

Curing Powder Coatings with Gas-Fired Equipment

Introduction

This paper has been prepared to familiarize you with powder coatings and the process of curing them in gas-fired infrared and convection ovens. It contains information and guidelines on the selection of heating equipment and points out some of the pitfalls to be avoided in making those selections. In researching this paper, we interviewed the technical representatives of four major powder coating manufacturers. Their comments on ovens and combustion systems provided some valuable insights into the process and its requirements.

What Are Powder Coatings?

They are protective or decorative finishes applied to products without the aid of solvents or carrier liquids. Most powders are primarily fine particles of clear or pigmented plastic resins blended with agents to promote desired surface textures, improve flowing characteristics or speed curing times.

Most resins can be divided into two categories: thermoplastic and thermosetting. Thermoplastic resins, the basis of the original powder coatings, can be repeatedly reheated and softened. On the other hand, thermosetting resins undergo polymerization (cross-linking) when they are heated, causing a permanent molecular change, so they will not soften on reheating. They are now the basis of most commercial powder coat finishes. Table 1 lists some of the major families of powder coating resins.

Table 1
Types of Powder Coating Resins

Thermoplastic	Thermosetting
Nylon	Acrylic
Polyvinyl Chloride (PVC)	Epoxy
Polyester	Polyester/Epoxy Hybrid
Polyethylene	Polyester/TGIC*
Polypropylene	Polyester/Urethane
Polyvinylidene Fluoride (PVDF)	Urethane

* Triglycidil isocyanurate

History

Powder coating originated in Germany in the mid-1950s. The original process, which used thermoplastic resins, consisted of suspending preheated objects in a fluidized bed of coating powder. The part temperature was high enough to cause the powder to soften and stick to its surface, after which it was transferred to an oven to finish the fusing process.

With the advent of electrostatic spraying, new applications opened up for powder coating. In this process, the dry powder particles are given a high voltage electrostatic charge as they pass through a spray gun. This charge causes them to be attracted and cling to the workpiece, which is electrically



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grounded. The workpiece is then heated, causing the particles to soften, flow together to form a uniform, non-porous coating, and finally, to cure, by cross-linking, into a durable finish.

Powder coatings have three advantages over solvent-based coatings: first, because they contain no solvents, they can be cured more quickly, which permits faster line speeds. Second, they are somewhat easier to apply without defects. But their third asset is becoming the most important— they are environmentally more friendly. Lacking solvents, they emit no VOCs (volatile organic compounds) during the curing process, and this eliminates the need for fume incinerators, solvent adsorption systems and worries about accidental discharges of vapors. It also reduces concerns about the fire and explosion hazard of solvent vapors, although the fine powders still have to be handled with reasonable care. The powders themselves can be recycled as long as care is taken to avoid contamination and mixing of colors. Consequently, overspray and spilled powder can be reused instead of having to be disposed of as a hazardous waste.

What Is The Curing Process?

The drying of solvent-based coatings (Figure 1) consists of heating the workpiece to evaporate the solvent. An abundance of oven makeup air is required to carry off the solvent vapors and dilute them well below their minimum flammable concentration. A slow, gentle temperature rise is also needed to avoid hardening the surface of the coating before the solvent underneath is driven off.

The mechanism of curing powder coatings is entirely different (Figure 2). When they are first exposed to heat, the resin particles begin to soften. As their temperature increases and their viscosity decreases, they flow into one another and into the microscopic irregularities of the workpiece's surface, filling the voids between themselves and adhering to the part. This process is called *gelling*. If the coating is a thermoplastic resin, it must then be removed from the heat to harden. With thermosetting resins (Figure 3) the temperature is raised another 50 to 100°F to activate the cross-linking reactions. As these reactions take place, the coating becomes more resis-

