# Essentials to understanding infrared processing

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*Infrared (IR) processing and convection processing have differences. This article discusses those differences and explains why no simple math can be applied to calculate the energy density requirement of the IR process. The article stresses the importance of choosing a supplier who can provide access to a quality test facility that encompasses the various IR technologies (long-, medium-, and short-wavelengths) to find the most suitable process for your curing requirements.*

In convection processing, one heats an airstream, not a very dense material from a physics standpoint, and then impinges the heated airstream on the process object (part). With adequate impingement, the boundary layer at the surface of the part is constantly disrupted, allowing the airstream to present itself with a higher energy load than the part.

The coating on the part, which happens to be denser than the impingement airstream, conducts the energy from the airstream into itself, but it's typically sitting on a substrate that's even denser than the coating, which conducts the energy out the backside of the coating into the part mass. The actual curing of the coating never begins until the entire part mass has been elevated to the curing schedule temperature range for the coating. The limited capability of an airstream to transfer energy is easily understood if you consider walking into a 240°F convection oven and taking some measurements, which wouldn't be possible if the oven were filled with a denser circulating transfer medium—240°F water for example.

FIGURE 1

Processing powder coating on steel wheels through a long-wavelength electric infrared oven

## Infrared processing

The general principal of infrared (IR) processing is based on the premise that an IR emitter will directly transfer electromagnetic pulses to primarily the resin component of the coating on a part.

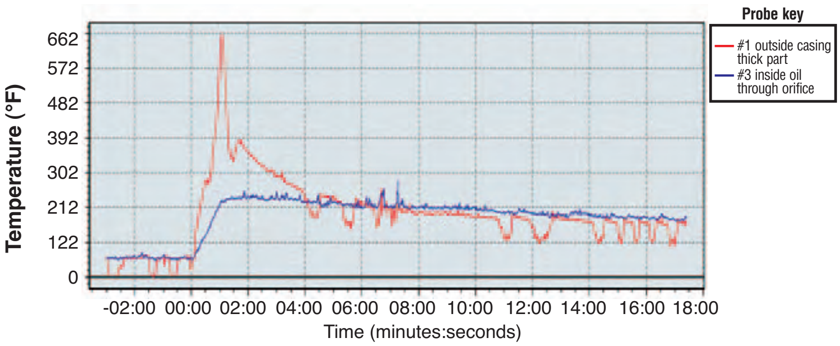
The wavelength of any emitter is directly tied to the operating temperature of the actual emitting surface. Long-wavelength emitters (Figure 1) typically have emissive surface temperatures of less than 1,200°F, requiring relatively small energy input to the emitter to achieve and maintain this surface temperature, and emit over a range of wavelengths from 4.0 to 10.0 microns. On the long-wavelength end of the IR spectrum, specifically around 5.4-micron wavelength, plastics (or any item constituted of considerable carbon/hydrogen chemicals—the resin component of the coating) readily and willingly act as absorbers of the electromagnetic pulses. Thus, long-wavelength IR energy in a well-designed oven is efficiently absorbed by the coating on parts within the oven whether the electromagnetic pulses travel directly to the coating surface or are reflected by the oven interior and travel a further distance and strike the part surface from an entirely different incident angle.

At the other end of the IR segment of the electromagnetic spectrum, we find short-wavelength emitters with emitter element temperatures from 2,000°F to 4,200°F and emissive capabilities in wavelengths as short as 0.8 micron. Short-wavelength emitters require tremendous energy input to support their operating face temperatures but have a unique characteristic defined by the Stephan-Boltzmann law, which renders down to a generic statement that "small increases in surface temperature yield (to the fourth power) large increases in energy emitted."

The short-wave technologies are fully capable of processing coatings on parts at such an accelerated rate that the part doesn't remain in the process long enough to fully behave as a heat sink. This type of technology is expensive to operate in true high-intensity status but can be used for curing powder on part surfaces without elevating the part internal temperatures dramatically, thereby allowing parts with internal thermally limited seals and so on to be processed without risk of damaging the internal parts. (See Figure 2, a thermal record of a hydraulic motor filled with hydraulic fluid and containing internal parts that aren't tolerant of temperatures in excess of 302°F. The large thermal spike is the exterior coating temperature, and the lower curves are the oil and seals internal to the part. The process takes 62 seconds.)

