Topical Report

IR Heating for Powder Coatings Application and Curing Process

Prepared by:
SS Energy Environmental International, Inc.
Rockford, Illinois

Gas Research Institute

Distribution and End Use Business Unit
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IR HEATING FOR POWDER COATINGS APPLICATION AND CURING PROCESS

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In a typical finishing process, there are four heating sections: a washer, a dry-off, a preheat, and a curing/drying section. This report mainly addresses the three sections: dry-off, preheat, and a curing/drying section. The objective of this report is to provide the steps involved in a coating curing process in which a gas IR can be used to improve efficiency, to reduce operating cost, and/or to help design compact ovens. GRI and SSEEI have developed additional tools useful for this purpose including a heat transfer model for evaluating performance of various gas or electric heater/oven combinations.

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EXECUTIVE SUMMARY

Powder coatings are plastic resins. When they are heated above a certain temperature, the resin particles begin to soften, which permits them to flow together and penetrate pores and rough spots on the surface underneath. This process, known as gelling, gives the coating its smoothness and adhesion. If the powder is a thermoplastic resin, it must then be removed from the heat to harden. However, if it is a thermosetting resin, its temperature is raised to trigger a process known as polymerization, or cross-linking. This alters the molecular structure of the powder, causing it to harden, even while its temperature is high. The result is a tough wear and chip resistant coating.

A typical finishing process consists of the following steps: (1) Surface preparation, (2) Dry-off, (3) Powder application, and (4) Powder curing. Curing occurs in (a) convection ovens that circulate hot air to heat the part, or (b) radiation ovens that directly transmit heat to the surface. Convection ovens, with their low temperature heads and large volumes of re-circulating air are not capable of faster speeds. Just bringing the work piece up to the curing temperature may take twice as long, since the resin needs to cure. Further, because of the slow, uniform heating in these ovens, the entire part will be raised to the curing temperature, whether it is necessary or not. Therefore, this is a waste of heating energy, and largely negates two of the greatest advantages of powder coating - greater productivity, and lower energy costs. An added concern was the fear that large air velocities in the oven and at its entrance air seal would dislodge the powder from the part before it had a chance to cure properly. In fact, an ideal curing oven should have a combination of radiant and convective heating to accommodate large variations in the load geometry and different coating thickness. A catalytic IR oven followed by a convection oven has become a popular combination for many continuous ovens. This is because catalytic IR energy is produced by flameless combustion at a much lower emitter temperature. These heaters produce most of its energy in long wave field, which matches with coatings absorption characteristics.

Gas IR heaters can be configured to match the existing oven shape, therefore, avoiding a major overhaul and thus reducing capital cost. The cost may be higher if a complex control scheme is required to run a variety of parts and coatings composition. However, the ovens can be rapidly switched on and off to bring the production line up and running. It is important to recognize that the radiant heating cannot have similar impact on the batch type oven performance, particularly if the load geometries are quite different in shape and size.

Field results indicate that a combination of catalytic and convection ovens would result in 20 to 45% increase in productivity at 15 to 20% less energy compared to the convection oven alone. If space is a concern, this combination could reduce the space requirement by 8 to 10%.

Finally, a gas IR oven would require less air handling systems, reduced exhaust gas flow, and lower electric power usage. These ovens produce significantly lower air pollutants.

The objective of this report is to provide the steps involved in a coating curing process in which a gas IR can be used to improve efficiency, to reduce operating cost, and/or to help design compact ovens. More detailed assistance can be obtained for application of gas infrared in powder coating processes by contacting GRI or SSEEI directly as they have formed a cooperative effort that combines the practical experience of SSEEI and the technology, databases, and know-how of GRI, to offer its clients independent and objective solutions for their process heating needs.
Additional information can be provided by contacting:

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CHAPTER 1
INTRODUCTION

Powder coating is creating revolutionary changes in the finishing industry. Since its inception in the 1950s, powder coating has grown from a low-volume specialty process to a high-volume widely-accepted process. Powder coatings are replacing traditional solvent-based enamels and lacquers in a steadily growing list of applications. Many industry experts believe that in time, they will dominate the finishing industry. Powder coating's unique characteristics lend themselves well to infrared heating. Powder coating is a finishing method that offers significant performance and economic advantages, and is a solution to current and anticipated environmental regulations. The economic advantages over liquid finishing stem from savings in energy, labor, production, waste disposal, and the relative ease in meeting environmental standards.

In a typical finishing process, there are four heating sections: washing dry-off, preheat, and curing/drying section. This report mainly addresses the three sections: dry-off, preheat, and curing/drying sections. These three sections mostly utilize convective type ovens using hot gas burners produced by Maxon and Eclipse. Some users utilize electric IR heaters to accomplish the same. Electric IR heaters used, are mainly short wave and medium wave types, which are tunable to different power densities.

There are several issues, however, that need to be addressed as to which type of IR heater should be used in achieving the best results for attaining a high quality produce and in lowering the operation and maintenance cost. For example, in a typical powder coating curing process, users want to have low heat flux and low surface temperature heating to avoid over heating the parts and maintaining a uniform temperature distribution. This does not preclude the use of high heat flux heaters. It is a choice that needs to be made considering the oven configuration, parts geometry, and the type of coatings.

Our coating application survey indicates that both catalytic and non-catalytic gas IR heaters are used by several oven/heater integrators and users. It is important to mention however, that high flux, high temperature IR heaters are more suited for drying and curing of liquid based coating because both convection and radiant heating is needed for rapidly raising the temperature and simultaneously carrying out the moisture vapors. To be more specific, low flux heaters are designed to produce 6000 to 7500 BTU/hr/ft² as opposed to a high flux heaters producing 60,000 to 125,000 BTU/hr/ft² or even higher. Thermal response of the gas IR heaters, vary from a few seconds to a few minutes. These heaters can be arranged in specific shapes and patterns to fit the oven design configuration. They can be turned down to a relatively low level of heat release by using a complex control scheme. Most of these heaters can be controlled in an on/off or proportional control modes.

Specifically the report contains a detailed examination of the following topics:

- Types of ovens, their advantages, and disadvantages.
- Types of gas and electric IR heaters.
- Combustion control schemes and safety.

