falk,Textile Technology, Tel. # 910-397-9088
Primary Markets:	Textiles, High Speed Printing, Plastics Processing
IR Equipment Type:	Produce MW oven systems with convection.

Company	RDM Enterprises, Inc. Greenville SC, Tel. # 803-967-2460 Mac McColm, Tel. # 803-967-2460
Primary Markets:	Auto Body Shops
IR Equipment Type:	Auto and vehicle down-draft spray booths with IR curing.

Company	Research, Inc. Eden Prairie MN, Tel. # 612-941-3300 Jim Lee, Tel. # 612-829-8384
S.E. Distributor:	Ken Emerich, Tel. # 704-442-0000
Primary Markets:	High Speed Printing, Drying Water Base Coatings, Plastics Processing
IR Equipment Type:	SW only, produce component heaters and complete oven systems with and without convection.

Company	Solaronics, Inc. Rochester MI, Tel. # 800-223-5335 Brian McLane, Sales Div, Tel. # 800-223-5335 X115
Primary Markets:	Space Heating, Cooking, Process Applications
IR Equipment Type:	MW and LW oven systems.

Company	Solar Products, Inc. Pompton Lakes NJ, Tel. # 860-739-2901 Tom Stryker, Tel. # 860-739-2901
Primary Markets:	Plastics Thermoforming, Screen Print, Powder
IR Equipment Type:	MW and LW emitters.

Company	Tempco Electric Heater Corp. Wood Dale IL, Tel. # 630-350-2252, 800-817-8640 Fermin Dalames, Tel. # 630-350-2252
Primary Markets:	Plastic, Food, Packaging
IR Equipment Type:	MW and LW calrod and ceramic emitters.

Company	Thermcraft, Inc. Winston-Salem NC, Tel. # 910-784-4800 Robert Reed, Tel. # 910-784-4800
Primary Markets:	Metal Heat Treat, Semiconductor Heater Elements, RandD Units
IR Equipment Type:	Ceramic fiber heaters and heat treat ovens. Construct turnkey systems.

Company	Thermovation Engineering, Inc. Cleveland OH, Tel. # 216-691-1410 George Heath, Jr., Tel. # 216-691-1410
Primary Markets:	Polymers, Powder Coating, Adhesive
IR Equipment Type:	SW, MW, LW and gas IR ovens. Manufacture complete systems with convection.

Company	Thermovation, Inc. Burnesville MN, Tel. # 612-894-1638 Don McGee, Tel. # 612-894-1638
Primary Markets:	Medical, Automotive, Adhesive
IR Equipment Type:	SW, MW, and LW custom oven systems with and without convection.

Company	Tri-Matix Corporation Bayshore NY, Tel. # 516-231-6800 Edward Zimmerman, VP Mkting, Tel. # 800-680-6604
S.E. Distributor:	NC and SC: Jason Tucker, T-N-T Distr. Co, Tel. # 704-754-6425; VA: Rob Stinson, Patroit Assoc.(VA), Tel.# 215-297-8099
Primary Markets:	Plastics Thermoforming, Drying Systems, Curing Systems
IR Equipment Type:	SW, MW, LW with or without convection. Manufacture complete systems.

Company	Watlow Electric Mfg. Co. St. Louis MO, Tel. # 314-878-4600, 800-893-4022 Chad Murphy, Radiant Products Mgr., Tel. # 314-878-4600
Primary Markets:	All markets. Manufacture SW, MW, and LW emitters.
IR Equipment Type:	SW, MW, and LW emitters, sensors and controls. Will produce custom ovens.
Internet Site:	http://www.watlow.com

Company	Web Systems, Inc. Boulder CO, Tel.# 303-440-4868 Ed Nowaczek
S.E. Distributor:	PenTek Industrial, Tel. # 215-361-3962
Primary Markets:	Water or Solvent-Based Inks, Coatings and Adhesives
IR Equipment Type:	SW with convection, hot air knives, air cooling and vacuum extraction. Produce complete oven systems.
Internet Site:	http://www.wsinfo.com

Company	Xeric Web Drying Systems Neenah WI, Tel. # 414-722-8123 Ray Juhlin, Tel. # 414-722-8123
Primary Markets:	Paper and Film Converting, Web Coating Curing, Powder Coating Curing
IR Equipment Type:	SW, MW, and LW with or without air flotation and convection drying. Produce complete oven systems.

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Advanced Energy Corporation

Advanced Energy, located in Raleigh, North Carolina, is an independent nonprofit organization that helps industrial, commercial, and residential customers improve the return on their energy investment. With expertise in industrial process technologies, motors and drives, and applied building science, Advanced Energy provides solutions through consulting, testing, and training. The primary mission of Advanced Energy is to increase efficiency and productivity in industries, businesses, and homes as they transform energy into goods, services, and environmental conditioning. At its Industrial Energy Lab, Advanced Energy provides access to cutting-edge industrial process technologies and state-of-the-art motors and drives testing.

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