FIGURE 2

Infrared curing of a hydraulic motor filled with hydraulic fluid



## Energy density

The primary difference between IR processing and convection processing can be reduced to energy density—IR ovens are designed with far more British thermal units per hour per cubic foot (Btuh/ft$^3$) of oven interior than convection ovens due to the physics of how much energy an airstream can transport versus the direct Btuh output capabilities of IR emitters.

Within the various IR technologies, there is excessive attention given to specific wavelengths and how they will interface with the coatings. The reality is that while wavelength may be important to analyze the chemical constituents of a substance (IR spectroscopy), it's far less relevant when considering curing coatings.

Industrial coatings curing applications are theoretically more energy efficient at 5.4 microns, but due to the limited energy output of long-wavelength emitters it's only possible to create an IR density of less than 7,000 Btuh/ft$^3$. Typical powder applications are approximately 1,800 to 2,400 Btuh/ft$^3$. This IR density is intense enough to provide processing in generally 26 percent of the time required by a convection oven and yet moderate enough to allow a broad mix of part geometries and significant differences in part component mass.

Shorter wavelengths allow the creation of brute force IR ovens with IR densities in excess of 40,000 Btuh/ft$^3$ of oven interior. At higher levels of density such as this, there is so much energy in the oven that even though the coating isn't theoretically assisting in absorbing the energy, it has the energy forced upon it at rates that far exceed the substrate capability to conduct the energy out the backside of the coating. This type of process (see Figure 2) reduces the process time to as little as 3 percent of the time required by convection, assuming that in the convection process the internal thermally limited parts didn't exist or could be ignored.

## Combined IR-convection processing defined

Some confusion exists in the finishing industry concerning combined IR-convection ovens and their overall benefits.

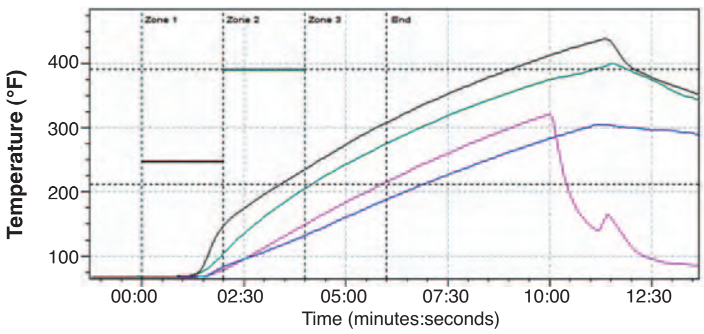
A true statement would be "an IR oven can be used as a ramp section to boost coating and part temperatures before they enter a convection oven for the final cure." This type of ramping into a convection oven has great merit not only in gelling powder (or evaporating solvents from wet coatings) before passage through a convection oven entryway air knife, but also in heat loading the part before its entry into the convection oven. The benefits are multiple:

- Since powder coating can no longer be dislodged by the air knife, the air knife can now be run at full capacity, which better retains the convection airstream within the convection oven and lowers the convection burner input requirement. In wet coats, the benefit is even greater because the solvents have evaporated and cross-linking has begun before the parts are exposed to any significant airstream. With wet coats on metallic substrates, the flash time can be radically reduced because the risk of solvent popping was dealt with by evaporating the solvents in the IR section while the coating was still open and before the coating was exposed to the impingement airstream in the convection oven. This frees up valuable floor space for better use.

- In both instances, the part is delivered to the convection oven already having a very significant temperature increase. This allows the burner package of the convection oven to be run at lesser input levels, allows shortening of the convection oven, or more typically allows dramatic increases in line speed through the existing convection oven.

FIGURE 3

**Processing of a geometrically complex 500-pound part with no recirculation airstream**



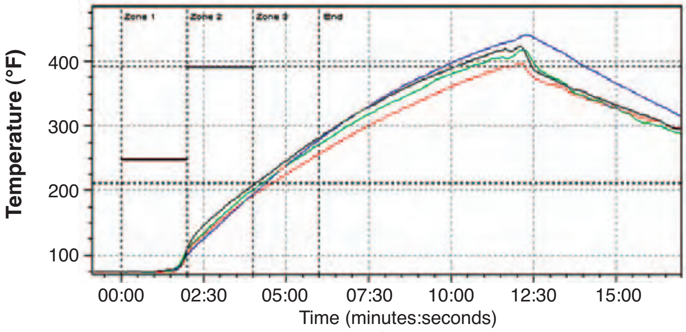
Note: Process to cure low-melt powder takes 10 minutes with large temperature differentials from place to place on part.