This text is not a design tool, but is meant to provide some insights into the heater options, which may be employed in the powder coating application and curing process. Additional analysis is recommended prior to hardware selection. GRI and SSEEI have developed additional tools useful for this purpose including a heat transfer model for evaluating performance of various gas or electric heater/oven combinations.
IR Heating for Powder Coatings Application and Curing Process

CHAPTER 2
POWDER COATING MATERIALS

Powder coatings have gained popularity over traditional liquid paint due to the Clean Air Act of 1990. Since the technology is an excellent method to eliminate the emission of volatile organic compounds (VOC’s) and complies with most environmental regulations, the air is not laden with pollutants when powder-coating methods are used. Therefore, the exhaust air from a coating booth can be returned to the coating room without treatment. Consequently, a smaller quantity of the oven air used during the coating process is exhausted to outside the room. Furthermore, the process does not require special transportation, storage, or handling techniques for its components. The first-pass coating transfer efficiency is higher than liquid paint applications, and fugitive coating material is readily collected and recycled during processes. Almost all powder coatings are free of heavy metals and not classified as hazardous wastes under the Resource Conservation and Recovery Act (RCRA).

Coatings are provided to protect (functional use) and/or enhance the appearance (decorative use) of a substrate. The degree of functional to decorative use is determined by the specific application. Decorative coatings are relatively thin (25–100 microns or 1–4 mils) and are most frequently applied using electrostatic spray processes and thermosetting powders.

Powder Types

There are two types of powder coatings: (1) thermosetting and (2) thermoplastic. The coating choice depends upon the application.

**Thermosetting Powder Coatings**

Thermosetting coatings react chemically during their application to form a polymer network that is more resistant to breakdown. These coatings are based on epoxy resins and do not melt if reheated. Very thick (greater than 2500 microns of 100 mils) coatings are applied by fluidized bed equipment using multiple heating and dip cycles. More typical thick coatings (250–750 microns or 10–30 mils) are applied by flocking or fluidized bed applicators in which the part is first preheated and then dipped into the powder. Thermosetting coatings are primarily composed of relatively high molecular weight solid resins (as compared to liquids) and cross-linkers.

Motor rotors and stators are coated using thermosetting powders. Pipe interiors and exteriors, and the surfaces of reinforcing bars (rebars), are coated by spraying epoxy powder coatings on hot substrates. Thermosetting powders are also continuously applied to coils, wires, and screen mesh using electrostatic fluidized bed coating techniques. Decorative thermosetting coatings are used in numerous applications where appearance and durability are required, e.g., for appliances (such as refrigerators, stoves, and washers), automobile parts, clear coating of brass and other metal parts, and lawn mowers. Table 1 illustrates the type of thermosetting and their application.

**Thermoplastic Powder Coatings**

Thermoplastic powders do not react chemically during their application or baking. Consequently, these materials remelt after cooling when they are reheated. They are mostly applied as functional-type coatings (with a thickness greater than 250 microns of 10 mils) with fluidized bed applicators. Typical usage includes wire good coatings, such as dishwasher and freezer baskets, pipes, and valves for corrosion protection, spline shafts and shifter forks for low friction and wear, and as electrical insulation for bus bars and circuit breakers.

Thermoplastic resins have a high molecular weight and, therefore, require higher temperatures 150–210°C (or 300–350°F) to achieve melt and flow during application. Polymer degradation may occur because of these high temperatures. Both preheating and post-process heating of the parts to be coated is required to
accurately control the heat history. In general, they have poor to marginal adhesion to surfaces, and sand or shot blasting and/or priming is recommended prior to their application. Few thermoplastic resins have the desired combination of physical properties, melt viscosities, thermal stability and other necessary characteristics. Commonly used resins include polyamides, polyolefins, vinyls or plasticized PVC, polyester, polyvinylidene fluoride (PVDF) coatings.

Powder coatings offer several advantages over liquid finishes.

1. The powder coating method offers higher quality, since consistent results and lower process variations are obtained. These coatings can be supplied ready for application and do not require premixing, stirring, solvent additions, or viscosity and other property adjustments. Finishing problems that arise with conventional paints, e.g., pigment settling, poor atomization due to high viscosity, and sagging due to over reduction with the solvent, are avoided.

2. An optimum film thickness can be achieved, since there are no drips, runs, or sags. Film thickness can vary between 25–350 microns or 1–15 mils, but there are no inherent spatial restrictions on the process.

3. Since powders can be formulated to furnish a wide range of melt viscosities and film thickness, they provide better edge protection coverage than single-coat liquid coating applications.

4. Powder coatings offer an excellent breadth of mechanical properties such as impact resistance, hardness, and abrasion resistance. Superior film properties can be formulated with extra hardness, greater chemical resistance, improved exterior gloss retention, and flexibility, although it may be difficult to attain all of these properties in a single coating.

The energy savings arise due to the elimination of solvents that require heated make-up air. This lack of solvents eliminates the need of the associated air and water pollution problems and no liquid paint sludge that must be removed to hazardous waste sites is formed. Consequently, the high cost of environmental controls and the resources spent in dealing with regulatory agencies is virtually eliminated. Powder coatings do not require any flash-off time so that racks can be more closely spaced on conveyors, thereby increasing productivity and reducing unit costs. In spite of the higher production, part reject rates are lower for powder coating processes than for liquid paint-based methods. Powder coating systems are readily automated and, with the more favorable work environment and smaller cleanup times, result in lower human resource costs.
**TABLE 1: THERMOSET RESIN POWDER PROPERTIES AND APPLICATIONS**