Figure 1
Drying of Solvent-Based Coatings

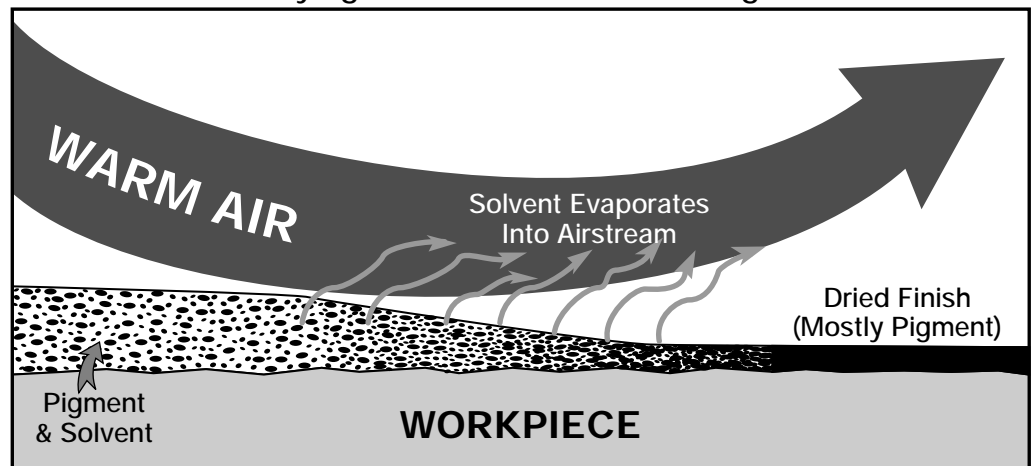
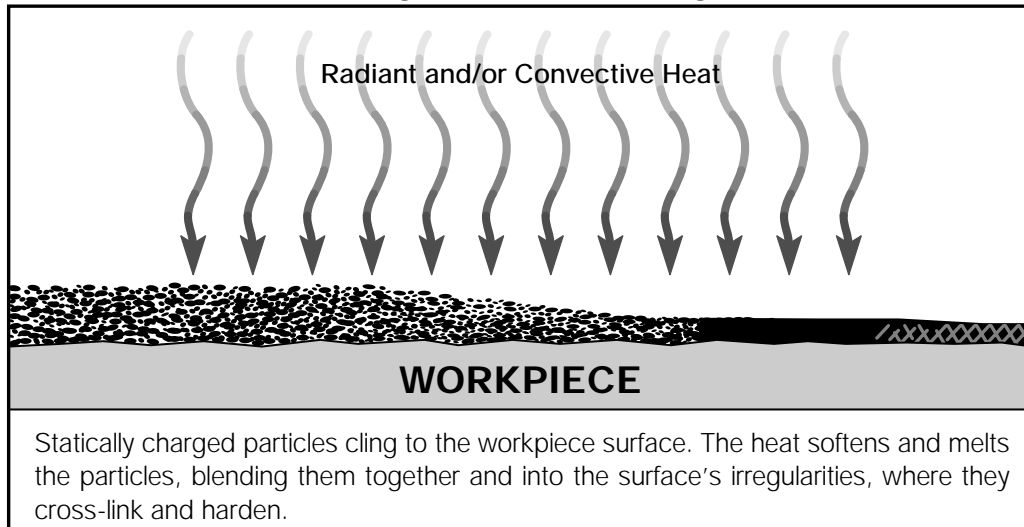


