Successful Spray Drying

To achieve successful spray drying, it is important to understand the process and its capabilities, as well as its limitations.

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A co-current drying system in operation.

Spray drying is one of the most efficient ways to convert ceramic slurries into a free-flowing powder. It has been used for decades to process clays for whitewares manufacturing, as well as to produce oxide ceramics such as aluminas, ferrites, steatites and titanates.

The most common application of spray drying is in producing powders that will subsequently be pressed and fired, where the unique properties of spray dried products—namely, a narrow particle size distribution and spherical particle shape—result in excellent flow characteristics. For this reason, spray drying has been widely adopted for the manufacture of advanced ceramics, such as carbides, nitrides and borides. Other applications include powders for plasma spray and slip casting, as well as ferrites for toners and magnetic tapes.

However, for a spray drying application to be successful, it is important that users understand both the benefits and the limitations of the spray drying process. It is also important that users choose the right system based on the requirements of the application.

The Spray Drying Process

The basic spray drying process consists of three processing steps:

- Atomization of the feed slurry into tiny droplets. This is accomplished using rotary or nozzle atomizers.
- Mixing of the atomized spray with the hot drying gas, typically air, and drying of the individual droplets into solid particles. This is carried out inside the drying chamber, and it is important that the particles are dry (at
least on the surface) before they contact the internal surfaces of the
drying chamber.
- Recovery of the dried product. This can be done partly from the base of
the drying chamber and partly from separation equipment for the spent
drying air.

The typical spray drying system for ceramic applications includes a feed system
for pumping the feed slurry to the atomizer, an inlet air system with a heater, a
drying chamber with product discharge, a cyclone collector for fines recovery, a
bag filter for air pollution control and an exhaust fan for controlling the air flow
through the spray drying system.

This type of equipment allows many different grades to be processed with the
least possible cleaning of the equipment between the grades. The press powder
is typically discharged from the base of the drying chamber, and the fines
recovered in the cyclone can either be mixed in with the chamber faction or
recycled back to the preparation equipment for the ceramic slurry. The small
amount captured in the bag collector can be discarded if the raw materials are
reasonably inexpensive or recycled in the very front of the feed preparation
process. Cleaning of the drying chamber is fairly simple and can be
accomplished using a tank cleaner nozzle inserted into the drying chamber after
the dryer is shut down.

**Spray Dryer Configurations**

![Diagram of a mixed flow drying system using a nozzle atomizer.](image)

**Figure 1. A schematic of a mixed flow drying system using a nozzle atomizer.**

The most common configuration for producing press powders is mixed flow
drying with a fountain nozzle (see Figure 1). The air is introduced through the
top of the drying chamber, and the ceramic slurry is atomized by a nozzle that
sprays upward from the base of the drying chamber.
The maximum average particle size of the product discharged from the drying chamber is 75-150 microns, depending on the size of the drying chamber. Using a pressure nozzle, a very narrow particle size distribution can be obtained with a typical yield of 85-95%, depending on the specific gravity of the spray-dried ceramic. However, if the feed rate to the spray dryer is low (less than 100 lbs/hr), the orifice in the pressure nozzle becomes so small that plugging is inevitable. In such cases, a two-fluid nozzle is used, and the expected yield is reduced to 75-85%. (Yield in this context is defined as the fraction of product discharged from the drying chamber; the rest is conveyed with the spent drying air to the cyclone and bag filter.)

A typical spray dryer installation using this configuration is shown in the photo at right. The cylindrical height required for the spray drying chamber is based on the desired average particle size and specific gravity of the ceramic material.

![Diagram of a co-current drying system with a rotary atomizer.](http://www.ceramicindustry.com/CDA/ArticleInformation/features/BNP__Features__Item/0,2710,7892...)

**Figure 2. A schematic of a co-current drying system with a rotary atomizer.**

Where smaller average particle sizes are desired, the typical configuration is co-current drying using a rotary atomizer. This concept is illustrated in the schematic in Figure 2. Finer powders are normally required for pressing very small pieces or for applications such as plasma sprays. For this configuration, the typical average particle size is 25-100 microns, depending on the capacity of the spray drying system. A spray drying system using this configuration is shown in the photo on p. 60.

When using the co-current drying configuration, all of the spray-dried powder is often conveyed with the spent drying air to the cyclone collector, eliminating the need to externally mix the two fractions. By using this concept, the yield is normally 95-98%, with the remaining small fraction collected in the bag filter.

