Understanding gas-fired convection curing equipment for powder coating

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Proper curing equipment and energy application are important to powder coaters. The powder coatings supplier provides information on the specific characteristics of a material, and the oven equipment supplier determines the appropriate oven design. Product quality and price are related in part to efficient and reliable curing.

Although many powder coaters use infrared equipment alone or in combination with a convection oven to enhance cure, most powder coaters use a gas-fired convection oven alone to cure their products. Even with widespread use, however, gas-fired convection ovens aren’t well understood. As a result, many badly designed ovens are built and sold. This article explains how gas-fired convection ovens work so that you can select the right equipment for your powder coating operation.

Convection heating uses air as an energy transfer medium. The air heats the metal substrate, and energy is transferred from the substrate to the coating by conduction. The oven must maintain the desired metal temperature for a certain time to achieve 100 percent cure. This time and temperature relationship is somewhat flexible, as shown in the example cure index in Figure 1.

Up to a point, increasing the time a part spends in the oven allows you to lower the temperature. Conversely, up to a point, increasing the temperature allows you to lessen the time a part spends in the oven. The temperatures expressed are part temperatures, not air temperatures. For this reason, the time in the oven must include the time required to bring the part to temperature.

The actual cure window involves three important temperatures: (1) the minimum required temperature to start curing, (2) the target temperature, and (3) the maximum temperature. Below the minimum temperature, no curing takes place. Above maximum temperature, the appearance and performance of the powder coating can be adversely affected. The goal is to reach
the target temperature as soon as possible and hold it for the time indicated by the cure index without exceeding the maximum temperature.

**Gas-fired convection oven types**

Basically, a gas-fired convection oven is an insulated enclosure with a heat source, a distribution duct, and an exhaust for combustion by-products. Several designs, burner types, and heat distribution methods are available.

**Direct-fired gas convection ovens.** The most common type of convection oven used in curing powder coatings is the recirculating, direct-fired gas oven. The heat source, referred to as the burner box, is attached to the insulated enclosure. The burner box is simply a gas burner with a blower to distribute the heat into the oven atmosphere (see Figure 2).

The burner can be a nozzle-mix design, such as the one shown in Figure 3. In this design, a combustion blower supplies air to the burner nozzle where it is mixed with fuel. These burners, which are specifically designed for ovens, include a controller that regulates the ratio of air to gas. They have a wide range of energy output, or turndown ratio, usually 40 to 1, and they are very energy efficient. This wide turndown ratio allows the burner to modulate, maintaining just enough energy output to satisfy the process. The inlet of the burner should be filtered to help keep the oven interior clean. It should also be accessible to make inspection and maintenance easy.

Sometimes line burner designs are used (see Figure 4). In this design, process air is passed through a set of mixing plates that are mounted on a cast-iron burner body and mixed with fuel at the nozzle tip.

**Indirect-fired gas convection ovens.** An indirect-fired gas oven uses an air-to-air heat exchanger. The heat exchanger is heated and air is circulated through it and into the oven (see Figure 5). This prevents combustion contaminants from entering the oven. Indirect heating equipment is more expensive than direct heating equipment, and it uses more fuel than direct heating because the heat exchanger is only 50 to 70 percent efficient.

**High-velocity convection ovens.** These ovens blow heated air directly onto the parts being cured. Using direct air impingement on parts accelerates the cure cycle, an advantage because the hot air speeds up the molecular reaction in the coating. Consequently, the oven takes up less floor space and provides a faster cure cycle than is possible with other types of gas-fired convection ovens.
An indirect-fired gas convection oven uses an air-to-air heat exchanger to circulate air into the oven.

**Exhaust**

**Fan**

**Heat exchanger**

**Return-air opening**

Some cautions should be considered before selecting this type of curing oven, however. The air blown onto the parts will dislodge some of the uncured powder coating, fouling the oven environment and risking product defects. Because high-velocity ovens don't recirculate the heated air, they require more energy than recirculating ovens to maintain oven set-point temperature. In addition, a high-velocity oven may require a lot more exhaust volume compared with a recirculating oven. This can drive operating costs up.

Another factor to consider is the high-velocity oven's very narrow process window. The flexibility of the standard recirculating oven is a major advantage over high-velocity ovens. If you can vary line speed and temperature, you have a wide tolerance for different parts and powder coatings. This can be a big plus if a new part is thrown into the mix or production requirements call for more output.

Because of the potential for blowing powder off parts, the extra operating expenses, and the narrow processing window, high-velocity ovens aren't typically recommended for curing powder coatings. Nevertheless, in some cases, such as when operating space is limited or shorter-than-average process times are required, this type of oven may be a plus. An infrared preheat section at the oven entrance can start the curing process and help prevent powder from blowing off the parts.

**Gas-consumption factors**

Gas consumption is primarily related to three factors that must be considered in the oven design: (1) product loading; (2) oven-panel radiation loss; and (3) exhaust loss. Some energy will also be absorbed by the powder coating during crosslinking.