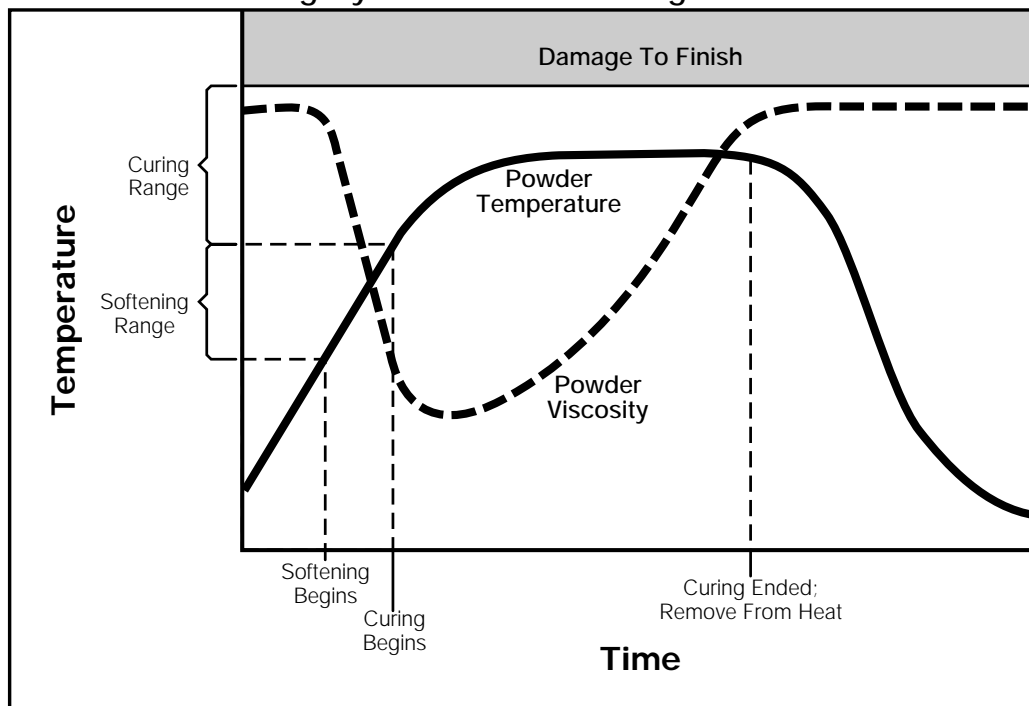
Figure 2
Curing of Powder Coatings



tant to flow and finally hardens completely, even while it is still hot. All this can take 20 minutes or less, depending on the coating formulation and the part it's applied to. Some parts can be cured in as little as five minutes.

Two of the most important quality attributes of any coating are its finish and its resistance to chipping and peeling. Both are enhanced by giving the powder finish as much time as possible in the upper part of its gelling temperature range (when its viscosity is low) before cross-linking sets in. This provides ample time for the coating to flow and develop a smooth surface and good adhesion to the base material. Consequently, the optimum heating cycle consists of a rapid heat-up followed by holding at a steady curing temperature. The curing (cross-linking)

Figure 3
Curing Cycle of Thermosetting Powders



temperature range depends on the type of resin and additives in a specific powder formulation. As a general rule, thermosetting resins cure between 300 and 400°F, with the exact temperature range being specified by the coating manufacturer. Within that range, the curing speed increases with the temperature (Figure 4). For example, a coating that cures in 20 minutes at 340°F might take only half that time at 380°F.

Curing Methods

Because powder coatings don't require solvent removal, users

have more latitude in the ways they cure them, and the speed of curing allows much faster processing of the work.

Convection Ovens

Many powder coat lines were converted from liquid paints, so finishers often continue to use their convection ovens. From a product quality standpoint, convection ovens can do a fine job (in fact, the technical representatives of some paint companies prefer them), but they're frequently criticized as too slow. This capacity shortfall is usually due to speeding up the line to take advantage of powder's faster curing cycle. Because the oven operates at a relatively low thermal head and with large amounts of makeup air, it simply can't provide the needed heating intensity. Although it's sometimes possible to upgrade an oven with a larger burner, modified air handling system and higher operating temperatures, a more practical approach is to add an infrared booster section (Figure 5).

Two other potential problems are frequently mentioned when convection ovens are considered for powder coatings— powder blowoff and contamination.

Powder blowoff refers to the dislodging of statically-charged powder by the oven's airstream or, more often, by the air curtain at the oven's entrance. A poll of coating manufacturers' tech reps suggests that the problem may be overstated—they said that blowoff isn't usually a concern as long as the oven is properly balanced and its air curtain is set correctly. Exceptionally thick coatings (6 mils and up) are at greater risk because the electrostatic charge gets weaker as the coating thickness increases, but coatings this thick are rare. If there is an infrared