*(Taken from the Web site of Universal Powder Coating)*

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<tr>
<th>Powder Type</th>
<th>General Properties</th>
<th>Typical Applications</th>
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<tr>
<td>Functional epoxy</td>
<td>Produces excellent corrosion protection and has good electrical insulation properties.</td>
<td>Automobile alternators, electric motors, and switch gear. Coats gas oil field distribution piping and reinforces steel bars for highway and bridge decks against corrosion.</td>
</tr>
<tr>
<td>Thin film epoxy</td>
<td>Produces highly attractive coatings of various gloss or surface textures while retaining toughness, corrosion resistance, flexibility and adhesion characteristics. Color chalks upon exposure to ultraviolet light (sunlight).</td>
<td>Fire extinguishers, toys, hospital equipment, business machines, bathroom fixtures, garden tools, and kitchen furniture.</td>
</tr>
<tr>
<td>Urethane polyester</td>
<td>Outstanding thin film appearance, excellent flexibility, very good weathering properties and toughness and mechanical properties, and good chemical and impact resistance.</td>
<td>Appliance and general metal finishing areas including office furniture, lawn and garden equipment, boat trailers and garden tractors. Automobile wheels and trim, playground equipment and fluorescent light fixtures.</td>
</tr>
<tr>
<td>Polyester TGIC</td>
<td>Film thickness of 3 to 5 mils offers excellent flow, gloss and toughness, excellent mechanical properties at high thickness, excellent weathering properties, good chemical and impact resistance and edge coverage.</td>
<td>Coating used where a combination of good edge coverage with good exterior durability is required such as air conditioner cabinets, outdoor furniture, and wire fencing. Also used to clear coat aluminum wheels.</td>
</tr>
<tr>
<td>Acrylic</td>
<td>Excellent exterior color/gloss retention, excellent thin film appearance, very good chemical resistance and fair mechanical properties.</td>
<td>Originally used in the appliance industry to coat range side panels, refrigerator cabinets, washing machine parts, dishwasher exteriors, microwave ovens. Also utilized for automotive trim parts and aluminum extrusions.</td>
</tr>
<tr>
<td>Epoxy/polyester hybrid</td>
<td>Very good chemical and corrosion resistance and mechanical properties. Poor exterior color/gloss retention.</td>
<td>Water heaters, radiators, transformer covers, office furniture, and power tools.</td>
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*IR Heating for Powder Coatings Application and Curing Process*
CHAPTER 3
COATING APPLICATION AND FINISHING PROCESS

A typical finishing process consists of the following steps:

1. **Load or surface preparation.** The load surface must be prepared prior to coating. All organic and inorganic contaminants must be removed by cleaning in a chemical bath followed by rinsing.

2. **Dry-off.** The excess water is removed during this step by using blow-off methods or dry-off ovens. In case, dry-off ovens are used, the part must be cooled prior to entering the powder booth.

3. **Powder application** in a powder booth. The powder booth also collects the over spray powder for either reuse or disposal.

4. **Powder curing.** Thermoset powder coatings must be cured to the desired chemical and mechanical properties. This is accomplished in cure ovens in which a part is heated and the byproducts of the cure and combustion (in case burners are used as the heat source) are exhausted. The following ovens are used:

   - Convection ovens circulate hot air to heat the part.
   - Radiation ovens directly transmit heat to the surface without heating the air in between the part and the radiation source.
   - Induction ovens induce electrical eddy currents that generate heat in metal parts.

Figure 1 is a simplified flow schematic of a finishing process.

Surface Preparation

Surface preparation is an important process to maximize powder performance. The usual substrates that are used include steel, aluminum, and zinc.

**Types of Contaminants**
Surface contaminants are of several types and are described in Table 2, below.

**TABLE 2: TYPES OF CONTAMINANTS AND REMOVAL TECHNIQUE**

<table>
<thead>
<tr>
<th>Contaminant</th>
<th>Removal Technique</th>
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<tr>
<td>Petroleum oils and greases (metalworking fluids).</td>
<td>Highly alkaline materials, solvents, or detergents. Not miscible in water.</td>
</tr>
<tr>
<td>Polymers (for lubricity or in paint formulations).</td>
<td>Typical removal techniques employ acidic compounds.</td>
</tr>
<tr>
<td>Soaps (drawing compounds or dry lubricants).</td>
<td>Mechanical action and the use of highly alkaline compounds.</td>
</tr>
<tr>
<td>Oxides (created by corrosion).</td>
<td>Acidic solutions.</td>
</tr>
<tr>
<td>Particulate soils (metal fines, carbon smut, buffing and polishing compounds, and rouges).</td>
<td>Acidic cleaners, alkaline compounds, or specific soil removal compounds.</td>
</tr>
</tbody>
</table>
Figure 1 A schematic diagram of coating-finishing process
Cleaning involves the removal of all organic and inorganic material from the substrate. Cleaning chemistries for organic compounds involve aqueous-based chemical formulations that combine surfactants, detergents, alkaline builders, and sequestering agents. Wetting and surfactant technology play important roles during cleaning.

**Cleaning Mechanisms**

The following mechanisms may be involved during the process:

1. *Wetting* is the first step for soil removal. Cleaners containing active surface agents or surfactants wet the soil and loosen the soil-surface bond by reducing the surface tension.

2. *Emulsification* follows wetting, and two immiscible liquids, e.g., water and oil, are dispersed.

3. During *neutralization* (or saponification) a reaction between fatty acid soils is neutralized by an alkali.

4. The solubility of water-insoluble oils is increased in the presence of surfactants during *solubilization*.

5. The soil may be *displaced* from the surface as a result of select surfactant activity.

6. *Mechanical action* can greatly increase the speed and efficiency of soil removal by either solution or part movement using air, impeller, ultrasonic, spray, and gas scrubbing applications.

7. *Deflocculation* occurs when the soil is broken down into very fine particulates and maintained in a dispersive phase to prevent agglomeration.

Water must be properly softened in order for effective cleaning or rinsing to occur. Hard water contains calcium and magnesium ions that must be complexed (or sequestered) for better surfactant performance.

**Rinsing**

Rinsing is performed in order to accomplish any of the following:

1. *Flush* the remaining wetted soils from the substrate.

2. *Neutralize* the remaining alkalinity or acidity.

3. Maintain a wet substrate between stages.

4. *Clean* excess water hardness and salts prior to dry-off.

After rinsing, phosphate coatings may be applied to promote the bonding of powder coatings to the metal substrates. When a clean metal is placed in contact with a slightly acidic phosphatizing solution, pickling occurs which results in a reduction of the acid concentration at the liquid-metal interface. The metal is dissolved and a phosphate coating is deposited. Iron, zinc, and chrome phosphates are used.