**Product loading.** In a convection oven, energy will be spent to heat the parts, racks, and conveyor chain and trolleys as they pass through the oven. The weight of the items being heated, referred to as total product loading, is used to calculate the British thermal units (Btu) required.

To get total product loading, multiply the total weight of the parts, racks, and conveyor chain and trolleys in pounds by conveyor line speed in feet per hour. To determine Btu requirements, multiply total product loading by the specific heat of the metal by temperature rise, which is the difference between ambient temperature and oven set-point temperature.

**Example calculation:**

Parts + racks + conveyor chain and trolleys × conveyor line speed: 8,688 lb/hr

Oven set-point temperature: 350°F

Ambient temperature: 70°F

350°F - 70°F = 280°F temp rise

8,688 × 0.12 × 280 = 291,917 Btu/hr

(assumes parts, racks, and chain and trolleys are at ambient temperature at entry to oven)

In the above calculation, the multiplying factor 0.12 represents the specific heat of steel in Btu per pound per degree Fahrenheit (Btu/lb °F). Specific heat is the ratio of the quantity of heat required to raise the temperature of a body 1 degree Fahrenheit to that required to raise an equal mass of water 1 degree Fahrenheit. Different metals have different specific heats, as shown in Table 1. The multiplying factor, or specific heat, must match the material being heated.

**TABLE 1**

<table>
<thead>
<tr>
<th>Metal</th>
<th>Specific heat (Btu/lb °F)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>0.226</td>
</tr>
<tr>
<td>Brass</td>
<td>0.092</td>
</tr>
<tr>
<td>Copper</td>
<td>0.0328</td>
</tr>
<tr>
<td>Gold</td>
<td>0.3312</td>
</tr>
<tr>
<td>Iron (99.97%)</td>
<td>0.1075</td>
</tr>
<tr>
<td>Lead</td>
<td>0.297</td>
</tr>
<tr>
<td>Magnesium</td>
<td>0.249</td>
</tr>
<tr>
<td>Manganese</td>
<td>0.1211</td>
</tr>
<tr>
<td>Steel</td>
<td>0.12</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.1125</td>
</tr>
<tr>
<td>Zinc</td>
<td>0.0931</td>
</tr>
</tbody>
</table>

Oven-panel radiation loss. A theoretical loss factor for the heated oven enclosure, called panel loss factor, occurs through the floor, the walls, and the ceiling of the oven. Insulation is important to minimize this loss. The panel loss factor varies according to panel thickness, as shown in Table 2.

Panel heat loss can be calculated by multiplying the total panel area in square feet by the panel loss factor by the temperature rise.

Example calculation:

Oven set-point temperature: 350°F
Ambient temperature: 70°F
Panel thickness: 4 in (0.35 panel loss factor)
Oven size: 20 ft wide, 50 ft long, 10 ft high

Ceiling and floor: $50 \times 20 \times 2 = 2000$ sq ft
Sides: $50 \times 10 \times 2 = 1000$ sq ft
Ends: $20 \times 10 \times 2 = 400$ sq ft
Total panel area: $3400$ sq ft
(This does not consider product openings)

350°F - 70°F = 280°F temp rise

$3400 \times 0.35 \times 280 = 333,200$ Btu/hr

Exhaust loss. Some energy is lost through the exhaust stack. Use the following formula to calculate exhaust loss: multiply exhaust volume in cubic feet per minute (cfm) by 60 minutes by 0.075 pounds per cubic foot.
weight of air) by 0.24 Btu/lb °F (the specific heat of air) by the temperature rise.

Example calculation:

Oven set-point temperature: 400°F
Ambient temperature: 70°F
Temperature rise: 330°F
Exhaust volume: 984 cfm

984 \times 60 \times 0.075 \times 0.24 \times 330 = 350,698 \text{ Btu/hr}

It should be noted that high humidity will place an additional load on the burner to evaporate moisture. Before you calculate exhaust loss, however, you must know the exhaust volume, expressed in cfm.

**Exhaust volume.** The proper exhaust volume is critical. Too little could create a safety hazard and color and gloss defects in the powder coating. Too much exhaust wastes money. The proper exhaust volume for a powder coating oven is related to the pounds of powder coating applied and the combustion by-products.

Insurance underwriters, such as Factory Mutual, require a rate of dilution of air inside an oven based on the volume of powder coating applied to parts that are run through the oven. This prevents curing by-products released into the oven from escaping into the plant. Following is a typical formula based on Factory Mutual Standards* for dilution of the air inside the oven to meet insurance requirements:

1. To get cubic feet per hour (cfh), multiply the number of powder coating spray guns by maximum powder coating output per gun per hour by 9 percent of the total powder volume by 360 cfh by four air changes.

(Nine percent is generally accepted for calculating ventilation rates because it's the highest typical percent of flammable gases given off by a powder coating in the cure process; 360 cubic feet is the volume of air necessary to keep the concentration of volatiles below 25 percent of the lower explosive level; the number 4 is a safety ventilation factor. The factors for percentage and cubic feet are based on maximums. They can be adjusted if the powder has a lower volume of volatiles. The number 4 is a constant.)