Figure 4
Characteristic Time/Temperature Curing Curve for Thermosetting Powders

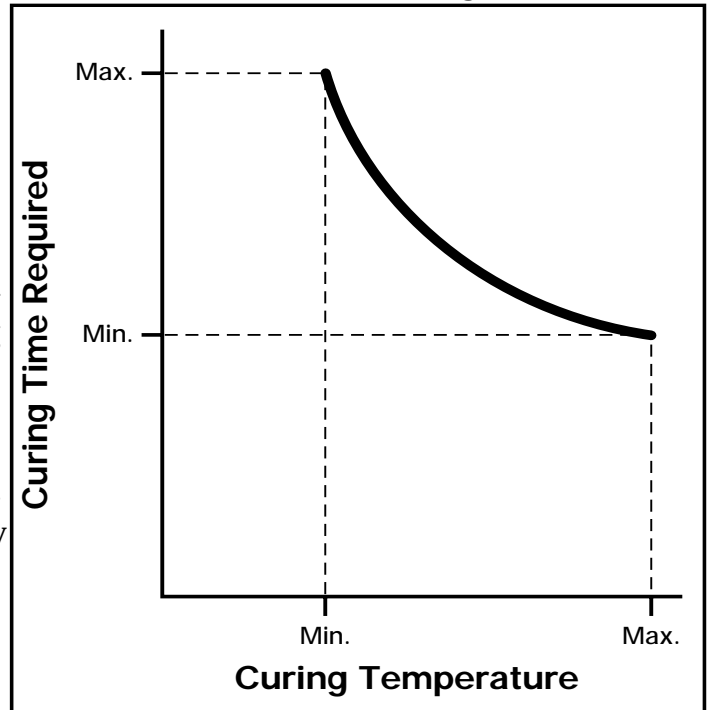
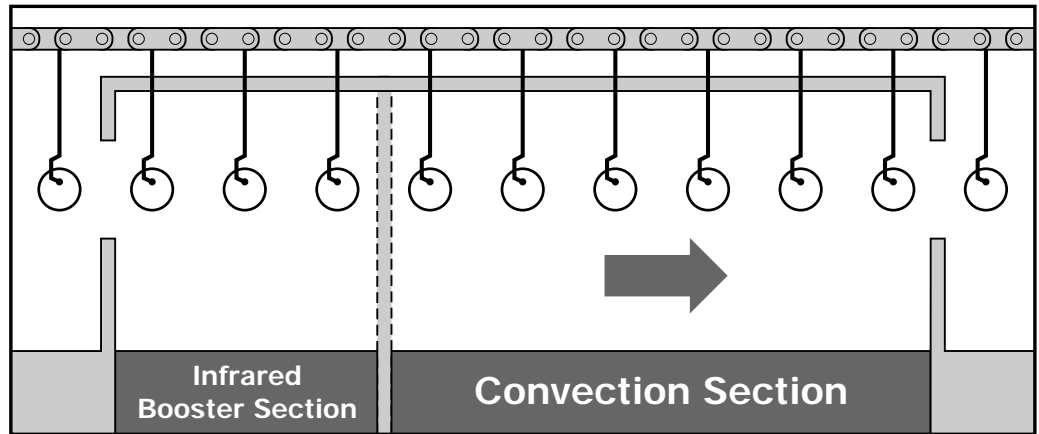


Figure 5
Convection Oven with Infrared Booster Section



booster section at the beginning of the oven, blowoff is not a problem, because the coating has already begun to melt and adhere by the time it enters the convection section.

Contamination can be a more serious problem, primarily because cleanliness is more critical in powder coating operations. Overspray and spills don't harden and stick to surfaces—they are loose particles, free to be blown or carried around the plant along with stray dust and dirt. Without scrupulous housekeeping, they all can enter the oven's recirculating or combustion airstream and wind up imbedded in the finish.

There are also occasional complaints of discoloration and deglossing due to exposure to combustion products. Whites or light colors may take on a yellowish cast. If lower curing temperatures or changes in the paint formulation don't fix the problem, indirect firing of the oven will. In fact, indirect-fired ovens are becoming popular in operations where color consistency and matching are important.

Combination Infrared/ Convection Ovens

These ovens use the best of both worlds—a high intensity IR section to obtain a fast temperature rise, quickly melting the coating, followed by a convection section to finish curing at uniform temperatures without overheating. Many of these ovens are simply convection units with IR booster sections added to keep up with faster line speeds. However, the concept has become a standard with many oven companies because it offers a good combination of speed and quality in less floor space than a straight convection oven.

