Radio Frequency Drying of Ceramics and Fiberglass

Radio frequency drying technologies can heat ceramic and fiberglass materials uniformly while reducing drying times.

Combination RF/hot air ceramic mat dryer.

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Radio frequency (RF) heating and drying has been in industrial use since the 1940s, and has been used by the ceramics and fiberglass industries for many years. Ceramic products such as filters and cellular structures, catalytic converter substrates, and ceramic fiber mat and insulation can all be dried using RF energy. In addition, fiberglass strands and rovings are commonly dried in RF ovens.

The drying of ceramics and fiberglass presents many challenges to manufacturers. Long drying times are a common issue, leading to low throughput and high work-in-process costs. Materials with low thermal conductivity are difficult to dry conventionally, as the rate of water removal slows down as the outer surfaces dry. This can lead to thermal stresses and cracking of ceramic parts, or binder and solids migration in fiberglass packages.

The answer is to use RF energy to heat the entire volume of the product uniformly, greatly improving both the drying time and the product quality. Drying times can be reduced from 12 hours to 30 min in the case of some ceramics, and from 24 hours to 90 min for some fiberglass roving packages.

Another challenge can be the high costs of labor and poor energy efficiency associated with conventionally heated batch drying ovens. RF ovens can overcome the batch oven problem by allowing a continuous conveyor system to process product through the oven "tunnel." Parts can be placed on the moving conveyor at any time and proceed through the drying process immediately. Gaps in production are not a problem, as RF ovens run with any load from full to empty.

In addition, since the RF energy only heats the water in the product, there is little wasted heat (i.e., energy) used to heat the oven structure. The RF energy is directly absorbed by the water present in the materials being heated. This also has the beneficial effect of limiting the energy usage to actual water removal.

How It Works

Most people are familiar with the microwave oven as a heating appliance, and RF ovens use the same principles of dielectric heating. Water molecules tend to orient themselves with respect to an external electric field due to their dipolar nature. As the A/C electric field polarity is changed, the water molecules rotate and tend to rub together and cause friction heating directly in the material. This heating effect is uniform throughout the material, assuming the electric field is uniform.

Different materials, and differing moisture contents, result in different heating rates. Areas with higher moisture content tend to heat more than drier areas. This can be a great benefit in moisture leveling. In addition, the process tends to self-regulate, as the amount of heat deposited is reduced as the moisture level is reduced.

The difference between RF energy and microwave is essentially the frequency or wavelength of the energy. Microwaves in heating applications generate energy at either 2,450 MHz (the common home microwave) or at 915 MHz. RF heating systems typically operate at 13.56 MHz, 27.12 MHz, or 40.68 MHz. The formula that relates the frequency of the energy to its wavelength is:

$$\text{wavelength (m)} = \frac{300}{frequency\ (MHz)}$$

At 915 MHz (the most common microwave industrial frequency), the wavelength is 33 cm, and at 27 MHz (the most common RF industrial frequency), the wavelength is 11.1 m. The importance of wavelength is that it's a big factor in determining the maximum physical size of the oven electrode and the size of the materials to be processed. In order to uniformly heat a material, the energy must be applied uniformly. This means that a uniform electric field is required for even heating, which implies that the size of the electrode or oven, as well as the material, needs to be about one-quarter of a wavelength or less in each dimension. This means that a 2-m-wide web of ceramic fiber insulation is best dried by a lower frequency oven than a machine drying small cast ceramic parts. The amount of power (heat) absorbed by a product in a dielectric oven is given by the formula:

$$\text{power} = \text{frequency x loss factor x (electric field intensity)}^2$$

The frequency is the rate of change of the polarity of the electric field between the electrodes. The loss factor is a number that relates the relative absorption of the RF energy. Water has a high loss factor and is heated easily. By comparison, ceramic is low loss and is not heated easily by RF energy. The electric field intensity is simply the applied RF voltage divided by the distance between the electrodes. For a given voltage, the electric field is higher if the electrodes are closer together.

The squared factor plays a big role in the power dissipated into the material. If the voltage is doubled, the power dissipated goes up by a factor of four. If the electric field is too high, arcing through the air will occur. This arcing point is dependent on many factors, including the shapes of the electrodes and the material being heated, the ambient atmosphere, and the dielectric properties of the material.

As is usual in almost every engineering problem, many factors must be considered when designing a dielectric heating process. Trade-offs regarding material size, production rates and moisture content are considered with regard to frequency choice, electric field intensity, and heating rate.

Fiberglass roving dryer.

Combination Technologies

Most dielectric heating processes benefit from a combination of technologies in order to optimize the drying process. In every case where dielectric heating is used for drying, there must be a method to remove the water vapor from the oven. This is usually warm air that carries the water vapor away from the product and eliminates condensation inside the oven. Systems are adjusted to regulate the temperature and humidity of the air, and can optimize the water removal rate while reducing drying stresses and cracks in ceramic parts.

Producers of ceramic fiber products use combination oven lines to dry their products. Typically, hot air convection ovens are used to dry the surface moisture, and RF zones are used to heat the center of the mat and complete the drying process. Mat thickness determines the ratio of conventional drying to RF drying. The thicker products are much easier to dry, and throughputs are much higher with RF drying ovens. Since the ceramic fiber mat is such a good insulator, it is difficult to get any heat into the center of the mat once the surface is dried using convection technology alone.

In glass fiber production, roving spools are easily dried in RF ovens, which use a warm air system to maintain the temperature and humidity level inside the oven while removing the excess moisture. As the water evaporates and moves through the packages in vapor form, the binder solids are not wicked to the outside of the package, resulting in more uniform binder distribution throughout the package and a higher quality product. The use of continuous conveyors from the forming areas through the ovens on to final packaging also reduces the handling of packages, minimizes the chances of damage, and improves productivity and quality.

Bulk ceramic fiber products can be dried in containers that are loaded onto the oven conveyor in a semi-continuous process, with excellent drying uniformity. In addition, ceramic fiber mat, which has been cut into shapes using water jet cutters, can then be dried using continuous RF ovens. This redrying operation is a quick way to process these products with minimal handling and floor space requirements.

Challenges

RF drying technologies face a few challenges with certain products and materials. Conductive materials cannot be processed in RF ovens, as the electric fields are effectively shorted out by the conductivity of the material. Dense ceramics are also difficult to dry, as the water removal rate cannot be too high without developing pressures inside the parts and causing cracks and defects.

Another potential problem is product that has organic solvents. RF heating doesn't work well with organics, and can be a hazard if arcing occurs. Lastly, products with complex shapes can be a challenge to heat uniformly. Non-uniform fields could heat one area and not another, causing stresses and uneven drying.

Proven Success

RF drying technology has a variety of uses in the ceramics and fiberglass industries, and has a proven success record over many years of use. The benefits to RF drying include a significant reduction in drying times, faster line speeds, less floor space usage and easy incorporation with lean manufacturing processes. RF dryers are readily automated into production lines and do not require long warm-up and cool-down times. The RF energy is available almost immediately after powering up.

RF offers a more uniform temperature gradient within the product, as the materials are heated from within. This produces lower thermal stresses in the materials due to uniform temperature throughout the thickness of the product. Since only the water is being effectively heated, the materials are not overheated, and the drying process is self-limiting. Most materials won't overheat when dry, which allows lower temperature drying, reducing unwanted chemical reactions at higher temperatures. Moisture leveling is another benefit of drying with RF, as the energy is attracted to the wettest areas of the product. RF drying provides an efficient, green, and cost-effective method of drying many of today's hard-to-dry ceramic and glass fiber products.

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