**Dry-Off Section**

If the part is not dry enough following rinsing, dry-off methods are used. Part drainage is important during dry-off and is affected by how the part is hung on the conveyor.

One of three procedures is used. These involve:

1. * Blow-off* methods that may use a fan and a duct or compressed air.

2. *Dry-off* ovens are often used. The oven temperature is set roughly at 135°C (250°C), that is just high enough to evaporate the water. This temperature is limited by the upper temperature, at which part degradation will occur.

   - *Convection* dry-off ovens convey hot air to the parts. Therefore, the air velocity fields in the oven and on the part surface are an important design factor. For difficult part dry-off situations, high air velocity ovens are used in which the velocity out of the air slot is at least 120 m/s (400 ft/s). However, in this case more energy is required to drive the supply fans.

   - *Infrared* (IR) radiation dry-off ovens are often used, since water is a good absorber of IR energy. In these ovens the water is heated and air is blown to evaporate the water off the part.
3. *Cool-down* is accomplished by convection prior to entering the powder booth, since the powder will melt on the part surface if the substrate temperature is too high and the film thickness increases on a part that is coated while still hot. Also, if the part temperature is non-homogeneous, the film thickness will be non-uniform.

**Powder Coating Application**

Powder coatings are applied either by (a) electrostatic sprays, (b) dipping the part in an electrostatic or (c) non-electrostatic fluidized bed or (d) by flame spraying. However, electrostatic spraying is more common in industry since it provides better control over the coating thickness.

**Curing Process**

Powder coating is done to obtain the functional and decorative properties for which the powders were formulated. This important task is accomplished in curing ovens in which a part is rapidly heated to the desired temperature without disturbing the coating on the surface. The combustion byproducts are exhausted through the ducts. Since no solvents are used, the exhaust rate for powder coating ovens is far lower than for liquid systems; and there is no need for a large exhaust fan which otherwise consume a significant amount of electricity.

The process of heating a powder-coated part *in order to obtain the desired properties of a thermoset coating* is called curing. Temperature and time are the two critical conditions during the curing process. The cure time (or oven cycle time) includes the heat-up time (i.e., the time required to bring the part to its desired temperature) and the dwell time (that is the time required for the powder to properly cure). The oven and part temperatures are different. The heat-up time is monitored by measuring the part surface temperature. In batch ovens, the cure time influences the oven size for a given sized part.

Three types of ovens are generally used:

1. Convection ovens/Indirect heating ovens
2. Radiation ovens
3. Combination of convection and radiation ovens

**A. Convection Ovens**

Convection ovens are designed to provide specified temperature gradients throughout the oven. The major components of these ovens are: (a) Heating System; (b) Oven ductwork and exhaust system; (c) Oven chamber; (d) Heat seals; and (e) Oven controls.

* a. Heating System

The heating system consists of three components: the enclosure, the burner, and the supply fan. The enclosure is fabricated from corrosion and high temperature resistant materials, such as aluminized steel. Properly insulated access doors prevent the outside air from becoming excessively hot and also facilitate routine and corrective maintenance, including possible supply fan replacement. Careful design eliminates hot spots from the interior. Figures 2 & 3 show a simplified model of the batch oven and continuous oven system.

The burner size depends upon the production requirements. The weight of the parts, hangers and conveyor components, the line speed, part hang centers, and estimated heat losses also play a role in burner design.
Commonly used fuels include natural gas and propane. Most popular burner designs in the U.S. use natural gas and air mixtures in a direct-fired application due to the ease of availability and relatively low cost of natural gas. Propane is used when natural gas is not available, and can be diluted (or cut) with air to maintain a heating value consistent with that of natural gas. In this case no equipment changes are required for a burner design based on natural gas. Undiluted propane requires design modifications and, therefore, additional costs. Electricity is also used in many cases but it is higher in cost compared to natural gas and propane.

Combustion air filters protect the burners from particulate contamination problems in the cure oven. These filters are inexpensive and are instrumental in maintaining a clean oven environment that is required for high-quality finishing. Air is supplied through a supply fan that is usually of a centrifugal type with a backward-aligned, non-overloading wheel. The fan must be able to operate at the maximum temperatures that are encountered, and to overcome the system static pressure resistance. It must be able to provide enough air to efficiently convect the thermal energy in the entire oven system. The fan turnover per minute should be at least three times the oven volume.

Figure 2 A schematic of batch type ovens
Convection Oven
Top View

Duct Burner & Ceiling Duct
Parts Conveyor

Duct Burner & Ceiling Duct

Convection Oven
Side View

Figure 3 A schematic of continuous oven with convection or radiant heating.

b. Oven Ductwork and exhaust system

The duct is laid out in the oven to provide a uniform flow of circulated air over the entire part surface, and throughout the conveyor path. The air issues through adjustable outlets and is balanced. The ductwork system provides control over the volume and ductwork speed of the air so that parts are rapidly heated without the powder being blown off their surfaces. Only small batch ovens are designed without ductwork. Ductwork is required in all conveyorized ovens. Typical ductwork designs, as shown in Figure 4(a) include:

Floor-mounted ductwork is the simplest way to distribute gas rapidly throughout the cure oven. Slide dampers on the top and sides, and spouts in the duct sides provide proper air control. Naturally-rising hot air heats the top of the oven. However, this design makes cleaning of the oven floor problematic.

Roof-mounted ductwork relieves the cleaning problem, but the heat distribution to lower parts can be problematic, and fine-tuned damper controls may become necessary.

Combination floor- and roof-mounting ducts are used in very tall or large ovens to control the heat distribution and these two portions are occasionally used separately for supply and return air.

Return-air ductwork can be helpful in controlling the heat distribution evenly throughout the oven. This ductwork carries heat from remote areas back to the heater to be reheated and redistributed. If enough oven air turnovers are available, return ductwork is generally not required.

