Ensuring Uniform Drying

by **Cameron Harman Jr.**

Drying problems can often be avoided by ensuring that your drying process is as uniform as possible.

Calculating Drying Time in a Fixed Air Dryer

The following formula, which was originally developed by Carrier circa 1905, shows the amount of water removed per square foot of surface area per hour using a fixed-air dryer:

$$\text{Water removed} = .192 * k * ((1+ \text{Velocity (ft/min)})/200) * (w_0 - w_{RH})$$

where k represents a constant that varies with the product and the system, w_0 is the amount of water in the air when it is saturated at the given air temperature, and w_{RH} is the amount of water in the air at the given temperature and the percent relative humidity

If you assume that the constant (k) doesn't vary in a particular dryer when drying the same materials of similar shape, and that the velocity is also fixed, then the variation in drying is directly proportional to the formula ($w_0 - w_{RH}$). If you know the temperature and relative humidity, you can calculate a number that gives the relative amount of drying time using the same formula.

For example, suppose you have a velocity of 100 ft per minute, a constant (k) of 1 and a water saturation level (w_0) of 3. At 50% relative humidity (w_{RH} =1.5), the water removal rate would be 0.432 lbs of water per sq ft of surface area per hour. If you have to remove a total of 2 lbs of water per sq ft, the total drying time might be 2/0.432, or 4.6 hours.

If, however, the relative humidity changed to 70%, then the amount of rater removed per square foot per hour would be 0.2592, and the relative drying time would increase to 7.7 hours.

It is widely known that ceramic bodies that contain a great deal of clay will shrink significantly during the initial stages of drying. If drying takes place faster on one side of a piece than on the other, the sides also shrink at a different rate. As this uneven shrinkage occurs, the piece will warp or crack. Even ceramics that contain no clay will react unfavorably to rapid water removal from one side of the piece. Both types of problems should be treated the same way—by ensuring that the drying process is as uniform as possible.

Understanding the Drying Process

How can you ensure that your drying process is uniform? First, you need to understand what causes water to leave the product being dried. In a conventional air dryer, the amount and speed of water removal are regulated by the air velocity and absolute humidity within the dryer. Wet air dries products more slowly than dry air, and fast-moving air dries more quickly than slow-moving air.

The air temperature also plays a role—a higher air temperature typically lowers the absolute humidity. In many successful dryers, the air temperature is held to a maximum of 90°F in the winter and 100°F in the summer. However, in some applications, the temperature must be higher to drive the relative humidity down at the end of the drying cycle or to penetrate a heavy load. In general, the temperature should be as low as possible (generally about 20° above room temperature) to avoid wasting energy while still permitting efficient, uniform drying.

The temperature of the part can also affect drying by changing the surface tension of the water within the part. Higher temperatures reduce the water's surface tension, enabling the internal or residual water to move more easily through the small pores inside the ware. Although this can be very important in some cases (e.g., very thick pieces with tightly compacted bodies made through a wet process), it is not a factor in most applications.

Heating, ventilating and air conditioning (HVAC) engineers have developed equations to help determine the rate of evaporation in a pool room, and these same equations can be used to determine the maximum rate at which water can be removed from a ceramic product. (See the "Calculating Drying Time in a Fixed Air Dryer" sidebar.) Clearly, water should not be evaporated from a ceramic product at its maximum rate to avoid damaging the piece. But knowing the outer limits of drying can help you choose the right dryer and avoid using too much energy for extra heat or higher fan speeds.

Choosing the Right Dryer

The best air dryers have a very uniform supply of air propelled across a limited distance. The farther the air must travel, the more moisture it absorbs. In a very long dryer, the parts at the end will dry much more slowly than the parts in the middle. Furthermore, the air must move at the same velocity from the top to the bottom and from front to back to ensure uniform drying. Generally, the maximum recommended width is 8 ft across the dryer in the direction of the airflow. However, the ideal dimensions for a specific application will depend on the load setting and on the thickness of the product being dried.

Many different types of successful dryers exist, and there is no one-size-fits-all solution. However, by understanding how the drying process works, you can draw some general conclusions about the type of drying system to use for a given appli-

Putting Drying Principles into Practice

Fast, Continuous Drying

A major china manufacturer processes bowls with an automatic wet processing system, similar to jiggering. The bowls, which contain a high percentage of clay, were previously dried in six hours using several large box dryers. The company wanted to add a continuous dryer to its operation to reduce handling requirements (and thereby labor costs), but it had only 15 ft of space available in its plant. Installing a new dryer that would adequately dry the bowls in such a small amount of space would require the company to increase the speed and efficiency of its drying operation.

The company chose a tightly controlled, high-humidity, low-velocity air dryer to achieve its goals. The bowls are set on the tunnel kiln cars and are automatically sent to the 15-ft-long dryer, where their moisture content drops from 17% to the required 3 or 4% in just three hours. The kiln cars then automatically move to the tunnel kiln without intervention by an operator.

This tightly controlled, high-humidity, low-velocity continuous air dryer enabled a major china manufacturer to increase the speed and efficiency of its drying operation.

Reducing Product Losses

A manufacturer of grinding wheels uses several large, room-type dryers that were converted from ovens. The wheels contain very little clay and only about 5% binder in the mix. For the most part the company's dryers worked well, but some of the particularly large wheels (36-in.-diameter by 6-in.-thick) often cracked during drying or firing, leading to high product losses.

The company converted its drying ovens to a tightly controlled, high-humidity, low-velocity design and was able to significantly reduce its losses. The savings from higher recovery rates paid for the conversion costs in a very short period of time.

Improving Speed in a Periodic Dryer

A manufacturer of high-tech ceramic products extrudes its greenware in 4-in.-diameter by 24-in.-long "logs," which must be thoroughly dried before they can be machined into the final components. The ceramic body is composed of about 10% clay. The plant's previous drying method was to set the logs on trays to air dry in a drying room, but this process took about six weeks—or longer, depending on the temperature and humidity in the outdoor environment—for the pieces to be dry enough to machine.

The company recently installed a cart-style air dryer that dries the logs in just three days. The logs are still placed on trays, but these trays are now positioned on a moveable rack that is rolled into the dryer. The dryer is sealed from the outside and follows a computer-controlled program for temperature and relative humidity. The program has been adjusted to optimize drying for even the largest logs and now dries the same way every time, regardless of outside climate conditions.

In addition to improving the company's drying operation, the new dryer has also reduced storage requirements, allowing the rack area previously used for drying to be used for expanded manufacturing equipment.

cation. For parts that do not shrink much while drying or are physically strong, high-velocity air can be very useful. However, be sure that the air is directed uniformly throughout the dryer or you will not get even drying.

For parts that have high clay content or otherwise must be treated gently, the low-temperature, high-humidity, low-air-velocity approach is generally preferred. Some brick dryers use moving fans to generate a relatively uniform distribution of high-velocity air over the ware. The brick are strong and can take the force of the air without cracking or breaking, but the removal of water from the surface makes drying the interior more difficult.

Maintaining a wet surface helps create a water "chain" inside the part, and this chain helps the water migrate from the inside of the product to the surface through osmosis. With high temperatures and a dry surface, the water must evaporate inside the piece before it can reach the surface. For this reason, high-humidity, low-velocity dryers can often provide much faster drying.

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Maximizing Efficiency

The concepts behind uniform drying are relatively simple. A lot of good dryers based on these principles are working successfully in plants all over the world. By understanding both your product and the drying process, you will be able to choose a dryer that will not only dry more uniformly, but also more efficiently.

About the Author

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