Infrared Temperature Measurement: Optimizing Stationary and Rotary Thermoforming

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Consistent, accurate temperature measurement is critical in the plastics industry to ensure correct finishing of thermoformed products. In both stationary and rotary thermoforming applications, low forming temperature produces stresses in the formed part; while temperatures that are too high can cause problems, such as blistering and loss of color or gloss.

In this article, we will discuss how the latest advancements in infrared (IR) non-contact temperature measurement not only help thermoforming operations optimize their manufacturing processes and business results, but also enable compliance with industry standards for final product quality and reliability.

Figure 1. Consistent, accurate temperature measurement is critical in the plastics industry to ensure correct finishing of thermoformed products.

Background

Thermoforming is the process by which a thermoplastic sheet is made soft and pliable by heating, and biaxially deformed by being forced into a three-dimensional shape. This process may take place in the presence or absence of a mold. Heating the thermoplastic sheet is one of the most crucial stages in the thermoforming operation. Thermoforming machines typically use sandwich-type heaters, which consist of panels of infrared heaters above and below the sheet material.

The core temperature of the thermoplastic sheet, its thickness and the temperature of the manufacturing environment all affect how plastic polymer chains flow into a moldable state and reform into a semi-crystalline polymer structure. The final frozen molecular structure determines the physical characteristics of the material, as well as the performance of the final product.

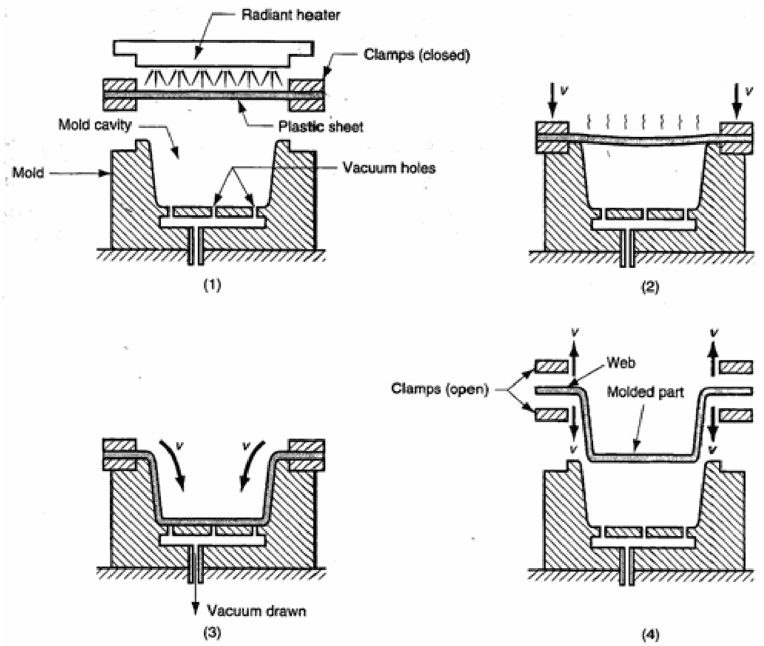

Figure 2. Thermoforming is the process by which a thermoplastic sheet is made soft and pliable by heating, and biaxially deformed by being forced into a three-dimensional shape.

Ideally, the thermoplastic sheet should heat up uniformly to its appropriate forming temperature. The sheet then transfers to a molding station, where an apparatus presses it against the mold to form the part, using either a vacuum or pressurized air, sometimes with the assistance of a mechanical plug. Finally, the part ejects from the mold for the cooling stage of the process.

The majority of thermoforming production is by roll-fed machines, while sheet-fed machines are for smaller volume applications. With very large volume operations, a fully integrated, in-line, closed-loop thermoforming system can be justified. The line receives raw material plastic and extruders feed directly into the thermoforming machine.

Certain types of thermoforming tools enable cropping of the formed article within the thermoforming machine. Greater accuracy of cut is possible using this method because the product and skeletal scrap do not need repositioning. Alternatives are where the formed sheet indexes directly to the cropping station.

High production volume typically requires the integration of a parts stacker with the thermoforming machine. Once stacked, the finished articles pack into boxes for transportation to the end-customer. The separated skeletal scrap is wound onto a mandrill for subsequent chopping or passes through a chopping machine in-line with the thermoforming machine.

Figure 3. Typical plastics thermoforming machine (photo courtesy of General Plastics Machines, Ridgefield, WA).