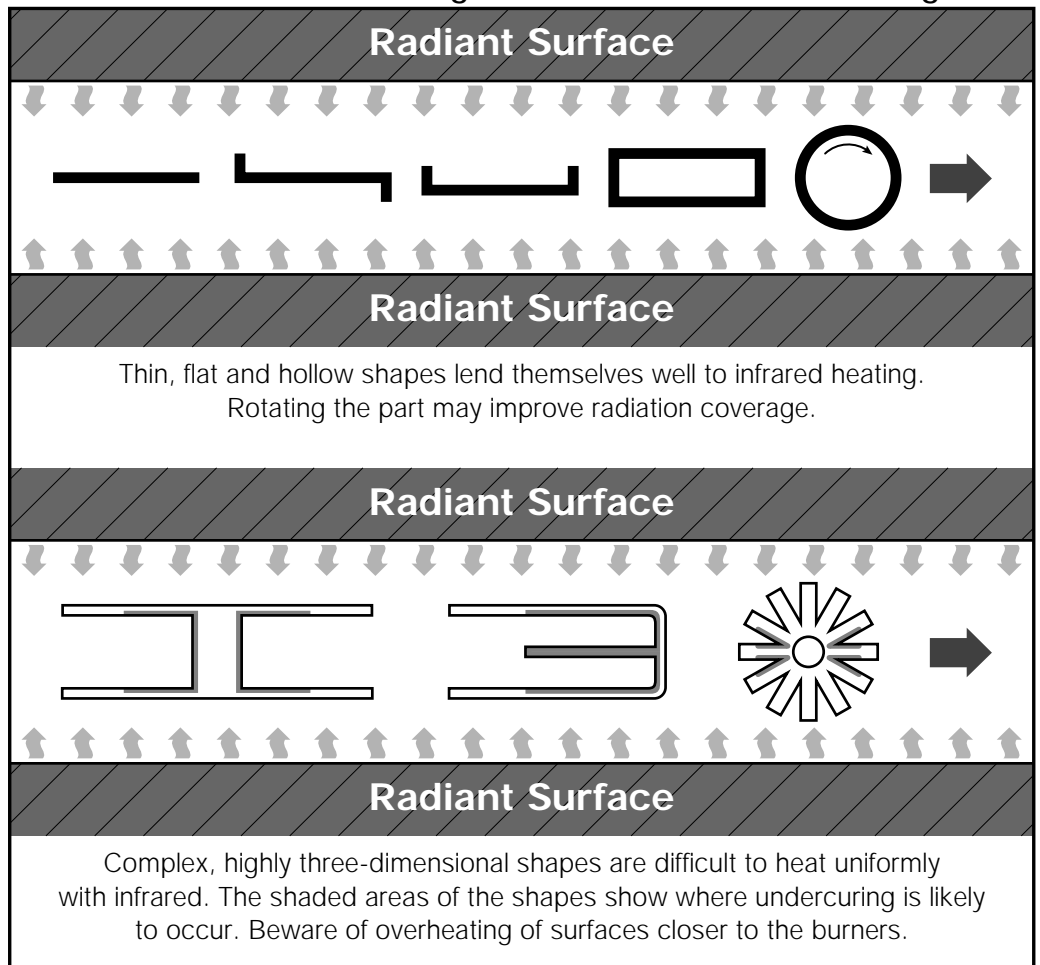
Some combination ovens are essentially convection ovens with rows of Infrared burners running through them. The theory behind this concept is that the IR burners provide a continuous heat boost along the length of the oven. The shortcoming in this approach is that mixing convection and radiation heating systems in a common chamber can compromise the best qualities of both. Unless the IR burner heads are carefully located with respect to product flow, they can promote temperature non-uniformity the convection system was supposed to avoid.

The flip side of the problem is that if enough IR burners are installed to make a significant increase in line speed, the convection heating system contributes little to the process. From a heat transfer and temperature control standpoint, it makes more sense to concentrate the IR heating at the entrance of the oven and allow the rest of the oven to operate as a straight convection unit.

Straight Infrared Ovens Ovens employing only IR heating, whether gas or electric, are gaining popularity as manufacturers continue to switch to powder coatings. They provide the intense, rapid heat-up favored for powder coatings and can handle a given production rate in a fraction of the floor space taken by a convection oven. However, because IR operates at such a high temperature head, it must be carefully controlled to avoid product damage, and because it heats only those surfaces it sees, it's sometimes difficult to use with complex or highly three-dimensional product shapes (Figure 6). The key consideration is whether all coated surfaces will be exposed to radiation. Unless conduction through the part can be counted on to carry heat to coated areas out of IR's line of sight, convection or a combination oven may be a better choice.

In addition to product configuration, the conveying system should be considered when selecting a heating system. If the conveyor allows parts to

Figure 6
Suitable Product Configuration for Effective IR Heating



Guidelines for Selecting a Heating Method

hang in random orientations, the quality of the finish may be equally random.

Table 2 shows some of the points that have to be considered in selecting a heating system for a powder coating line and how the different heating methods stack up in that regard.

Table 2
Comparison of Heating Methods

Parameters	Straight Convection	Straight Radiation
Floor space required	High	Low
Energy consumption	High	Low
Heating speed	Low	High
Product configuration	Any	Simple only
Product mix (shapes & weights)	Many	Limited
Susceptibility to overheating	Low	High

In summary, convection ovens offer flexibility and low risk of overheating, but at the expense of size, speed and energy efficiency. Radiation (infra-red) ovens deliver high production rates in a small space and with low energy consumption, but they're not as flexible and require close control to avoid overheating the product. Combination ovens, as expected, represent a compromise between the two.

Keep in mind that if the product mix includes any solvent-based coatings, the finisher will need a traditional convection oven, although he can add a booster IR section for the powder coat jobs. This booster may also help speed up the line when curing solvent-based coatings, but use care—the booster section must be enclosed and provided with proper exhaust to keep solvents from escaping into the workspace, and its heat input must be carefully controlled to avoid finish defects resulting from too-rapid heating.