Exhaust fans remove the combustion and cure by-products, rapidly purge the oven of unburned fuel before ignition, prevent the accumulation of fumes, and maintain control over powder color. The amount of cure and combustion by-products affect the powder clarity and color. In general, dark colors require exhaust rates of a minimum of three turnovers per minute, clear coatings require rates of 6-8 turnovers per minute, and light colors require at least 8-12 turnovers per minute.
c. Oven Chamber

The oven chamber is the interior of the oven enclosure. It is designed to maintain proper airflow that helps prevent hot and cold spots that can over and under-cure the powder coating. Proper insulation of the chamber improves the thermal efficiency by minimizing heat losses. Oven chambers are fabricated from insulated metal panels that are designed to withstand high temperatures. The panel joints are also properly insulated with high temperature caulking and gaskets. Flashing overlaps the panels in order to prevent smoke penetration. Insulated floor panels are preferable to bare floors, since bare concrete floors will crack through thermal stresses leaching air contaminants into the chamber and, eventually, on the powder-coated parts. Washdown drains can ease cleaning of the chamber. Finally, the structural integrity of the oven must support the chamber, the heater, the conveyor and the part load.

d. Heat Seals

Heat seals prevent thermal losses from the oven enclosure and through the oven conveyor openings. Four major heat seal categories are (1) Bottom entry/exit seals; (2) Air barrier seals; (3) Perimeter air seals; and (4) Canopy exhaust air seals.

Bottom entry/exit seals are simple and effective, and are used in elevated ovens (see Figure 4(b)). They allow the part to enter and/or exit the cure oven through floor openings. They need not be powered, since they take advantage of the fact that hot air rises. However, elevated ovens are impractical for some installations where height or roof loading limitations may preclude their use.

Floor-mounted cure ovens must have powered heat seals. Air barrier seals use a fan that distributes oven air from the top down across the oven opening, and are only practical for openings that are less than 1.5 m (or 5 ft) tall. Perimeter air seals use a fan to distribute oven air around the opening from the top down and across the sides. The air velocity in these seals may be lower, since a larger airflow is used. Canopy exhaust air seals are the least desirable, and are used to exhaust heat from the plant. Here, a canopy or hood collects hot air as it escapes from the oven and removes it from the plant.

e. Oven Controls

A description of oven controls and safety can be found in Chapter 5.

Oven Balancing

Oven balancing is a process whereby the circulating air is evenly distributed throughout the conveyor length over the entire part surface. This eliminates the occurrence of hot and cold spots in the oven. Periodic profiling of the oven temperature can monitor the airflow.
Figure 4(a) Simplified illustration of ductwork for uniform flow of circulating air.
Figure 4(b) A schematic of elevated A-type oven
B. Indirect Heating Ovens

In indirect-fired ovens the flame is exposed to an air stream inside a heat exchanger which transfers heat to the circulated air. Indirect-fired ovens are required when the powder coatings can be discolored by the combustion byproducts. Indirect-fired ovens are more expensive and space-consuming than direct-fired ovens due to the presence of additional heat exchanger equipment, ductwork, and other hardware. Indirect fired ovens are also less efficient than direct-fired ovens due to the additional heat exchange step. Figure 5 illustrates an indirect fired oven system.

![An Indirect Fired Gas Convection Oven](image)

Figure 5 Indirect fired oven system.
C. Radiation Ovens

Radiation ovens use infrared (IR) thermal radiation to cure the powder coating on the part. IR heating is ideal in melting and fusing the powder coating without disturbing the electrostatically applied powder coating. IR heat flux depends on the fourth power of the temperature and, therefore, the cure time can be very quick. These systems are deficient in that they have line-of-sight problems so that only those surfaces that are “seen” by the emitter are heated. Therefore, parts with indentations and of complex surface shapes for which no variation in the surface-to-surface temperature can be tolerated are better heated in convection ovens.

Radiation ovens are generally electric or natural gas–fired, and available over a range of intensities. The radiant efficiency of electric emitters is generally higher than that of gas-fired emitters, radiant efficiency alone does not dictate overall oven efficiency. The oven efficiency depends upon factors such as insulation, oven design, airflow control and accuracy of temperature control. Electric emitters are broadly classified into three categories based on the wavelength of their emission as, short wavelength, medium wavelength, and long wavelength. The selection of electric IR emitters is based on the spectral characteristics of the product to be heated, usually the medium and long wavelength IR emitters are preferred for powder coating curing.

Flameless catalytic IR natural gas ovens reduce energy costs, provide clean and safe operation, and give fast payback. Gas ovens can be designed to process various shapes and parts. Their modular construction also makes them relatively simple to alter in case the need arises. Figure 6 is a typical radiant oven system having both melt zone and convection zone utilizing radiant heaters. Advantages of radiation heating are fast production start-up, fast line speeds, relatively small footprint, quiet operation and effective zoning of heating sources.

IR heating is only suitable for processes that can use a high heat transfer rate. Convection ovens are designed to provide an ambient temperature that is not significantly higher than the desired part temperature. IR ovens, on the other hand have far higher operating temperatures, and the equilibrium temperature of a part that is left indefinitely in an oven would be far higher than that required for a specific coating cure process. Therefore, the exposure time in an IR oven must be accurately controlled to reach uniform results, since variations in the exposure time will produce far greater variations in the part temperature than in a convection oven.

**Powder Coating Application Using Radiant Heat Burners in Both Rapid Melt & Cure Zones**

![Diagram](image)

*Figure 6 A radiant oven for both melt and cure zones*
D. Combination of Convection and Radiation Ovens

These ovens are a combination of the above two types of ovens, convection and radiation. The combination ovens use an IR oven and a convection oven, which provides flexibility in dealing with a wide range of operating conditions. The IR oven is used to melt the powder without blowing it off, and a convection oven to cure the coated parts. This is effective in countering problems associated with the higher air velocity from powered heat seals. Powered heat seals at an oven entrance can disturb the fresh powder coating on a part. A low temperature IR preheat zone allows the powder to set before it encounters the heat seal, and the heat seal need not be compromised by lowering the air velocity as is occasionally done. Figures 7a and 7b show typical ovens with two styles of convective and radiant heating combination.

Figure 7(a) A schematic of oven having radiant melt zone and convection curing zone
Combination Radiant & Convection Heating
Front View

Blower for Radiant Burners

Combination Radiant & Convection Heating
Top View

Blower for Convection Heat

Radiant Heat

Convection Heat
E. Combination Dry-Off and Cure Ovens

Dry-off and cure ovens can be situated adjacent to each other and share a common wall that need not be as well insulated as the others, since it is not exposed to the plant ambient conditions. The advantage here lies in the decreased insulation cost. Figure 8 shows a dry-off oven utilizing high flux impinging gas IR heater.