Using either of the two configurations described previously, the achievable maximum average particle size depends on the physical dimensions of the
drying chamber. In very small plants producing a few pounds per hour of press powder, the products produced will have a maximum average particle size at the lower end of the range indicated. Conversely, for very big spray dryers with capacity in excess of 1000 lbs/hr, the maximum average particle size can easily exceed the upper end of the ranges indicated above. However, such large systems are seldom required in the manufacture of advanced ceramics.

Figure 3. A schematic of a co-current drying system with a nozzle atomizer.

One further application of co-current spray drying is the drying of precursors for very fine grain ceramics. For this application, the feed material to the spray dryer is a metal salt solution, made from nitrates or ammonium salts, for example, which is dried into fairly low bulk density powders. These powders are then subsequently processed by calcination, pyrolysis or any other suitable high temperature treatment. Such applications of co-current spray drying are used either with a rotary atomizer, as described above, or with a nozzle atomizer, as illustrated in Figure 3.

Closed-Cycle Spray Drying

Some ceramic slurries have to be prepared in organic solvents rather than water to prevent oxidation of one or more of the ceramic ingredients. In these applications, a closed-cycle spray drying system using an inert gas, such as nitrogen, is typically used. This concept has successfully been used to process tungsten carbide (hard metals) since the late 1960s. All of the spray dryer configurations described previously can also be used in this type of a spray drying system.

In closed-cycle spray drying plants, the atomized slurry is contacted by hot nitrogen in the spray drying chamber and processed into a free flowing powder like any other ceramic formulation. Dried product is discharged from the drying chamber and the cyclone, and the spent drying gas is introduced into a...
condenser system. The solvent evaporated in the drying chamber is condensed and recovered. The off-gases from the condenser are then reheated in an indirect heater for reuse in the drying chamber.

Due to the flammability of the solvents, the equipment in the spray drying system has to be explosion-proof, and the drying system itself has to be gas-tight to prevent leakage of solvent vapor into the operating area. This type of spray drying system typically operates under a slight positive pressure to ensure that no explosive mixture of in-leaking ambient air and solvent vapor can be created. Additionally, the instrumentation and control system usually includes oxygen monitors and other safety controls.

**Spray Dryer Selection**

A mixed flow drying system in operation.

Spray drying has been used successfully in the ceramic industry for a number of decades. However, to ensure the most efficient operation, it is important to understand the process and its capabilities, as well as its limitations. It is also essential to develop the proper design parameters based on the requirements of the application. Such data can be obtained from existing production facilities, in-house pilot plants or from vendors' test facilities.

**For More Information**

For more information about spray drying, contact Niro Inc., 9165 Rumsey Rd., Columbia, MD 21045; (410) 997-6622; fax (410) 997-5021; e-mail obc@niroinc.com; or visit http://www.niroinc.com.

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man who invented air conditioning. The heating, ventilating and air conditioning (HVAC) industry uses the following equation derived from Carrier's work to establish the maximum rate of evaporation from a pool of water:

\[ \text{lb water/sq. ft. of surface area/hr} = k(1+200/V)(W_d-W_{RH}) \]

where \( k \) is a constant for the particular situation (often taken as 0.192) and \( V \) is the perpendicular air velocity in feet per minute. \( W_d \) is the partial pressure of water vapor in fully saturated air at the given temperature in inches mercury, and \( W_{RH} \) is the percent of saturation as denoted by the percent relative humidity. These numbers are well known and are available in standard tables.¹

The equation says that at a given air velocity and a given temperature, only so many pounds of water can be removed per hour for each square foot of exposed surface area. The means that no matter what we change inside the piece, the water can still only leave the surface at some fixed rate. However, at high temperatures or high air velocities, this rate can be quite high. In fact, even in an open manufacturing room with low humidity, the speed of surface drying is so fast that even a gentle air movement is enough to cause pieces to warp before they are put into a dryer. For this reason, many manufacturers cover their ware with plastic immediately after forming to avoid having it dry too quickly on one surface. Drying one surface faster than another will cause that surface to shrink faster than the other side. This shrinkage causes a difference in movement often seen as a warp or crack. (See “Understanding Shrinkage” sidebar.) Even a piece that looks fine after drying can have hairline cracks that may not be visible until after the piece is fired. This defect, often mistaken for firing cracks (preheating cracks), can be prevented by drying on all sides evenly and by drying the surface no faster than the surface water can be replaced from the inside of the piece.

**How Quickly Does Water Move to the Surface?**

A self-contained conventional dryer. Photo courtesy of Ceramic Services, Inc.

The answer to how fast water moves from the inside of a piece to the outside is very complicated. We know that a mix of materials with larger diameter capillaries will allow faster water movement than smaller diameter capillaries. We also know that warmer water has lower viscosity than cooler water, so it will effectively be “thinner” and move more easily through the capillaries, or pores, inside the ware. But how can these principles be applied to ensure perfect drying?