IR Burner Sizing: To Heat the Part or Not?

There are differences of opinion whether it's necessary to heat the entire workpiece to the curing temperature to get good adhesion of a powder finish. In a convection oven, it's unavoidable; all portions of the workpiece and finish will come to the same temperature because of the way they're heated.

With IR heating, this isn't necessarily true. The radiation strikes the coating first, and the only heat reaching the workpiece underneath is residual radiation passing through the coating and conduction from the coating or other locations on the workpiece. If the workpiece is thin, such as a sheet metal part, it's probably safe to assume it will be within a few degrees of the coating temperature. If, however, it's thick or has a complex shape, uniform temperatures are less likely.

Process data sheets issued by coatings manufacturers usually relate curing times to substrate temperatures, and this suggests that the entire workpiece must be heated. Among coating tech reps surveyed, there seemed to be general agreement that as long as the surface of the piece in contact with the coating was up to temperature, that was sufficient. Bonding and adhesion are affected only by the temperature of the surface in direct contact with the coating.

In short, if the workpiece is thin and well-exposed to the source of radiation, size the burners to heat everything, because that's what

is most likely to happen. On the other hand, if the part is complex, heavy or poorly exposed to the radiation, like a cast wheel, its entire mass won't reach the curing temperature, and input can be scaled down somewhat. Exactly how much, unfortunately, is a judgment call. If in doubt, go heavy on the input and provide a control system with good turndown capability. Multiple control zones, allowing some burners to be turned off if necessary, may be the best approach.

Factors Affecting IR Burner Placement

These are no different for powder coating than for any other product, but now is a good time to review them.

The Burner Head Must See What It Heats. Radiation travels only in straight lines, so if part of the workload isn't in the burners' line of sight, it will not receive direct radiation. It may, however, be heated by radiation reflected from other surfaces or conduction from hotter portions of the same piece. If in doubt, visualize the workpiece as being illuminated by flashlights located where the burners will be. If portions of the workpiece will be in the shadows, they will not see direct radiation from the burner heads.

Radiation Scatterers. Although radiation travels in straight lines, it doesn't all travel in parallel lines. The beam of radiant energy leaving the burner head spreads as it goes away from the burner, much like the beam of a searchlight (Figure 7). The angle at which it spreads varies with the configuration of the burner, because the burner head is a focusing device, same as the reflector in the light. If the beam angle is narrow, the radiation remains highly concentrated, even at considerable distances from the burner, but it covers a limited area. Wide beam angles provide rapidly increasing area coverage, but the intensity of the radiation quickly decreases with increasing distance from the burner (Figure 8). From an application standpoint, this means that a solid array of burner heads isn't required to produce a uniform pattern of radiation—the overlapping beams will provide it. The farther the workpiece is from the burner heads, the more uniform the radiation will be, although it will also be less concentrated. The optimum