A more cost-effective method utilizes a single oven for both the dry-off and cure processes without partitioning the space. The cost advantage arises due to lower structural costs, the need for only a single heater unit, common exhaust equipment, a common control panel, and lower fuel utilization. However, this type of oven is seldom used, since the high temperature in the cure area can affect the temperature in the dry-off region. The moisture released during dry-off also creates humidity problems in the cure zone, and the additional costs to remedy these problems usually offset the initial savings.

Another system that is used, places the dry-off oven underneath the cure oven so the floor panels of the cure oven are also the roof panels on the dry-off oven. This further diminishes the insulation and structural costs.

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**High Speed Gas Radiant Heat Burner**

**Pre-Dryer Application**

![Figure 8 A dry-off oven utilizing high flux impinging gas IR heaters](image)
CHAPTER 4
GAS IR HEATERS

Gas IR burners operate between (600–2200°F). The temperature is determined by the energy input per unit area of the radiating surface. In gas fired IR burner designs, hot combustion gases heat porous or non-porous metal or refractory surfaces to a temperature at which the surface becomes radiant. Some characteristics of typical gas–fired and electric IR sources are presented in Table 3 & Table 4.

Salient Features of New Generation of Gas IR Heaters
1. New catalytic IR and metal fiber based IR heaters have potential opportunities in overcoming some of past perception of gas IR being inferior to electric IR heating. In addition, a very desirable convection component is inherent property of each gas IR heater and therefore helps in smoothing the temperature distribution within the confinement of the oven and loads to achieve similar results. Electric IR heaters, on the other hand need a fan, and operation and maintenance costs could be significant depending upon the size of the ovens and parts being cured.

2. Majority of the continuous and batch types ovens requires convection heating to accommodate a large variation in the parts geometry. Therefore it is easier to add a gas IR heating system to the existing operation, since required piping, valves and blowers are already in place.

3. Gas IR heaters are far less susceptible to the build up of contaminants on the emitter surface than the electric IR heaters whose efficiency and temperatures uniformity would gradually degrade. In fact, this could affect the quality of the final product as well, since heat flux and temperature distribution will be uneven.

4. Selected fiber gas IR heaters in actual operation could provide rapid thermal response, both in heat up and cool down comparable to any electric IR heaters.

5. Gas IR heaters system can be tailored to the existing or a new oven configuration to match the suitability of the product being cured.

6. Gas IR heaters oven system can be as compact as the electric ovens because of their ability to release more energy per unit area than the electric.

7. A combination of a catalytic IR and a non-catalytic IR oven can cure thinner to thicker coatings with light to deep penetration of radiant energy, can equalize the overall heat distribution within the oven and the parts.

8. All gas IR heater manufacturers design a FM and an IRI certified system, to meet industry standards for safe operation. In fact, there are thousands of these systems in operation.
### Table 3: Types of Gas IR Heaters and Their Performance

<table>
<thead>
<tr>
<th>Type of Burner</th>
<th>Performance</th>
<th>Supplier</th>
</tr>
</thead>
</table>
| Surface Combustion Burner (Emitters are made out of ceramic or metal fiber matrix). Figure 9(a) | **Firing rate** (Btu/hr/ft²)  
Metal fiber 40k-125k  
Ceramic fiber 25k-75k  
**Combined Efficiency ~ 85%**  
Thermal Response (Sec.) 5-10 ceramic fiber 15-85 metal fiber  
Operating hours 10,000 – 15,000. | Acotech, Marsden, Glenro |
| Impingement Type  
Emitters are specially designed impingement type with ceramic surfaces made out of hard ceramic block) Figure 9(b) | **Firing rate (Btu/hr/ft²) ~ 30k-150 k**  
Combined Efficiency ~ 65%  
Thermal Response (Sec.) 8,000 – 10,000 Operating hours | Eclipse, Indesco, Pyronics, Red-Ray, Burdett, Advance Curing |
| Catalytic IR Heater  
Multi-layer fibrous structure with catalyst being coated within the middle of the structure. Figure 9(c) | **Firing rate (Btu/hr/ft²) ~ 6 – 7.5 k**  
Combined Efficiency ~ 70%  
Thermal Response (Sec.) 240 to 500 Operating hours 10,000 or higher. | Vulcan, Infrared Tech., American Catalytic, Solaronics, Catalytic Industrial Systems |
| Ported Tile w/without Screen  
Emitters are ported tile made of ceramic or metal with high temperature resistance screen. Figure 9(d) | **Firing rate (Btu/hr/ft²) ~ 30 –80 k**  
Combined Efficiency ~ 65 – 70 %  
Thermal Response (Sec.) 60 to 300 Operating hours 8,000. | Maxon, Solaronics, Perfection Schwank, Eclipse |

Combined Efficiency = \( \frac{\text{Radiant + Convection}}{\text{Total Heat Input}} \)
Figure 9(a) Photograph of a surface combustion heater

Figure 9(b) Photograph of impingement type gas IR heater
Figure 9(c) Photograph of a catalytic IR heater

Figure 9(d) Photograph of ported tile with screen
TABLE 4: TYPES OF ELECTRIC IR HEATERS AND THEIR PERFORMANCE

<table>
<thead>
<tr>
<th>Types of Emitter</th>
<th>Performance</th>
</tr>
</thead>
</table>
| Short Wavelength       | Temp. with reflector 1100 °F - 1400°F  
                        | Flux - 30,000 Btu/hr/ft²  
                        | Operating hours - 3000 - 5000  
                        | Thermal Response - seconds to minutes  
                        | Efficiency - 80% |
| See Figure 9(e)        |                                    |
| Medium Wave            | Temp. with reflector 1300 – 1800 °F  
                        | Flux - 10,000 Btu/hr.ft² - 18,000 Btu/hr.ft²  
                        | Operating hours - 5000 – 10,000  
                        | Thermal Response – 60 to 200 Sec.  
                        | Efficiency - 50 – 60 % |
| See Figure 9(f)        |                                    |
| Long Wave              | Temp. with reflector 500 – 1400 °F  
                        | Flux - 10,000 – 12,000 Btu/hr.ft²  
                        | Operating hours – 5000 – 8000  
                        | Thermal Response - 60 to 90 Sec.  
                        | Efficiency - 60 to 80% |
| See Figure 9(g)        |                                    |