Production Challenges

Large sheet thermoforming is a complex operation susceptible to perturbations, which can greatly increase the number of rejected parts. Today's stringent requirements for part surface quality, thickness accuracy, cycle time and yield, compounded with the small processing window of new designer polymers and multi-layer sheets, have prompted manufacturers to look for ways to improve control of this process.

During thermoforming, sheet heating occurs through radiation, convection, and conduction. These mechanisms introduce a great deal of uncertainty, as well as time-variations and nonlinearities in the heat transfer dynamics. Furthermore, sheet heating is a spatially distributed process best described by partial differential equations.

Thermoforming requires a precise, multi-zone temperature map prior to the forming of complex parts. This problem is compounded by the fact that temperature is typically controlled at the heating elements, while the temperature distribution across the thickness of the sheet is the main process variable.

For example, an amorphous material such as polystyrene will generally maintain its integrity when heated to its forming temperature because of high melt strength. As a result, it is easy to handle and form. When a crystalline material is heated, it changes more dramatically from solid to liquid once its melt temperature is reached, making the forming temperature very narrow.

Changes in ambient temperatures also cause problems in thermoforming. The trial-and-error method of finding a roll feed speed to produce acceptable moldings might prove to be inadequate if the factory temperature were to change (i.e., during the summer months). A temperature change of 10°C (50°F) can have a significant influence on output because of the very narrow forming temperature range.

Traditionally, thermoformers have relied upon specialized manual techniques for sheet temperature control. However, this approach often yields less-than-desired results in terms of product consistency and quality. Operators have a difficult balancing act, which involves minimizing the difference between the sheet's core and surface temperatures, while ensuring both areas stay within the material's minimum and maximum forming temperatures.

Additionally, direct contact with the plastic sheet is impractical in thermoforming because it can cause blemishes on plastic surfaces and unacceptable response times.

Infrared Technology Solution

Increasingly, the plastics industry is discovering the benefits of non-contact infrared technology for process temperature measurement and control. Infrared-based sensing solutions are useful for measuring temperature under circumstances in which thermocouples or other probe-type sensors cannot be utilized, or do not produce accurate data.

Non-contact IR thermometers can be employed to monitor the temperature of fast moving processes quickly and efficiently, measuring product temperature directly instead of the oven or dryer. Users can then easily adjust process parameters to ensure optimal product quality.

What are the specific advantages offered by infrared technology?

- It is fast, allowing for more measurements and accumulation of data.
- It facilitates measurement of moving targets.
- Measurements can be taken of hazardous or physically inaccessible objects.
- Measurements can be taken in high-temperature environments.
- There is no interference — thus, no energy is lost from the target.
- There is no risk of contamination and no mechanical effect on the surface of the object.

IR instruments employ a non-contact measurement technique based on Planck's Law of black body radiation, which states that every object emits radiant energy and the intensity of this radiation is a function of the object's temperature. The sensor simply measures the intensity of radiation, thereby measuring an object's temperature.

Infrared radiation is part of the electromagnetic spectrum, and has a wavelength of 0.5 to 20 micrometers. It is emitted from all objects that have a temperature above absolute zero (-273.15° C). An object emits IR radiation directly as a function of its temperature, as determined by the Stefan-Boltzmann equation:

$$e = \sigma T4$$

Where e is the total energy emitted by radiation, T is the temperature of the object on the absolute scale, and σ is the Stefan-Boltzmann constant. IR sensors and thermal imaging devices, therefore, measure energy and produce a signal proportional to the amount of energy radiating from the object, which includes both emitted and reflected energy. Unfortunately, few objects are perfect emitters, and reflect to varying degrees based on their surface properties and radiation from nearby objects.

To make accurate infrared measurements, it is important to understand the proportion of radiation that an object emits compared with the radiation it reflects. This property is called emissivity. The emissivity of a surface is simply the percentage of a surface that emits. The remaining percentage of the surface reflects. Plastics are usually good emitters, with emissivity values around 0.9, whereas shiny metal surfaces act like mirrors reflecting more ambient radiation than they emit. As such, they are poor emitters, with emissivity values from 0.1 to 0.3. A blackbody is a perfect emitter, with emissivity of 1.0.

