Featured in the January 2018 issue of Process Heating:

WISCONSIN OVEN

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Drying NON-UNIFORM AND HEAT-SENSITIVE PRODUCTS

Non-uniform and heat-sensitive products have unique drying needs, so understanding the drying process is important.

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Uniformly drying a non-uniform product is difficult. Decreasing the drying time of heat-sensitive products is challenging. One example is a three-dimensional product saturated with water — for instance, molded-fiber packaging products. Other examples of demanding drying applications include:

- Drying water-based finishes applied to nonwoven fabrics without melting the polymer fabric.
- Kiln-drying lumber in an accelerated manner without case hardening, splitting or cracking.
- Drying pressure-sensitive adhesives on release liners without skinning or blistering.

Lightweight, nonwoven fabrics vary in thickness and basis weight after being formed. Uniformly drying a saturated finish without overheating the lightweight areas of the fabric is difficult. Drying lumber takes forever and a day. Actually, it requires many days, and aggressive attempts to reduce the drying time can result in boards splitting or cracking. Effectively drying pressure-sensitive adhesives presents a host of issues for web converters like label manufacturers.

Product manufacturers struggle with these types of applications because the conventional process dryers and ovens utilized are inherently uniform by original design. Supply air plenums deliver process air at a constant volume, velocity and temperature. Banks of infrared heaters operate at a uniform watt density over their entire heated area. Thus, three-dimensional part geometries, non-uniform product loadings and temperature-sensitive products pre-

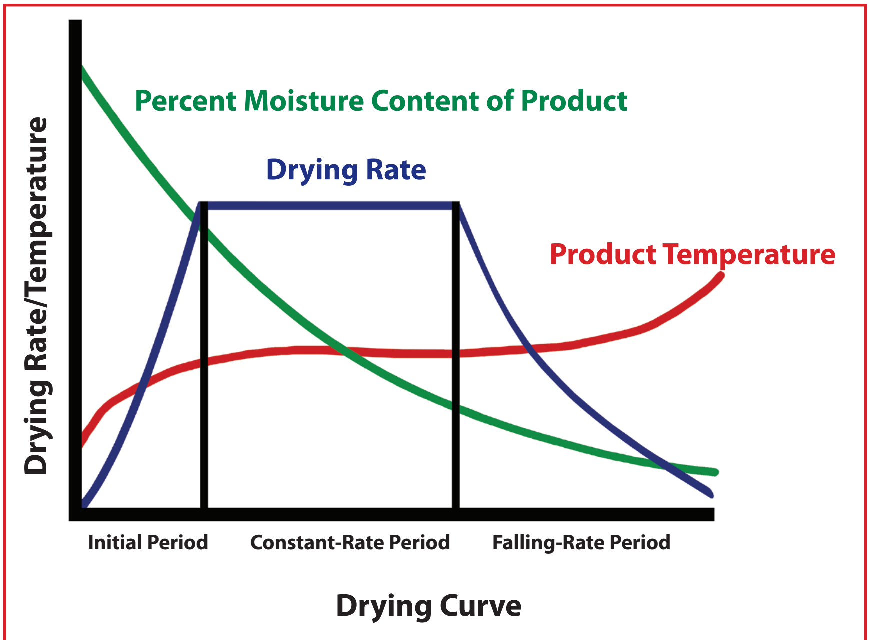

FIGURE 1. Consider the common drying curve. The curve illustrated is believable if the product being dried is flat, uniform and the rate of moisture removal is well controlled over its entire surface area. Unfortunately, this is not the case when heat processing shapely, non-uniform, sensitive products.