Radiant Efficiency = \( \frac{\text{Radiant Output}}{\text{Total Power Input}} \)

**Note:**
1. These data were measured for selected emitters for each of these categories at Purdue University laboratory. Their performance would vary depending upon the types of heating elements, design and operating conditions.
2. Due to a high number of electric IR heater manufacturers, we have not listed them in this table.
3. The operating hours of electric heaters are based on manufacturers’ literature and end users’ comments.
IR Heating for Powder Coatings Application and Curing Process

Figure 9(e) Photograph of short wave electric IR heater

Figure 9(f) Photograph of medium wave electric IR heater

Figure 9(g) Photograph of long wave electric IR heater
CHAPTER 5
CONTROLS AND SAFETY

The oven control panel contains the equipment necessary to start and stop the burners and fans from a central location. It also houses the safety circuits required for purging and safeguarding the flame. The purge circuit does not generally allow the burner pilot to ignite until the oven chamber volume has been turned over four times. The flame safeguard does not allow fuel into a burner unless a pilot light is present. Temperature controllers monitor and control the oven temperature.

Gas Heating and Control Systems

Whether the heating system is convection or IR, the fundamental method of heat input control is the same - a closed loop consisting of a temperature sensor, a temperature controller, an automatically-operated gas (and maybe, air) control valve, and finally, a burner. Proportioning control systems are most common, although high-low control (a refinement of on-off) can be used where temperature uniformity is not especially demanding.

Within that framework, however, there are significant differences between the ways convection and IR systems operate.

Figure 10  A schematic of combustion control scheme for convection heating system.
Most convection heating systems operate on the fixed air principle. Combustion air flow to the burner is locked in at a fixed rate, and only the gas flow is varied to raise or lower the heat input. This is also known as excess air control. At high fire, the burner operates close to stoichiometric ratio, producing a stream of combustion products at temperatures exceeding 2500°F. As the requirement for heat decreases, only the gas flow is throttled back. The air flow being constant now, exceeds what is needed for combustion. This excess air acts as a heat load, mixing with the combustion products, absorbing heat and lowering the average temperature of the mixture. With the proper burner design, it is possible to generate combustion product - excess air mixtures with temperatures of only 250 to 300°F. This ratio of maximum to minimum heat input is known as the heating system's turndown ratio. In convection systems like these, turndown ratios of 50 to 1 are not unusual.

Regardless of the burner firing rate, the combustion products are further diluted and cooled by mixing with additional makeup air, which is re-circulated back into the heating chamber. The net result is almost unlimited control over the temperature of the air entering the oven. This is what gives convection ovens their reputation for flexibility and temperature control sensitivity.

In convection ovens, the product is further protected from accidental overheating by placing it in a chamber separate from the burner. This prevents the flame radiation from reaching the products.

Except for catalytic heaters, gas IR burners are premix units; this is, the combustion air and gas are mixed ahead of the burner. This limits the burner's range of operation to near-stoichiometric ratios – the burner will go out if large amounts of excess are used. Consequently heat input is controlled by raising or lowering the flow of both air and gas.

The primary input control is the combustion air valve (1), which opens or closes in response to a signal from the temperature controller. This creates a suction in the venturi mixer, which, in conjunction with a zero governor gas regulator (2), automatically proportions gas flow to the air flow. The IR burner (3) shares the same space with the workload (4) and radiates energy directly to it. Figure 11 illustrates this control principle. If the two are in close proximity or the load is placed above the burner, the combustion products from the burner may also contribute some convection heating to the load.

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**Figure 11** A schematic of combustion control scheme for radiant heating system.
Oven Safety Control

National Fire Protection Association (NFPA), Bulletin 86 has defined two classes of ovens: Class A and Class B. Class A ovens are those in which solvents, volatile materials, or other flammable/combustible materials are evolved during processing. These materials include parts, powder coatings, inks and adhesives normally used in a finishing process. Class B ovens are those in which no combustion or flammable materials are present. For details, one must refer to the NFPA 86 Bulletin. All direct fired ovens classified as class 'A' types, must have safety features.

Gas-fired IR heating systems, more often than not, operate in open or semi-enclosed spaces. Therefore, it could be argued that they are not as susceptible to light off explosions. Nevertheless, they are governed by the same safety specifications as other gas-fired industrial combustion systems.

In the US, two codes are almost universally used. NFPA 86, Ovens and Furnaces, published by the NFPA, is a consensus standard that has now been accepted as the national standard for safety practices and equipment on industrial ovens and furnaces, including IR systems. Most combustion equipment manufacturers now use NFPA 86 as their default standard for system design (See Figure 12).

Figure 12 A Schematic of Gas and Air Trains Feature by NFPA 86
End users covered by certain insurance carriers may find themselves required instead to conform to the standards of Industrial Risk Insurers (IRI), who accept NFPA 86 with a few additions, most notably, a vent line between the two gas safety shutoff valves. This vent is equipped with a normally open solenoid valve, whose purpose is to relieve any gas pressure that might build up between the valves in the event both might fail and leak during a system shutdown, see Figure 13.

Canadian Gas Association (CGA) industrial combustion safety system requirements are set forth in standard CGA B149.3, see Figure 14. In specifying equipment requirements, it considers several variables, including number of burners, total firing rate, and gas pressures upstream and downstream of the pressure reducing regulator. Nevertheless, its underlying philosophy and principal requirements are very similar to NFPA 86 and the IRI standards.
All these codes include certain basic requirements:

- Combustion air pressure or flow switch, if a combustion air fan is used.
- High and low gas pressure proving switches.
- Two safety shutoff valves on systems over 400,000 BTU/hr capacity (CGA permits one to have a proof-of-closure interlock).
- Electronic combustion safeguard, either ultraviolet flame scanner or rectification flame rod.
- Time pre-purge of combustion chamber before energizing spark or lighting pilot.
- Forced low fire light off of main burners.
- Limited time ignition trial for pilots and main burners (15 seconds in the US, 10 seconds in Canada).