Figure 7
Radiant Energy Spread From An IR Burner

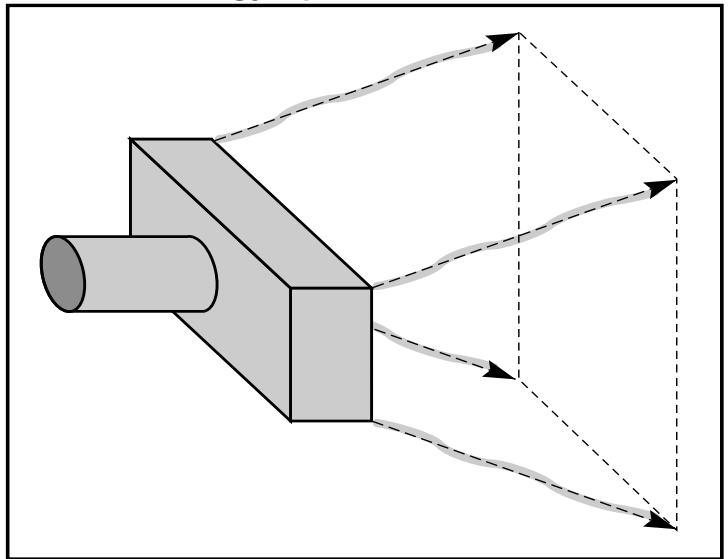
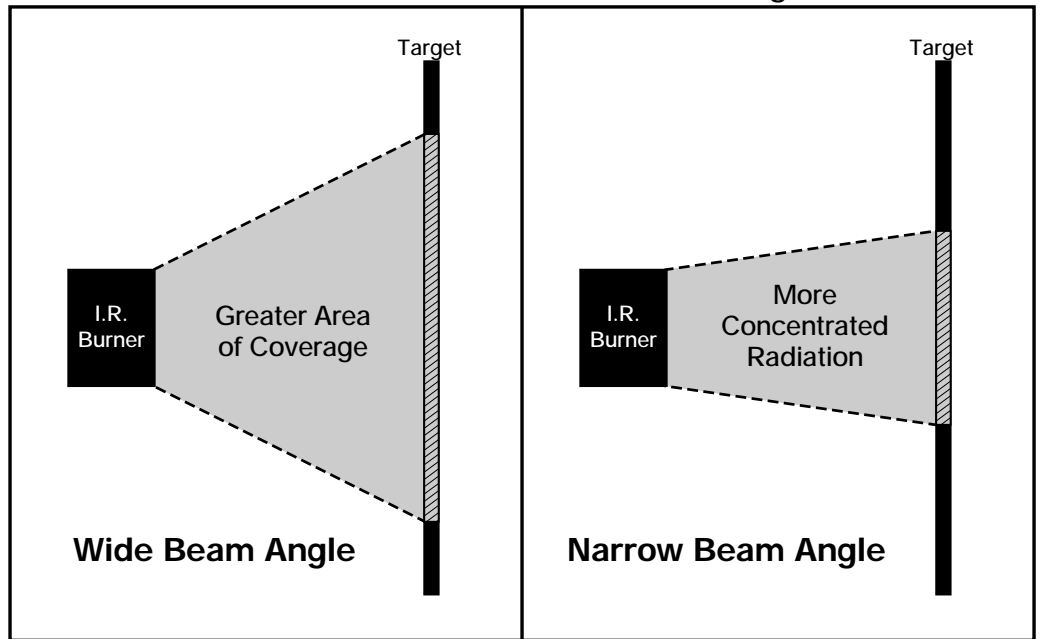


Figure 8

Wide vs. Narrow Radiation Beam Angles



burner-to-product spacing is one that will heat the product evenly without a lot of radiation escaping past the edges of the product.

In most IR ovens, the work is continuously moving past the burners. This also tends to even out the heat flow to various portions of the work, but it's still a good idea to stagger or zig-zag burner head patterns to get uniform coverage, especially on large pieces.

Product surface characteristics are probably the biggest variable in radiation transfer, and, unfortunately, they're the least understood. It's not that difficult to determine the radiating power and pattern of a burner head, but that's only half the picture. No surface will absorb all the radiation that strikes it; some is reflected away. The absorptivity of a surface (its ability to accept radiant energy) is mainly a function of its texture, although color and temperature also play a part. Highly polished metal surfaces may absorb less than 10% of the radiation that strikes them, while a rough, oxidized or sandblasted surface could absorb up to 90%. There's no reliable way to calculate absorptivities—what little data that exists has been determined by experimentation, and very little work has been done on powder coatings applied to metal surfaces. In any case, they will vary with the coating thickness and the size of the powder granules. On the basis of data for other materials, however, absorptivities probably average from 0.4 to 0.6 (40 to 60% of the radiation absorbed). In all likelihood, the absorptivity is initially higher, but decreases as the coating melts and presents a smoother, more reflective surface to the incoming radiation.

**Gas vs. Electric IR:
Is the Ability to
“Tune” Radiation
an Asset?**

As radiant heating of powder coatings has gained popularity, many of the old gas vs. electric debates have resurfaced. One which has gone on since the earliest days of IR drying of solvent-based paints is that because colors absorb radiation at different wavelengths, the IR source should be able to be tuned to match the paint. It seems to have its origin in the observation