Raising the temperature of the inside of the piece will allow the water to move a little more quickly to the surface by lowering the viscosity of the water (i.e., the “thinner” water moves through the pores of the ware more easily). However, the temperature must be carefully controlled. If the water turns into steam, it might...
move from the surface more quickly, but the expansion of the water to steam could cause internal damage to the ware.

Of course, steam does not always harm a ceramic body. Some mixes are very “forgiving” and dry easily. In other formulations, adding grog to the body can enhance the drying process by enlarging the capillaries to allow the water to pass more easily from the inside to the outside of the ware. Any steam formed in these types of pieces can escape almost instantaneously without damaging the ware. In other cases, the green strength of the body is high enough that the expanding steam can be contained without harming the bond. However, these examples are all exceptions to the norm. The formation of steam during drying will damage most body formulations, and should therefore be avoided through carefully controlled drying whenever possible.

Heat can be applied to a drying ceramic to raise the temperature of the inside water and make it migrate to the surface more easily, but it must not be applied too soon in the drying process. If the ceramic is too wet, the water will be removed from the surface of the ware faster than it can migrate from the inside of the ware to the surface, as explained previously. On the other hand, a piece that does not contain much water going into the drying stage can be dried faster—with heat—and without much risk of damage. How much water a piece contains depends on its body formulation and on how it was formed. For example, dry pressed ware has very little water (approximately 5-6%) and can dry quite quickly. Ceramics that do not contain a lot of clay can also be safely dried faster than their clay-laden counterparts, which will shrink significantly during the drying process. (See “Determining Water Content” sidebar.)

In any case, the secret to good drying is to drive the water from the center of the piece to the outside surface and then remove it as fast as it gets there—not simply to remove the water as fast as possible from the surface.

**Drying Methods**

![A hybrid RF/convection heating system. Photo courtesy of Radio Frequency Co., Inc.](image)

Once we understand how the drying process works, we will then be better equipped to choose the right type of dryer for our facility. Four basic drying methods are used in the ceramic industry:

- Air drying or open drying
- Air drying in a closed room
- Drying in a conventional dryer
- Microwave and radio frequency (RF) drying

Air drying or open drying is the most inconsistent form of drying and is mainly used by small facilities and studios. In this form of drying, products are placed on shelves in the manufacturing facility and allowed to air dry. In some cases, the products are set on the ground outside and allowed to dry in the sun. Aside from the great lengths of time that this drying process requires, many products are often damaged due to the inability to control drying conditions.
Many of the manufacturers that once air-dried their products have “upgraded” to a closed room reserved specifically for this purpose. In reality, a closed room provides little improvement over air drying. Although confining the products in one indoor room provides slightly more control over the climate, conditions are still largely unregulated, and numerous losses still result.

For many ceramic facilities, a conventional dryer provides sufficient speed and control to ensure thorough, efficient drying. The conventional dryer is either a stationary enclosed room or a continuously moving platform through an enclosed room in which the speed and direction of the air can be controlled. In some cases, the dryer is nothing more than a series of heaters placed so that the product passes by them. In other cases, the dryer provides very large movements of air with a series of increasing temperatures, and many of today’s models offer programmable control over both the temperature and relative humidity of the air. (See “More About Conventional Dryers” sidebar.)

More recently, microwave and RF dryers have also been put into service. These dryers work by sending electromagnetic energy to the water molecules inside the ware. The ceramic is transparent to these waves of energy, so all of the water inside the piece is affected. Radio frequency dryers operate on a different frequency than microwave dryers and are able to evenly excite all of the water molecules throughout the ceramic, so that the water migrates from the inside to the outside at a more uniform rate. The factory space required for an RF dryer is often smaller than the space required for a conventional dryer. And since heating begins instantaneously throughout the product, the dwell time in an RF dryer is far less than in a conventional dryer. However, their smaller size also restricts the size of the ware that can be placed in the dryers, limiting them mainly to small components and glass fibers. There is also a danger that the pieces may heat too much and cause steam or expanding water vapor to harm the piece.

### Selecting a Dryer

Which dryer you choose depends on your ware. Some manufacturers require several weeks to dry their ware. Others are able to dry their products completely in 48 hours using a modern conventional dryer, and many have achieved drying cycles of 24 hours or less.