2. To get standard cubic feet per minute (scfm), divide cfh by 60 minutes.

3. To get the temperature correction in cfm, multiply scfm by the result of dividing 460 plus oven set-point temperature by 460 plus ambient temperature. (The constant 460 is related to absolute zero, a hypothetical temperature characterized by the complete absence of heat and equivalent to approximately -460°F.)

4. To get the safety factor, you have to calculate scfm by dividing the maximum burner Btu by 95 cubic feet per second (cfs) times 60 seconds, then correct for temperature as in 3 above (95 cfs is the recommended dilution rate to ensure that enough oxygen is present in the oven atmosphere).

5. To get total cfm exhaust volume, add the results of 3 and 4.

Example calculation:

Oven set-point temperature: 400°F
Ambient temperature: 70°F
Powder output: 8 guns applying
25 lb/hr per gun
Burner Btu: 1 million

1. \(1.8 \times 25 \times 0.09 \times 360 \times 4 = 25,920 \text{ cfm} \)

2. \(25,920 \div 60 = 432 \text{ scfm} \)

3. \(432 \times \left[ \frac{(460 + 400) \div (460 + 70)}{860} \right] = \)
\(432 \times \left( \frac{860}{530} \right) = \)
\(432 \times 1.62 = 700 \text{ cfm} \)

4. \(1,000,000 \div (95 \times 60) = \)
\(1,000,000 \div 5,700 = 175 \text{ scfm} \)

Temperature correction:
\(175 \times \left[ \frac{(460 + 400) \div (460 + 70)}{860} \right] = \)
\(175 \times \left( \frac{860}{530} \right) = \)
\(175 \times 1.62 = 284 \text{ cfm} \)

5. \(700 + 284 = 984 \text{ cfm total exhaust volume} \)

The total of the three loss factors—product loading, oven-panel radiation loss, and exhaust loss—is the theoretical gas consumption of the oven. The total of the three example calculations for these loss factors comes to 975,815 Btu/hr. These calculations can be used to compare relative variables by changing any of the volumes in the examples. Actual consumption will be slightly greater than the total because of energy absorption by the coating and losses through the product openings.

**Energy-saving oven features**

Several features can be incorporated into an oven to prevent heat loss and dirt contamination. These involve duct arrangement, heat containment, and filtration.
Designing an oven with a bottom entry and exit is an ideal way to contain heat. For ovens with horizontal entry and exit, two options are available: a powered air curtain or a heat-relief hood.

**Powered air curtains.** The conveyor entrance and exit can be furnished with high-velocity air to minimize heat loss into the surrounding atmosphere and to ensure the most efficient oven operation. Each air curtain should be equipped with its own fan assembly (see Figure 7). The air curtain uses oven air and doesn’t induce an additional fresh-air load into the surroundings.

The discharge velocity is determined by the oven manufacturer and is usually about 2,000 feet per minute. Because of the relatively high air velocity required to effectively contain heat, a powered air curtain isn’t recommended at the entrance to a powder coating oven. It’s perfectly acceptable at the exit, however.

**Heat-relief hood.** The conveyor entrance or exit can be furnished with a canopy-type heat-relief hood, or stack, to capture the majority of heat spillage from the product opening and disperse it to the outside atmosphere (see Figure 8). The hood should be made of galvanized steel and be oven supported, with a manually adjustable quadrant damper in a 24-inch joint of stack. The heat-relief hood will provide an escape for heat roll out to avoid heat gain in the building, and it will not disturb the uncured powder at the oven entrance. It will not help to reduce Btu loss through the opening, but the loss should be modest if the oven is designed properly.

**Filtration.** Dirt will often find its way into a convection oven, land on a part, and create a defect. Vacuuming the
oven interior weekly will help prevent contamination from building up and becoming a problem.

Another way to keep dirt out of the oven is to add return-air filtration. To do this, a filter framework is built into the return-air opening of the burner box. The framework includes a first filter layer that is 30 percent efficient and a second filter layer that is 90 percent efficient. Maintaining a constant sweeping action, these filter layers prevent the blower from circulating dirt onto the parts (see Figure 9).

Conclusion
When you're looking at oven equipment, check several references from any oven supplier you're considering. Ask for some typical heat charts from ovens the supplier has built previously. In addition, make sure you know what materials the supplier uses for construction. The formulas in this article will help you find out what your operating expenses will be. As a result, you should get the most dependable and energy efficient oven for your powder coating operation.

References
3. Reed.  

Acknowledgment
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Editor's note
For more information about convection oven design, see the following articles: Bruno Ezerski and Bob Stoffel, “Curing methods and oven designs that save energy with reduced air movement,” Powder Coating, vol. 2, no. 6 (December 1991): 25-30; and Nick Liberto, “How to cure powder-coated parts without getting burned,” Powder Coating, vol. 4, no. 6 (November 1993): 61-64.

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