Basic Heat Transfer

Thermoforming involves first adding energy to plastic sheet to elevate its temperature to a forming temperature, then forming the sheet against a mold, then cooling the formed sheet to a temperature where the part retains the shape of the mold. There are three modes of heat transfer which are important during the heating and cooling of the plastic.

"Conduction" is energy transmission through solid objects. In thermoforming, energy is conducted from the surface of the polymer sheet to its interior during heating, and from its interior to its surface during cooling. As noted in an earlier article, the thermal conductivity or more properly, thermal diffusivity of the polymer is the fundamental property in determining the rate of energy transfer through the solid or rubbery polymer. The higher the thermal diffusivity of the polymer, the more rapidly energy is transferred and the more uniform is the temperature through the polymer.

"Convection" is energy transmission between solid objects and fluids. In thermoforming, air is the fluid surrounding the sheet in the oven and typically in contact with the free surface of the formed part on the mold surface. Convective energy transmission depends strongly on the flow rate of the fluid. The greater the flow rate, the greater the rate of energy transfer. The proportionality is called the "heat transfer coefficient." Convective heat transfer is also important during the cooling of the plastic part on the mold surface, since the coolant running through the mold piping is a fluid. Typically, the cooling efficiency of liquids is greater, by an order of magnitude, than that for air. For example, cooling water is about one hundred times more effective in cooling than fan-blown air.

"Radiation" is energy interchange between two solid objects having different temperatures. Unlike conduction, which requires direct contact between solid objects, and convention, which requires direct contact between fluids and solid objects, raidation is electromagnetic energy transfer, requiring no contact. However, radiation energy transfer requires that the two objects "see" each other. In thermoforming, radiation energy transfer occurs in the oven between the heater surfaces and the sheet surface. It also occurs between heater surfaces and oven walls, clamp frames, and the outside world if the oven is open. Radiation energy transfer also occurs when the sheet is removed from the oven, since the sheet is hotter than its surroundings. However, the amount of energy transfer is a function of the fourth power of the temperature of the solid object and so radiant energy transmission in the thermoforming oven is far more significant than anywhere else in the process. Radiant energy intensity is usually identified in terms of object temperature or wavelength. Traditional thermoforming heaters operate between about 100°F and 1500°F, and have peak wavelengths of 2.5 to 9 microns. This range is referred to as "far intrared."

First, it is important to realize that all three modes of heat transfer – conduction, convection and radiation – are important in the heating of thermoformable polymer sheets. The primary mode of energy transfer varies depending primarily but not exclusively on the thickness of the polymer sheet. Very thick sheets, 13 mm or 0.5 inch in thickness or thicker, can be heated rather efficiently in "pizza oven" heaters, where hot air is convected or blown around the sheet that is supported on all sides to allow for uniform circulation. Even though the air might be heated by being blown across hot panels, the primary modes of heat transfer are convection to the sheet surface and conduction of the energy into the volume of the sheet. At the other extreme, thin sheet, 0.75 mm or 0.030 inch in thickness, can be heated extremely rapidly with very intensive radiant heat, since conduction through thin sheet is very rapid.

All commercial energy sources used in thermoforming today produce heat both by convection [hot air moving across the heater surface] and radiation [heater surface temperatures greater than sheet surface temperatures].

Keywords: conduction, convection, radiation, far infrared

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