For most ceramic products, superior drying results can be obtained in very short periods of time using judicial air movement, humidity control and temperatures below 120°F. The fastest drying time for a given piece depends on:

- The moisture content of the piece (more moisture will take more time)
- The size and shape of the finished ware (thinner ware dries faster, and smooth shapes dry faster than complex shapes)
- The forming process used
- How difficult the mix is to dry

Conventional drying with properly controlled air velocity, temperature and relative humidity can be very inexpensive and is fast enough for many operations. Because of several issues, including the relatively high energy costs involved, microwave and RF dryers are still practical for only a handful of applications, mostly in the high-tech arena. However, when speed is of the utmost importance and uniform drying is crucial, the benefits of these systems can easily offset the extra energy and purchasing costs.

A dryer is an investment that should benefit your plant over the long run.
Evaluate your needs, and request test runs from potential suppliers. In the end, the dryer that works best with your product—and the supplier that best meets your needs—is the one you should choose.

Drying is an important part of any ceramic manufacturing process. Understanding how the drying stage works, and then choosing the best dryer for your facility and ware requirements, will go a long way toward ensuring a successful, problem-free manufacturing operation.

Editor's Note
For more information about drying, consider attending the Ceramic Manufacturers Association (CerMA) fall workshop, “Drying, Glazing and Firing.” The workshop will be held in Batavia, N.Y., September 13-14, 2001. For more information, contact CerMA at 1100-H Brandywine Blvd, PO Box 3388, Zanesville, OH 43702-3388; (740) 452-4541; fax (740) 452-2552; or e-mail cerma.info@offinger.com.

SIDEBAR: Understanding Shrinkage
Clay has an affinity for water, i.e., water will "cling" to the clay grain and may be rather difficult to separate from the clay. Not all products contain clay, however, so the study of drying must include insights into how the water leaves the compacted mass of ceramic, as well as how the water leaves the individual clay grains.

When any ceramic is very wet, with or without the presence of clay, the water leaves the surface very easily. As the ceramic becomes drier, the grains of material shrink together to fill the space occupied by that water. It is this shrinkage that brings the danger of damage to the ware during drying. If one side dries more than another and, hence, shrinks more than the other, the piece will either warp or crack. (If the ceramic is made of relatively coarse or non-plastic particles, enough space may exist between grains to allow the water to leave without any appreciable shrinkage.)

As the ceramic continues to dry it finally stops shrinking. However, the “safe point” is not reached until all the ceramic has stopped shrinking, including the inside.

Once all shrinkage has stopped, the temperature can be increased to speed the remaining drying. Adding heat lowers the viscosity of the entrapped water, allowing it to move more freely through the small spaces until the piece is completely dry.

SIDEBAR: Determining Water Content
The amount of water in a piece of ware will affect the success of the drying process. In most cases, the manufacturer's knowledge of the water present in the original body formulation is sufficient to determine the best drying process. However, scientific methods of determining the water content of a ceramic body also exist.

To determine water content using a non-destructive method, weigh the piece at the outset and continue drying until the piece stops losing weight. Subtract the light weight from the heavy weight, and divide by the light weight to determine the percentage of water in the piece at the start of the drying process. This method is cumbersome and generally cannot be used to provide immediate improvements in the production process because of the time required to complete the tests. However, if the dryer being used is sufficiently modern and
repeatable, the final test results can be used to improve the overall drying process.

A faster but destructive method of determining water content involves placing pieces of a known size and weight into a dryer and pulling them out at predetermined intervals. Weigh the pieces, then grind them to a powder and place the powder under a heat lamp mounted on a scale. The scale will indicate the percentage of water present in the powder and therefore in the ceramic body.

**SIDEBAR: More About Conventional Dryers**

Air/airless dryers, infra red dryers, jet dryers, steam dryers, gas-fired dryers and waste heat dryers are all various types of conventional dryers. Each type merely emphasizes one of the three forms of drying (air speed, temperature or humidity) or indicates the energy source (gas, waste heat, steam, etc.).

Other types of "conventional" dryers include vacuum dryers, which use a vacuum in conjunction with a conventional drying system, and dielectric dryers, which are similar to microwave or RF dryers but operate at lower frequencies.

Some manufacturers also use their kilns as dryers; however, this practice is not recommended. A kiln costs a lot more to operate than a dryer and can cause a great deal of product losses due to inefficient/ineffective drying.

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**REFERENCES:**


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**ABOUT THE AUTHOR:**

Cameron Harman Jr. is a kiln expert from Ceramic Services, Inc., Bensalem, Pa. If you have drying or firing questions that you would like to have answered, send them to Cameron Harman Jr., c/o Ceramic Industry, Business News Publishing Co., 755 West Big Beaver Road, Suite 1000, Troy, MI 48084, fax (248) 244-1294; or contact Cameron directly at (215) 245-4040, fax (215) 638-1812. Look for Cameron's answers to your questions in upcoming issues of Ceramic Industry magazine.

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