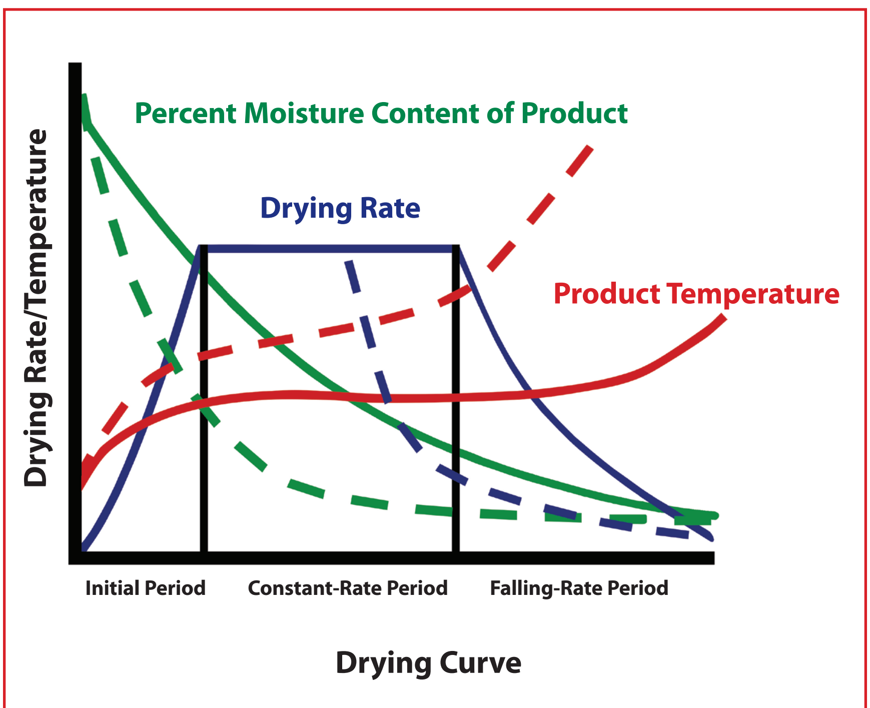

FIGURE 2. The dashed drying curve lines may help operators better visualize what the product experiences as it travels through the dryer.

sented to a uniform heating chamber limit heat and mass transfer rates.

Millions of molded-fiber products are produced everyday by packaging companies all over the world. Examples of this type of product range from the egg cartons almost all grocery shoppers flip open before placing in their carts to the protective packaging keeping the items purchased online safe during transit. These products and others like them demand lots of time to properly dry. Thin-wall, transfer-mold products like an egg carton typically require 4 to 10 min to dry, whereas 30 to 60 min is not uncommon for thick-wall, engineered, protective packaging solutions. Note for every 1 lb of dry fiber entering the dryer, there are 3 to 4 lbs of water. Therefore, product manufacturers consume and pay for an enormous amount of energy to satisfactorily dry these products. Energy costs are one of the highest contributors to the cost of goods sold (COGS). When facing a process and application in which the drying time cannot be significantly reduced, reducing energy costs becomes a priority. As is the case with molded-fiber product manufacturers.

A typical molded-fiber dryer design is a horizontal, recirculating hot-air impingement dryer of considerable length to produce the dwell times required. Multiple zones in the machine direction and constant volume airflows are normal. Some are single-pass dryers while others are multiple pass. Periodically, the dryers produce an unreasonable amount of scrap although it is typically recyclable. Documented and repeated product recipes usually are a result of trial and error, not “a-ha” moments of dryer wizardry.

To stave off insufficient drying and product overheating, go-to temperature profiles are used. Insufficient drying results in an unacceptably high moisture content somewhere in the package. Overheating, discoloration or scorching decreases throughput. The top and bottom product surfaces nearest the hot-air delivery system (also known as impingement nozzles or perforated supply air headers) experience the highest convective heat transfer rates and, thus, are the most vulnerable to damage.

One approach to reducing energy costs

while making better use of the entire heated length of the process dryer is to unravel what is happening to the saturated parts inside the dryer. Consider the common drying curve (figure 1). The elegant curve illustrated is quite believable — if the product being dried is flat and uniform, and the rate of moisture removal is well controlled over its entire surface area. Unfortunately, this is not the case when heat processing shapely, non-uniform, sensitive products.

The hot air — being at a temperature higher than the part — is transferring heat by convection (heat transfer). As liquid water in the part evaporates, it becomes water vapor, which then is absorbed by the surrounding hot air being recirculated with a portion exhausted away by the dryer apparatus (mass transfer). As previously mentioned, heat and mass transfer rates are limited because of part geometry. The dryers deliver heated air to a chamber filled with a bunch of three-dimensional, saturated parts. The air impacting the outer surfaces of the part, as compared to what impacts the various nooks, crannies and recesses of the part, is different.

For molded-fiber parts, if an outer surface is noticeably scorched or discolored, recyclable scrap is produced rather than sellable product. If insufficient drying within the part is persistent during a production run, the packages can be offloaded, set aside to air dry or placed inside a batch oven to finish drying. This is, of course, not ideal, but it is not a total loss.

The solid lines depicted in figure 1 and figure 2 are representative of the last area of the package to acceptably dry. Keeping this in mind, the moisture content of the top and bottom surfaces closest to the plenums drops faster (as demonstrated by the dashed green line). Surface temperatures climb more steadily and remain hotter than the middle (represented by the dashed red line). A temperature gradient develops between the outer surfaces and the last portions of the part to dry (the area between the two red lines). This gradient, if maintained and allowed to grow, leads to overheating and scorching at the surface. Lastly, the constant-rate period of the top and bottom surfaces is relatively short in duration (shown as a dashed blue line). Adding the dashed drying curve lines to the graphic may help operators better visualize what the product experiences as it travels through the dryer. This, in turn, may lead them to develop more cost-effective product recipes and temperature profiles.