On IR burners, the choice of an ultraviolet scanner or flame rod is usually specified by the burner manufacturer - on some types of IR burner, one or the other, but not both, may be suitable.

In addition to these essential controls and sequencing steps, most installations will be equipped with limit switches to verify that oven doors are open and conveyor drives are engaged before burner light off. In addition, most ovens are required to have a high temperature limit controller which will sound an alarm and shut down the combustion system in the event of a temperature runaway.

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**Figure 14** A Schematic of Gas and Air Trains Feature by Industrial Risk Insurers
CHAPTER 6
APPLICATION BARRIERS WHEN APPLYING INFRARED HEATING

For all its advantages, gas IR may not be seen as the optimum heating technology for a chosen application. Sometimes, there are sound technical reasons; in other cases, misconceptions or prejudices lie behind an end users reluctance to consider gas IR. This chapter discusses some of the more commonly raised objections to gas IR and examines their validity.

1. Product configuration is not suited to heating by infrared

IR radiation travels only in straight lines and so it cannot directly transfer heat to any surface it does not fall upon. These surfaces and the material beneath them can only be heated by conduction from other portions of the work load that have received direct radiation, or, if those surfaces become hot enough, by secondary radiation.

Simple shapes like sheet, cylinders or rods can be easily heated by IR, although rotating the work pieces may be necessary to get coverage of all surfaces. Rotating more complex shapes may also work, as long as all the areas to be heated are located on the outer surface of the product. Complex assemblies such as wire baskets, may also be good candidates for IR as they have an abundance of open spaces that serve as apertures for IR radiation from one side of the product or the other.

Massive, highly 3-dimensional products are usually the most difficult to heat by IR. In these instances, IR had the best chance of success where only the outer surfaces of the work piece need be heated, such as for the powder coating. If thorough heating is required, internal conduction will dictate how quickly and uniformly it can be done. If the material has low thermal conductivity, the rate of radiant heat transfer may have to be kept low to avoid surface overheating. This negates one of radiation’s greatest assets. In these cases, convection heating, with its lower thermal head, may be the better choice.

Even thin, mostly two-dimensional work pieces may present problems. At least one commercial powder coater reported a desire to convert from an all IR curing system to a convection heating line. Problems with IR arose when they attempted to cure coatings on some formed sheet metal pieces. The edges of these pieces were unavoidably closer to the IR heaters and were overheated and discolored when the remainder of the pieces were properly cured. In this case, a combination IR/convection oven probably would have avoided this problem.

Another manufacturer evaluated IR as a way to temper an assembly made from several different gauges of steel wire rod. They abandoned the idea because they discovered that the smaller diameter components would have become overheated and excessively soft in the time required to bring the heavier components up to proper tempering temperature.

2. Infrared heating is too intense for the product or its material

Radiation intensity developed by the heaters isn’t the issue; radiation reaching the product is. Controlling the product flow rate placement density of the IR heaters, and distance between the heaters and the product, will control radiation reaching the product. Finding the proper mix of these variables should be within the capabilities of any competent equipment manufacturer.

More serious concerns are the risk of local overheating due to product configuration, discussed under item 1, and damage of product conveying devices exposed for a long time to radiant heat. It is important to remember that many products, such as paper or textiles, have built-in overheating protection in the form of moisture. Conveyors are normally not provided with such protection, such as cooling water, and when they are, it is done only as a last resort. As a result, lubricants vaporize out of running parts or are baked into thick gummy varnish. Friction wear and drive forces increase and the lubricants have to be constantly replenished to avoid seizure of the conveyor.
3. Infrared does not provide mass transport required to remove moisture or solvents from the product

IR is highly effective at bringing moisture to the surfaces of products and at forcing them to evaporate into the open air space of the oven or dryer. From this point on, however, a constantly moving stream of air or gases is required to entrain these vapors and carry them away. Otherwise, the atmosphere surrounding the product becomes saturated with moisture or solvent vapors, and no further drying can take place.

Unlike electric units, gas IR heaters do produce a stream of exhaust gases, which are capable of absorbing at least some of the moisture. The key variables at work in this situation are the rate of moisture removal that has to be sustained, the flow rate of combustion products from the IR heater, and the effectiveness with which they can be put to use. In general, impingement type IR burners are the most effective at this. Of all burner types, they have the highest combustion product velocities, giving them the best ability to penetrate the product and pick up a portion of the vapors.

Applications such as paint, printing ink, or adhesives drying, where combustible solvents are evolved, must be approached with extreme care. If these solvents accumulate to a combustible concentration inside the oven or dryer, they can ignite and explode as soon as they come into contact with a hot surface. Enough dilution air must be provided to reduce their concentration to no more than 25% of their lower explosive limit (LEL) or 50% of LEL if continuous solvent concentration monitors are used.

In addition, the solvents must be properly diluted before they come into contact with the IR heaters located in the oven proper. Because of the difficulty in insuring that this condition is met, and because of the large volumes of dilution air that offset many of the efficiency advantages of IR, traditional hot air convection systems usually make more sense in these applications.

4. Gas Infrared requires a more complex and expensive control system then electric infra-red

This misconception to gas systems have been gaining momentum in recent years with the trend towards using ovens and dryers with a greater number of control zones. The argument against gas systems center-around the fact that the gas heaters require more control components to regulate the flow of air and gas. Some of these components may have to be located in the immediate vicinity of the burners, adding to the complexity and size of the overall installation, and an increase in the cost.

While there is a measure of truth in these claims, it is important to closely examine them to get a true idea of the differences in the complexities of multi-zone gas and electric IR systems. First, the number of components required for the temperature control loops (temperature sensor, temperature indicator/controller and input control device) will be the same. These components are dictated by the number of zones of control, not the heating method. Therefore, there is no inherent cost advantage for electric in this portion of the system. From this point on to the heating element, electric systems do have the advantage of fewer, simpler, less costly components. Nevertheless, the cost differences should be examined closely in light of the much lower operating cost of gas. A careful payback study may reveal that overall the gas system is still less costly.
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