

## Microwaves In High-Temperature Processes

Holly S. Shulman, Ceralink Inc., Alfred, N.Y.

The use of microwaves is making inroads into many high-temperature processes, such as firing ceramics, heat treating and melting. Because of the wide variety of microwave technologies to choose from, it can be helpful to use an independent microwave testing facility to ensure that you get the best value from microwave heating.

Microwaves are used in laboratories worldwide for drying, calcination, binder removal, glass melting and sintering of ceramics and powdered metals. Microwave drying of materials is an industrial reality, but high-temperature processing in the range of 1000 to 2200 C (1830 to 3990 F) is only recently finding its way into commercial products.

Using microwaves for firing or sintering ceramics, metals, and glass can provide both energy and time savings and improved products. Some examples of the industries moving into microwave heating technology (>1000 C) include heat treatment and annealing of ceramics and metals and firing electroceramics, carbide hard-metal wear parts and bioceramics.

An advantage of microwave heating is that the entire part couples in the energy field, directly absorbing energy throughout the volume. In microwave firing, heating rates from 100 to 150 C/min (180 to

270 F/min) can be used to fully sinter ceramics without cracking. Cooling also is fast because the refractories do not become as hot as in conventional firing. This translates to significant savings in time. For example, a heating process that requires 24 hours typically can be reduced to 6 hours.

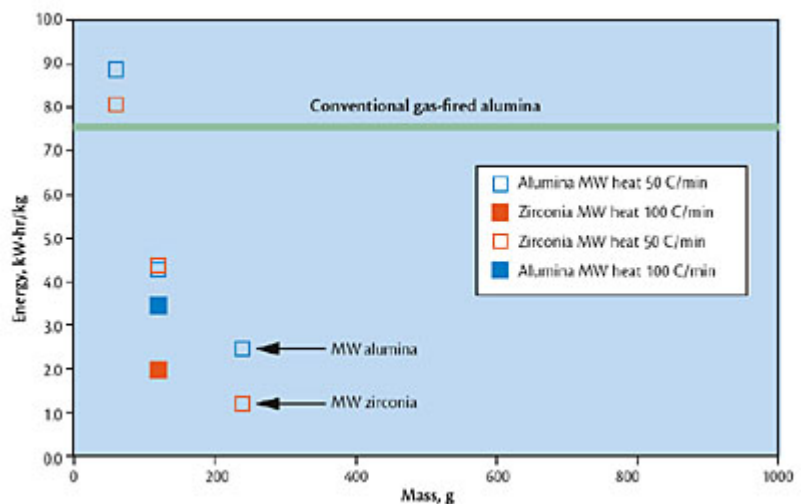
It also has been demonstrated that diffusion is accelerated or enhanced in a microwave field. This means that densification, reactions, bonding, etc., can occur at lower temperatures than those expected using conventional heating. This is significant for many reasons, especially the opportunity to use less expensive, lower temperature rated refractories. Significant savings in materials are possible since refractories will be cooler than in conventional firing because they do not absorb microwave energy and the parts can be fired at lower temperatures.

### Energy savings

There have been conflicting reports concerning energy consumption using microwaves. In general, it is agreed that an energy savings will be achieved, ranging from 10 to 90% higher efficiency compared with that of conventional electric or gas heating. Some of the confusion is due to the lower efficiency of microwave use with research-size loads.

As shown in Fig. 1, efficiency depends on the material being fired:

- Microwaves are more efficient than gas firing for large enough loads
- Microwave energy use becomes more efficient for larger loads
- Higher microwave heating rates are more efficient
- Less energy is required to heat zirconia than to heat alumina



## Overcoming barriers to microwave heating

Microwaves allow fast heating, but may develop an inverse temperature profile in the material. This means that the part is much hotter than the surrounding atmosphere, so it will cool from the surface through radiation. This is called an "inverse profile" relative to the conditions in conventional heating where the surface is hotter than the core.

Microwave heating also can produce hot spots or "thermal runaway." This occurs when one section of the material absorbs the microwave energy preferentially over the bulk material. These problems can be overcome with proper furnace design and attention to the thermal package.

Manufacturers are moving toward microwave technology as two major barriers are being overcome. These barriers are: 1) the need for standardized microwave furnaces, and 2) the need for inexpensive feasibility studies and experienced help with microwave scale-up. Several companies are rising to the challenge and providing equipment suitable for scale-up and industrial microwave firing. University researchers, microwave manufacturers, and independent microwave testing facilities can be used to develop process know-how and for assistance with scale-up challenges.