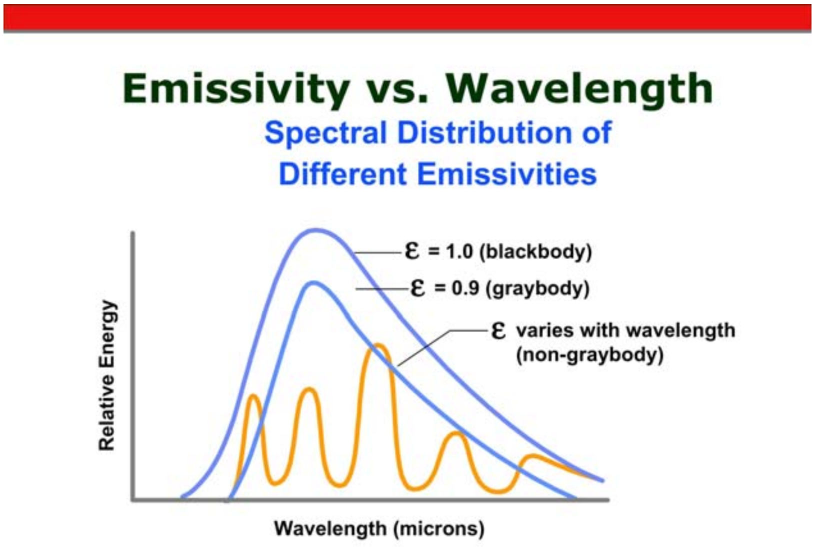

Figure 4. Emissivity is the measure of an object's ability to emit infrared energy.

How an IR System Works

For thermoforming applications, an automated infrared temperature monitoring system typically includes an operator interface and a display for process measurements from the thermoforming oven. An IR thermometer measures the temperature of the hot, moving plastic sheets with 1% accuracy. A digital panel meter with built-in mechanical relays displays temperature data and outputs alarm signals when the set point temperature is reached.

Using the infrared system software, thermoformers can set temperature and output ranges, as well as emissivity and alarm points, and then monitor temperature readings on a real-time basis. When the process hits the set point temperature, a relay closes and either triggers an indicator light or an audible alarm to control the cycle. Process temperature data can be archived or exported to other applications for analysis and process documentation.

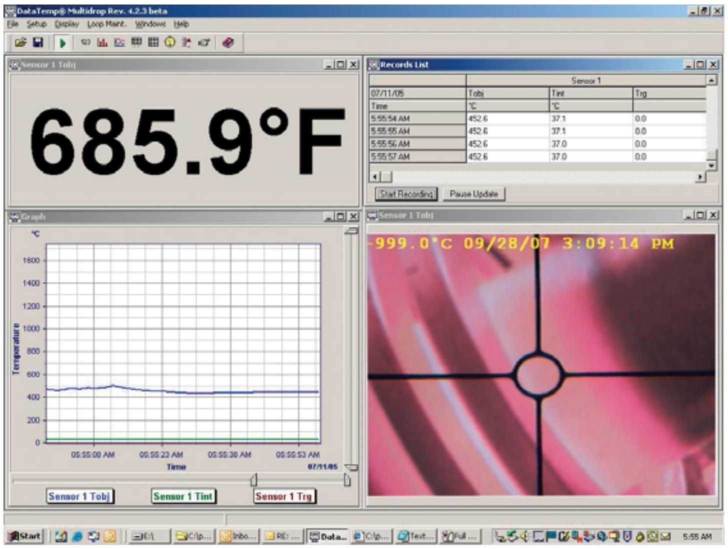

Figure 5. Using the infrared system software, thermoformers can set temperature and output ranges, as well as emissivity and alarm points.

Thanks to data from the IR measurements, production line operators can determine the optimal oven setting to saturate the sheet completely in the shortest period of time without overheating the middle section. The result of adding accurate temperature data to practical experience enables drape molding with very few rejects. And, more difficult projects with thicker or thinner material have a more uniform final wall thickness when the plastic is heated uniformly.

Thermoforming systems with IR sensor technology can also optimize thermoplastic de-molding processes. In these processes, operators sometimes run their ovens too hot, or leave parts in the mold too long. By using a system with an infrared sensor, they can maintain consistent cooling temperatures across molds — increasing production throughput and allowing parts to be removed without significant losses due to sticking or deformation.