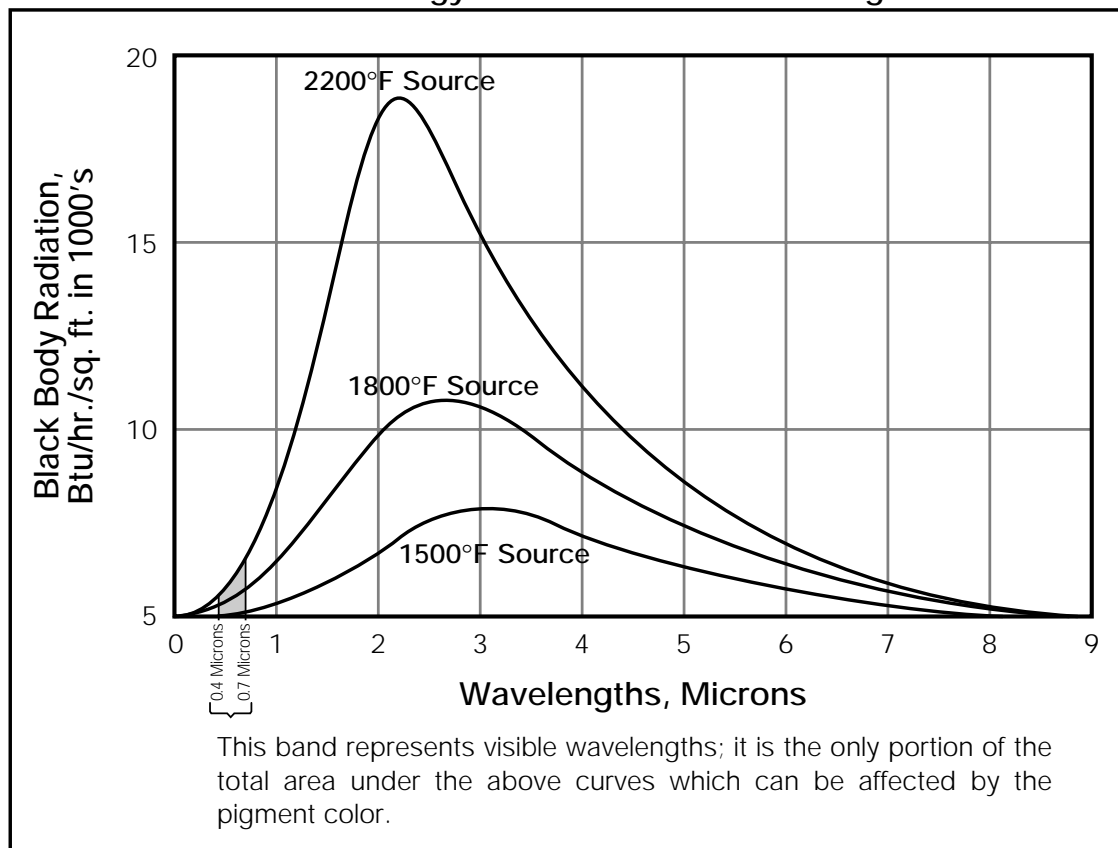
that some colors (reds are frequently mentioned) don't dry as readily as others, like black. The spectral absorption characteristics of different colors have been credited (or blamed) for the difference, on the theory that the wavelengths put out by the IR emitter weren't properly matched to the absorption frequencies of the pigment. The ability to control the emitter temperature, and therefore, the frequencies emitted, is said to produce more effective heating. The electric IR manufacturers have made particularly effective use of this argument.

There is only one problem with this argument—it isn't so. One of the reasons many solvent-based red paints are slower to cure is that they contain less pigment and more solvent. Why? Red pigments are among the most expensive, so paint manufacturers try to use as little as possible, depending on high solvent contents and, possibly, other additives to achieve uniform color coverage. Either way, it means more liquids to evaporate and slower curing times. Conversely, colors like black are so effective at covering that they can use lower solvent contents and can be applied in thinner coats.

The same logic applies to powder coatings, particularly with respect to coating thickness. All of the tech reps interviewed said they could not attribute differences in powder curing speed to color.

It is not difficult to understand if you look at Figure 9, which shows the radiant energy distribution vs. wavelength for various emitter temperatures. So little of the total radiation falls into the visible spectrum,

Figure 9
Radiant Energy Distribution vs. Wavelength



regardless of temperature or receiver color, that its effect on total heat transfer is negligible. Most of the real work is taking place to the right of the 0.7 micron line, where the infra-red spectrum begins. The real issues to consider in gas vs. electric radiant heating are system costs, energy costs, controllability, maintainability and ease of operation. A well-designed gas system with modern controls can match or beat an electric system in all these areas.

Summary

Powder coatings are the fastest-growing segment of the product finishing industry. This growth is being driven by their freedom from VOC emissions, their reduced volume of hazardous wastes to dispose of, and their ability to be cured more quickly than liquid finishes. This presents a major opportunity for oven and burner manufacturers to upgrade customers' curing lines. Radiant, convection and combination ovens are all feasible ways to cure powder finishes; the best choice will depend on factors such as product mix, configuration and temperature sensitivity.

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