Universities typically perform well in basic research, but are not focused on scale-up problems, and generally have a slow response time by industry standards. Microwave furnace manufacturers have an obvious vested interest in the success of microwave feasibility, and, therefore, can be innovative and helpful. However, the customer may not get the best value equipment for their needs. An independent microwave testing facility can offer an effective solution. For example, Ceralink Inc.'s Microwave Testing Center provides proof of concept and assists in product scale-up, including advice on furnace design and selection of an appropriate microwave manufacturer.

## Commercial microwave furnaces

Several companies offer standard microwave furnaces, and many companies design and build microwave systems to meet their client's specifications. Table 1 lists companies that offer standard systems having a range of prices and capabilities. Prices range from US \$7,000 to \$300,000 depending on the power and frequency needed.

The most inexpensive and common microwave frequency used for heating is 2.45 GHz, the same frequency used in microwave cooking of food. Susceptors often are used to start the heating and to prevent thermal runaway in difficult-to-heat materials, such as many ceramics. Susceptors are materials (usually semiconductors) such as silicon carbide (SiC), which heat easily from room temperature in the 2.45-GHz microwave range. Ceramics begin to heat "normally" by radiation first, and then are able to absorb microwaves and heat volumetrically. Table 2 provides a summary of the different approaches to the use of microwaves for high-temperature materials processing.

**Table 1 Specifications for commercially available microwave furnaces**

Company	Location	Frequency, GHz
C-Tech Innovations (formally EA Tech)	UK	2.45 + gas/electric
Communications and Power Industries (CPI)	USA	2.45, 18, 28
Dennis Tool Company	USA	2.45
Fuji Denpa	Japan	28
Gycom	Russia	30
Linn High Therm	Germany	2.45, 5.8
Research Microwave Systems (RMS)	USA	2.45

*These furnaces do not require design input from the customer*

**Table 2: Approaches to Microwave Processing**

Method	Advantages	Disadvantages
2.45 GHz Low-power magnetrons	Inexpensive	Susceptors often needed
2.45 GHz High-power magnetrons	Good for large systems	Medium expense Susceptors often needed
5.8 GHz	Improved uniformity	Not tested
Hybrid 2.45 + 5.8 GHz	Improved uniformity	Not tested
Hybrid 2.45 + gas or electric	Most energy efficient No susceptors Retrofit capability	Availability
18, 24, 28, 30 GHz	Best field uniformity No susceptors	Expensive

An inexpensive system that uses low-power 2.45-GHz magnetrons is Research Microwave Systems' ThermWAVE ([www.thermwave.com](http://www.thermwave.com)) shown in Fig. 2. This water-cooled microwave is a useful tool to explore a process. The system includes a controller and accessories, such as a casket and susceptors. The ThermWAVE package opens the door for many companies who don't have time to develop their own system. It can be used to process many types of materials including organics and inorganics, in processes such as drying, chemical reactions, annealing, and firing. Research Microwave Systems also provides accessories, such as crucibles, refractories and susceptors, for other microwave systems.

The Communications and Power Industries (CPI) Autowave ([www.autowave.tv](http://www.autowave.tv)) system uses high-power magnetrons, and can be fitted with a klystron (18 GHz) or gyrotron (28 GHz). The Autowave has two chamber sizes; the larger chamber is shown in Fig. 3. CPI provides an Acceptance Package to demonstrate that the Autowave can be used to reproducibly fire a ceramic. The system is versatile, can be used for research, scale-up, and/or production, but it is relatively expensive for initial feasibility studies. The chamber is not lined with refractory insulation, but instead, microwave transparent refractory containers or caskets are used inside the chamber. This increases the versatility and reduces power requirements for small-scale tests.

An example of a commercial system that uses only 2.45-GHz magnetrons is the Dennis Tool Co. (Houston, Texas) system (Fig. 4), developed in cooperation with Penn State University. The system is sold as a complete package including the materials-process technology. The focus has been on carbide (hard metal) manufacturing, and the process is in the final stage of scale-up at a cutting-tool company. In scale up, it was found that processing smaller loads produced a more uniform, superior product. However, even larger loads still are superior to conventionally fired tungsten carbides.