Latest IR Advancements

Even though non-contact infrared temperature measurement offers many proven advantages for plastics manufacturers, instrumentation suppliers continue to develop new solutions, further improving the accuracy, reliability and ease-of-use of IR systems in demanding production environments.

Specific IR sensor design improvements include:

Easier sighting: To address sighting problems with IR thermometers, instrument companies have developed sensor platforms that provide integrated through-the-lens target sighting, plus either laser or video sighting. This combined approach ensures correct aiming and target location under the most adverse conditions.

Thermometers may also incorporate simultaneous real-time video monitoring and automated image recording and storage — thus delivering valuable new process information. Users can quickly and easily take snapshots of the process and include temperature and time/date information in their documentation.

Higher resolution: Today's compact IR thermometers offer twice the optical resolution of earlier, bulky sensor models, extending their performance in demanding process control applications and allowing direct replacement of contact probes.

Some new IR sensor designs utilize a miniature sensing head and separate electronics. The sensors can achieve up to 22:1 optical resolution and withstand ambient temperatures approaching 200°C (392°F) without any cooling. This allows accurate measurement of very small spot sizes in confined spaces and difficult ambient conditions. The sensors are small enough to be installed just about anywhere, and can be housed in a stainless steel enclosure for protection from harsh industrial processes.

Innovations in IR sensor electronics have also improved signal processing capabilities, including emissivity, sample and hold, peak hold, valley hold and averaging functions. With some systems, these variables can be adjusted from a remote user interface for added convenience.

Greater flexibility: End users can now choose IR thermometers with motorized, remote-controlled variable target focusing. This capability allows fast and accurate adjustment of the focus of measurement targets, either manually at the rear of the instrument or remotely via an RS232/RS485 PC connection.

IR sensors with remote controlled variable target focusing can be configured according to each application requirement, reducing the chance for incorrect installation. Engineers can fine-tune the sensor's measurement target focus from the safety of their own office, and continuously observe and record temperature variations in their process in order to take immediate corrective action.

Figure 6. Today's advanced IR sensors provide additional flexibility for target focusing in plastics industry applications.

Suppliers are further improving the versatility of infrared temperature measurement by supplying systems with field calibration software, allowing users to calibrate sensors on site. Plus, new IR systems offer different means for physical connection, including quick disconnect connectors and terminal connections; different wavelengths for high- and low-temperature measurement; and a choice of milliamp, millivolt and thermocouple signals.

Increased accuracy: Instrumentation designers have responded to emissivity issues associated with IR sensors by developing short wavelength units that minimize errors due to the uncertainty of emissivity. These devices are not as sensitive to changes in emissivity on the target material as conventional, high-temperature sensors. As such, they provide more accurate readings across varying targets at varying temperatures.

IR temperature measurement systems with automatic emissivity correction mode enable manufacturers to set-up predefined recipes to accommodate frequent product changes. By quickly identifying thermal irregularities within the measurement target, they allow the user to improve product quality and uniformity, reduce scrap, and improve operating efficiency. If a fault or defect occurs, the system can trigger an alarm to allow for corrective action.

Greater efficiency: Enhanced infrared sensing technology can also help streamline production processes. Operators can pick a part number from an existing temperature setpoint list and automatically record each peak temperature value. This solution eliminates sorting and increases cycle times. It also optimizes control of heating zones and increases productivity.

Bottom-line Benefits

For thermoformers to fully analyze the return on investment of an automated infrared temperature measurement system, they must look at certain key factors. Reducing the bottom line costs means taking into consideration the time, energy, and amount of scrap reduction that may take place, as well as the ability to collect and report information on each sheet passing through the thermoforming process.

The overall benefits of an automated IR sensing system include:

- Improved part quality
- Simplified quality control monitoring and setup capability
- Identification of over-heated or under-heated sheets before making defective (off-spec) parts
- Ability to thermoform more difficult parts
- Ability to archive and provide customers with a thermal image of every part manufactured for quality documentation and ISO compliance
- Increased throughput by reducing part residence time in the heating section
- Higher yields by significantly cutting down equipment set-up and qualification times
- Early detection of heater problems affecting process efficiency and energy consumption

Conclusion

Non-contact infrared temperature measurement is not a new technology, but recent innovations have reduced costs, increased reliability, and enabled smaller units of measurement. Thermoformers utilizing IR technology see an improvement in production, and they do not have as much scrap. They also make better quality parts because they get uniform thickness coming out of their thermoforming machine.

References

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