Covering the Benefits of RF Heating

Radio-frequency (RF) energy can be used effectively to fabricate materials that are electrical and thermal insulators. Its use increases production speeds, allows greater control, improves product quality, and reduces costs. For years manufacturers of wood, textile, paper, and food products have taken advantage of quick and efficient RF heating. Additional applications such as baking sand cores for casting, drying ceramics, and heat sealing plastics are also well established.

Yet many new opportunities exist for RF heating in plastics. A few examples are:
- Acrylics—skylights, taillight lenses
- Epoxies—primer coatings, electrical laminates
- Melamines—circuit breakers, counter tops
- Polyesters—microwave cookware, boat hulls
- Poly(vinyl chloride) (PVC)—siding, packaging.

Because of improved reliability of RF systems and a greater understanding of appropriate uses of RF technology, manufacturers are rediscovering the benefits of RF heating. Today, they frequently consider RF technology when reevaluating their current production methods.

Advantages

RF heating is ideal for both thermoset plastics, those that cure to a permanent hardened state upon heating, and thermoplastics, those that soften or melt each time they are heated. Because RF energy heats the plastic directly, it offers decided advantages over conventional heating methods, such as infrared or convection ovens with high- or low-velocity hot air.

Quick, uniform heating — The plastic heats quickly to a uniform temperature throughout its thickness. Heating rate increases are determined by the ability of the plastic to absorb RF energy. Plastics such as PVC heat three times faster than by conventional methods, while water may heat up to 24 times faster. Production rate increases are process dependent but may double or triple for thermoplastic extrusion and thermoset molding.

Improved product quality — Exposure to high processing temperatures for long times causes many thermoplastics to lose mechanical and electrical properties. RF heating greatly reduces processing time, so vital properties are retained. Analogously, undercured thermosets may have reduced strength and may be brittle. RF preheating ensures uniform curing.

Increased flexibility — With RF heating, product temperature can be changed instantaneously. Also, the setup of RF heating equipment, with the exception of the electrode con-
Combination with conventional methods — RF heaters can be placed before, after, or inside conventional drying units to speed the process. This topic is discussed in detail in TechCommentary Vol. 4, No. 1.

High energy efficiency — As a measure of energy input to the material versus power supplied to the RF unit, the process is 50 to 70% efficient, compared with a 10 to 30% efficiency achieved by conventional methods.

Space savings — RF heating equipment requires approximately one-third the floor space of conventional heating units.

Applications

The fast, uniform nature of RF heating provides three important applications to plastics: drying, heating, and curing. RF heating is quicker and preserves material properties better than conventional methods. A few of these processes have depended on RF heating for years, while for many others its value is just becoming apparent.

Drying — Water responds to RF energy more quickly than most plastics, so moisture-laden areas heat fast. As the moisture evaporates from the plastic, it distributes evenly throughout the bulk, and drying continues at an even rate until the product is uniformly dry. In this way, RF drying is a self-limiting process.

Manufacturers of polyurethane foam must dry and remove solvents from the finished product. Hot-air dryers are not efficient because polyurethane is a good thermal insulator and heat cannot penetrate it easily. However, RF energy generates heat uniformly in foam slabs 12 or more inches thick. Drying time is decreased by 75%.

Several drying applications are currently under development. An important example is drying poly(ethylene terephthalate), a thermoplastic polyester that must be dried to at least 0.005% before it is molded to maintain its mechanical strength. Traditionally, it is dried for 4 or 5 hours in a dehumidifying hopper dryer. Applying RF energy to the drying process in combination with conventional heating or under a vacuum decreases the water content to a few parts per million in a few minutes.

Many plastics that are sensitive to water would benefit by high-speed drying with RF energy.

Heating — RF heating is not self-limiting as is drying. The plastic continues to generate heat as long as it is exposed to RF energy. The expense and good thermal properties of many thermoset compounds make them especially good candidate materials for RF heating.

Compression molding preforms that are not preheated risks nonuniform curing in the mold. Uneven curing gives the final product poor strength and a poor surface appearance and breeds high rejection rates. RF preheating uniformly and quickly heats the preforms, ensuring a uniform cure in the mold. In the semiautomatic molding of general purpose phenolics with a final cross section of 0.25 in., the preforms are RF heated to 225 to 250 F. RF preheating decreases the press cycle time from 120 to 45 seconds, increasing press output by over 60%. The final product has improved tensile strength, impact strength, dielectric properties, and surface appearance, resulting in a higher quality end product and fewer rejects.

The most common application of RF heating to thermoplastics is sealing PVC film, although it is used for sealing other plastics such as acetate, polyester, polyurethane, and acrylic films when strong, uniform bonds are required. Rainwear, inflatable objects, packages, leatherwear, automobile upholstery, furniture, and shoes use RF heating to achieve fast sealing at a high production rate. Plastics can
sometimes be RF sealed to other materials. For instance, automobile door panels are manufactured in three layers: hardboard, polyurethane foam, and PVC film. The assembly is RF laminated.

A heating application expected to become commercial in late 1988 is the addition of an RF unit before the extrusion or molding process to heat a thermoplastic to just below melting temperaturc. The heating unit replaces the hopper before the extruder or molding machine, and the plastic is conveyed or dropped through the heater. Several benefits are derived from this: (1) residual solvents and byproducts in the plastic are reduced, which improves final properties; (2) the production rate can double; (3) the horsepower needed to drive the extruder or molding machine screw is reduced by 30 to 40%.

Curing — Thermoets react under heat and pressure to form a hardened, cross-linked plastic. RF heating speeds up the curing process because heat is generated within the plastic, promoting the cross-linking reaction.

