Oven Design

THERMOFORMING 101

Various types of heaters were described in an earlier tutorial. In this lesson, the effect of the heat produced by these heaters is considered. The focus is on non-contact heating.

The Role of The Oven

The oven serves several purposes. It holds the sheet while it is being heated. For the most part, it isolates the heating sheet from the environment outside the oven. It provides a rigid structure for the heaters. It provides a way for the sheet to enter the oven and a way for it to exit the oven. And it provides fixed spacing between the sheet and the heaters. Most importantly, the oven must protect both the sheet and the heaters from thermal or mechanical damage, if something goes wrong.

The simplest oven consists of a single heater bank suspended over a clamped sheet, with no provision for isolating the sheet from the outside environment. This heating method is sometimes used, even though the heat transmission from the heater to the sheet is quite poor. Heater efficiency is improved by shrouding the heater in sheet metal and covering that with several inches of fiberglass. At the other extreme, ovens are available that actively clamp, top and bottom, against the sheet, completely isolating it from the environment. These ovens are very energy efficient and can be quite expensive.

Regardless of the type of heater used, the heaters are usually held in planes above and below the sheet plane. One thermoforming machinery manufacturer uses curved rod heaters, with the heaters curved downward near the sheet edges. This helps minimize heater inefficiency along sheet edges. Usually the heaters are fixed in position relative to the sheet plane. However, machines have been built in which the lower heaters travel downward as the heating sheet sags.

Most electric ovens operate on 480V/3Ø. Heaters are usually rated in "watt density", with W/in^2 being the standard US dimension. Rod, panel, and ceramic heater watt densities are up to about 40 W/in^2. Quartz heaters are available to 60 W/in^2. Gas-fired heaters operate at gas pressures of about 5 to 10 oz, although new ported burners require up to 5 lb/in^2 gas pressure. All catalytic gas heaters also require electric preheaters, which can operate at 240V1Ø but are more efficient at 480V/3Ø. Catalytic gas heaters have equivalent watt densities of up to about 30 W/in^2. Ported burners and free-surface burners have equivalent watt densities of about 500 W/in^2.

Just as there is no ideal heater, there is no ideal oven design. An optimum oven design sufficiently isolates the sheet from the outside oven environment to minimize drafts and energy loss. But the design should allow for relatively easy means of transferring the sheet into and out of the oven. And it should allow for any sheet movement during heating, such as sag, by spacing bottom heaters away from the final sheet shape.

Controls

Oven controls range from simple on-off electrical switches to temperature-sensed proportional and proportional-integral-derivative or PID controllers. Oven heaters can be ganged and operated from a single controller or individually connected to separate controls. Early ceramic heaters were sometimes individually connected to individual ten-turn potentiometers or pots, yielding a "B movie" science-fiction-like wall of hundreds of adjustable dials. Now, most small heaters are "clustered" into a more manageable number of controllable "zones" which are then adjustable through a digital or even touch-screen monitor at the process control station. PID controllers are a must for heaters that require rapid changes in power level. These controllers minimize power overshoot. This minimizes sheet overheating and extends the lifetime of the heater element

Burning or decomposing plastic is always a concern in thermoforming. Ovens are usually designed with both passive and active means of minimizing damage due to a dropped sheet. At the very least, the bottom heater is protected with easily removed, inexpensive chicken-wire screen suspended above it. In certain instances, quartz plates are placed above the bottom heater. When pristine, quartz is transparent in infrared energy and so does not affect the heater efficiency. Since the quartz does not heat, the dropped sheet is quickly frozen by the cold plate, this facilitating sheet removal and minimizing damage to the lower heater. Sag monitors, really photoelectric sensors, detect excessive sag and can sound a klaxon, shut down the heaters, drop baffles in place, or activate oven pull-back or fly-open controls. In some oven designs, high-volume blowers, activated either by sag monitors or infrared sensors, blow room temperature air over the overheated sheet, either before it drops onto the heater or while it resides on the chicken-wire screen. In other designs, the oven cabin is flooded with carbon dioxide whenever fire is detected. Mechanically, ovens can be equipped with baffles or doors that isolate the heaters from the sheet, or the ovens may be clamshell opened or horizontally retracted to remove the heat source from the sheet.

Keywords: Oven design, power requirements, watt density, fire control, heater control, on-off control, proportional control, PID control

[This is one in a series of articles introducing general concepts in thermoforming.]