A misleading statement would be that "adding convection airflow to an IR oven will hasten the curing process." This isn't remotely accurate for several reasons:

- The IR process transfers energy at a much higher rate than convection; therefore, the part isn't in the process long enough for the convective aspect to have a net positive effect.
- The actual function of re-circulated airstreams within an IR oven is exactly the reverse of speeding up the process. The reality is that airstreams (re-circulated, convective, or otherwise) perform a reverse convection effect by stealing the energy off the portions of the part that have the largest temperature differential with the airstream. This means the airstream easily accepts energy from the coating that is at the highest temperature relative to the airstream and prevents that portion of the part from going seriously over temperature, while allowing the portions of the part at lower temperature to come up to the prescribed cure schedule temperature. Low-velocity (very low by convection standards) airstreams actually compromise the IR process and slow it down. However, low-velocity airstreams provide superior part temperature uniformity and allow the processing of remarkably complex geometrical parts or parts with great variance in mass from one portion of the part to another in an IR oven. Moderate-velocity airstreams can be used to flatten out the rate of part temperature climb and hold at a specific temperature. Substantial-velocity airstreams (convection-type velocities) can be used to reduce coating-part temperatures for parts stopped within an IR oven during unscheduled line stoppages to provide protection until the line restarts or the IR emitters are cycled to a lower input level. The data charts in figures 3, 4, and 5 show the function of re-circulated airstreams:
  - Chart A (Figure 3): The processing of a geometrically complex 500-pound part with no recirculation airstream—process to cure low-melt powder takes 10 minutes with large temperature differentials from place to place on part.
  - Chart B (Figure 4): The processing of the same geometrically complex 500-pound part with modest-recirculation airstream—process to cure low-melt powder now takes 11½ minutes with very small temperature differentials from place to place on the part.
  - Chart C (Figure 5): Recirculation initiated in the middle of an ongoing low-energy density test to demonstrate the capability it has to halt the rate of temperature change (recirculation was initiated at the point the temperature plateaus—emitter settings remain constant).

FIGURE 4

**Processing the same geometrically complex 500-pound part as in Figure 3 with modest recirculation airstream**

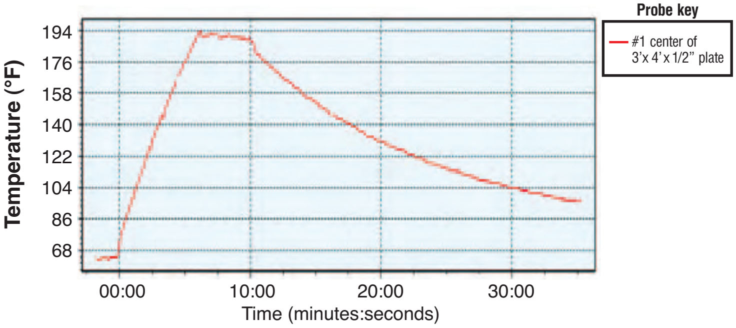


Note: Process to cure low-melt powder now takes 11½ minutes with small temperature differentials from place to place on part.

As you may have determined from this information, IR isn't like convection processing, and no simple math can be applied to calculate the energy density requirement of the process. Therefore, if you wish to investigate IR processing for your finishing line, it's important to become affiliated with a vendor that can provide access to a quality test facility encompassing the various IR technologies (long-, medium-, and short-wavelengths) and equipped to apply your coatings to your sample parts and thermally document process tests. As a result, your process requirements can be tested, your IR patterning configurations can be rationalized and proved, and the optimal IR technology can be selected for your process requirements. **PC**

FIGURE 5

**Recirculation initiated in the middle of an ongoing low-energy-density test to demonstrate the capability it has to halt the rate of temperature change**



Note: Recirculation was initiated at the point the temperature plateaus—emitter settings remain constant.

## Suggested reading

For more information, see *Powder Coating* magazine’s Web site at [www.pcoating.com]. Click on Article Index, Subjects, where you’ll find numerous case histories and technical articles on the topics covered in this article. If you would like to submit a question, click on Problem solving. Select the column that fits your question, fill out the form, and send it to us.

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