Pultrusion is a process for making profiles, such as rods and tubing, of glass fibers impregnated with polyester or epoxy resins. Pultrusions are used in coupling motors at the surface to oil well pumps deep underground. Traditionally, a typical 1-in. diameter glass rod is drawn continuously, pulled through a resin tank, and squeezed against rollers to remove excess resin. The resin is cured in a convection oven at 300 F or higher at 6 in. per minute. RF heating has helped change the pultrusion process. Now, the same 1-in-diameter rod can be RF pre-heated to 150 to 200 F and reduced to final diameter in an augmented heated die tube at a rate of 6 feet per minute, 12 times faster.

Latex coatings, backings for carpet and other textiles, are applied as liquids with a water base. Heating the coating drives off the water and cures the latex. Curing at 325 to 350 F in long convection ovens is time consuming and energy intensive. RF heating cures the coating in seconds at 215 to 220 F.

**Technical Considerations**

Each potential application should be evaluated carefully to determine if RF heating is the most appropriate technology. The following conditions can help with such an analysis:

**Material characteristics** — Most plastics will absorb RF energy, but some do not absorb a sufficient amount to heat to the necessary temperature. For example, while PVC absorbs RF energy quickly, Teflon® does not heat at all. The loss factor is a measure of a material's ability to absorb RF energy. Its value depends on the material's temperature, the frequency applied, and the voltage supplied to the work electrodes. In general, a loss factor between 0.02 and 1 indicates that the material heats at an appropriate rate under RF energy. But some plastics with loss factors too low at room temperature or 1 MHz can become susceptible to RF energy at 100 F or 100 MHz. Also, dielectric sensitizers are commonly formulated into a plastic to increase its ability to heat with RF energy. So even if a plastic appears to be a poor candidate for RF heating because its published loss factor is too low, RF heating may work under certain conditions.

**Power requirement** — The heating rate of the plastic is also determined by the power of the RF energy applied. Specific power needs for an application are calculated and confirmed with equipment tests based on the properties of the plastic being heated, the throughput, and the initial and final temperatures. Power levels are precisely controlled and adjusted with solid-state devices and high-voltage switches. Equipment power ratings range from 0.5 kW for sealing applications to 100 kW for heating and curing.

**Frequency/geometry** — Although the typical radio-frequency range is 2 to 200 MHz, the optimum frequency for a particular installation depends upon the material's loss factor and dimensions. Large objects, boards 5 feet wide by 60 feet long, and those with high loss factors require frequencies as low as 2 MHz. Small objects, 0.5 in. wide by 3 in. long, with low loss factors require frequencies up to about 100 MHz. RF heating works best for regular-shaped objects, large objects, and webs. Objects with many curves and edges or with uneven thicknesses heat nonuniformly.

**Electrode configuration** — Electrodes produce the high-frequency alternating electric field that heats the plastic. The shape of the electric field is affected by the shape and location of the electrodes, the shape of the work piece, and the air space between the electrodes and plastic. The plastic's heating rate is often adjusted by changing the distance of the electrodes from the plastic. An equipment supplier, experienced with many applications, will provide useful suggestions for a particular installation. Most applications use one of three basic types of electrodes: Parallel plate electrodes consist of two flat plates between which the plastic is placed. Loads 1 or 2 in. thick typically heat most effectively in these electrodes. Staggered field electrodes are a series of rods in the same plane, parallel to the product, with successive electrodes having opposite charges. Electric fields are thus set up between each pair of rods. This type of electrode is most effective in processing films or coatings with a thickness variation of a few millimeters. Staggered field electrodes are a series of staggered rods mounted above and below the material. The electric field is directed diagonally through the load. Staggered field electrodes usually heat loads of nonuniform thickness.

**Economic Considerations**

A thorough economic analysis is necessary to justify any major process changes. The following economic considerations will help determine whether RF heating might be cost effective for potential applications.

**Capital costs** — RF heating systems, including power supply, oscillator, applicator, controls, and shielding, currently cost between $1000 and $4000 per kilowatt of
power output, which is three to six times the cost of a convection oven or dryer. Higher power units cost less per kilowatt, while lower power units cost more.

**Operating costs** — Oscillator tube replacement is the major maintenance expense. Costs range from $200 for a 0.5-kW output machine to $10,000 for a 100-kW output machine. Labor costs are comparable to those for conventional heating processes. Energy costs will probably be equivalent with conventional ovens.

**Specific applications benefits** — If the heating or drying process limits the production line speed or if lack of space prevents production output increases, RF heating may produce significant savings. Production rates increase, and product quality usually improves. RF heating may convert a batch process to a continuous one or make possible a process that could not be achieved in any other way. These savings may offset the relatively high capital costs for some potential applications.

**In Conclusion**

RF heating technology, although mature, has been underutilized to date. Improvements in RF heating equipment and careful consideration of its appropriate uses have renewed interest in the field. Combinations of RF heating with conventional methods have a potential for dramatic growth in the next decade, as manufacturers realize that RF heating boosters for their current systems lead to energy savings and improved drying or heating abilities. In the next 3 to 5 years developments under way by manufacturers and industrial users will lead to successful installations in several new areas:

- RF heating in seconds of reinforced thermoplastic sheet for thermosetting into automotive parts
- RF preheating of sheet molding compounds
- RF heating for blow molding containers for packaging
- RF sealing in a variety of packaging applications.

The information contained in this *TechCommentary* is intended to give you a basic understanding of RF heating. A more detailed report of dielectric heating and its general uses is discussed in *TechCommentary* Vol. 4, No. 1. For help with specific applications, talk to your electric utility marketing representative or an equipment supplier.