An equally menacing drying challenge in which figure 2 is applicable exists for

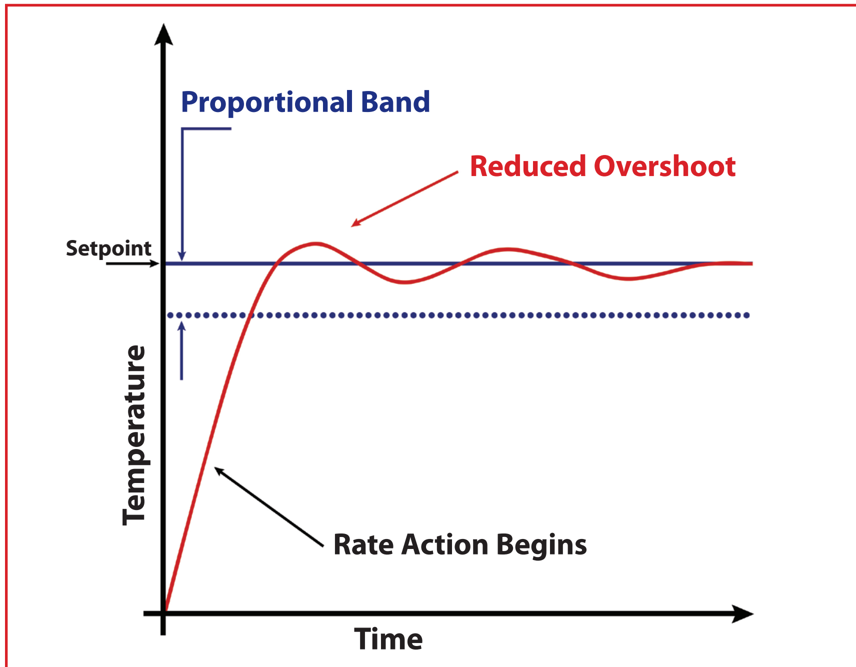

FIGURE 3. It may be helpful to relate these drying processes to a PID temperature control loop where the red curve represents product temperature. The illustration works for many heat-sensitive drying applications.

Unconventional Advice for Operating a Conventional Dryer

- The product temperature profile is more interesting than the dryer temperature profile. Use it to reduce scrap and lower energy consumption.
- Convection dryers deliver air at temperature to perform work. By varying both air volume and temperature, the operating cost of the dryer can be lowered.
- Ease up on the throttle in the entrance zone. Running "balls to the walls" is not always the answer.
- When airflows are uncontrolled, the weather matters.
- At some point in time, secondary heat recovery technologies pay for themselves. If you are in it for the long haul, invest in them.

Three-dimensional products saturated with water such as molded-fiber packaging products present a drying challenge.

those drying solvent-based, pressure-sensitive adhesives. Prematurely skinning over the surface of the wet adhesive is relatively easy to do. As the product is continually heated, liquid solvent below the surface vaporizes and bursts through the skin, resulting in coating-surface defects. Unacceptably high heat and mass transfer rates at the entrance of the dryer induce this result.

It may be helpful to relate these drying processes to a PID temperature control loop where the red curve in figure 3 represents product temperature. The illustration works for many heat-sensitive drying applications. For example, too much overshoot typically is the reason why a wet coating prematurely skins. For saturated molded-pulp products, avoidance of overheating and scorching is the goal. Thus, it is important to prevent the outer surfaces of the product from getting too hot during the drying cycle. Minimizing or eliminating product temperature overshoot is accomplished by dampening the rate action or slowing the rate of heatup.

In figure 3, the area below the proportional band can be likened to the initial period of figure 2, where the wet product is being sensibly heated with not much water evaporating. The width of the proportional band represents the constant-rate period in which water is being evaporated while the product temperature remains relatively constant. The drying process is under control, just as the process variable being controlled remains at or near setpoint. After most of the moisture is removed and the falling-rate period approaches, the top of the proportional band protects the product from getting too hot by turning the energy source off as necessary. This is similar to how the exit zones of the dryer are typically set up to operate at lower temperatures in an effort to keep the product surfaces from overheating before the part exits the dryer.

Molded-pulp drying times and other applications like it are extended, tough to manage and difficult to reduce using conventional heating technologies. Gaining a better understanding of what the product is actually experiencing inside the dryer coupled with integrating a few energy saving design build techniques, readily available from most responsible dryer and oven manufacturers, positively impacts the cost of operation by reducing it.

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For more information from Wisconsin Oven, call 262-642-3938 or visit the website at www.wisoven.com.