Linn High Therm ([www.linn.de](http://www.linn.de)) makes a laboratory size 2.45-GHz microwave sintering furnace, which has been available for about ten years. Linn's recent innovation is the development and inexpensive manufacture of 5.8-GHz magnetrons, an industrial frequency that has not been explored for high-temperature processing of materials. There is potential for increased energy-field uniformity, especially when combined with 2.45 GHz, and the possibility of heating more materials from room temperature without susceptors.

Linn High Therm also developed an efficient, modular continual-microwave drying system using a circular distribution of low-power magnetrons. It would be of interest to see this system modified for high-temperature processing.

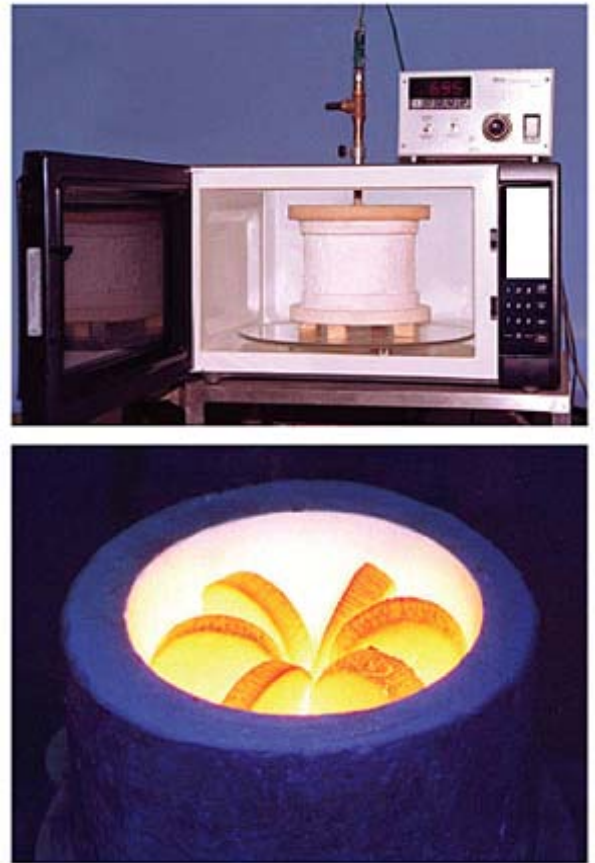


Fig 2 Research Microwave Systems ThermWAVE 2.45 GHz, 1300 W (top) and processing parts (bottom)



Fig 3 The CPI Autowave station can be fitted with different frequencies (2.45, 18 and 28 GHz) and power levels.

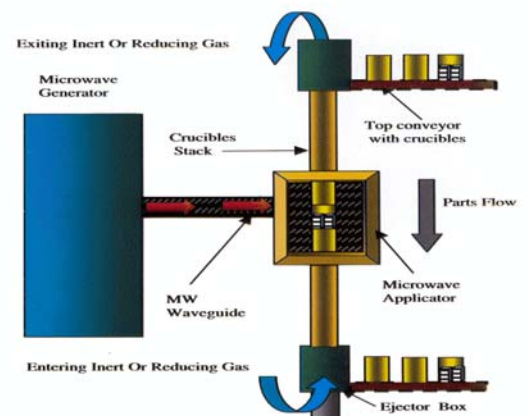


Fig 4 Dennis Tool Co. Stoke-Type microwave furnace

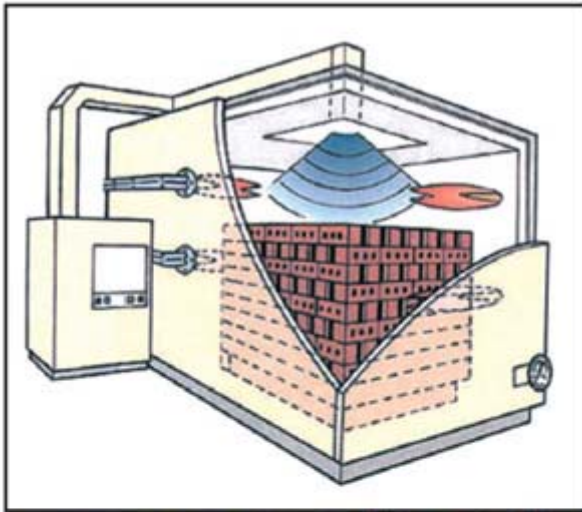


Fig 5 C-Tech Innovations (formerly EA Technologies) gas-assisted microwave firing systems; period kiln (top) and tunnel kiln (bottom)

Another hybrid system was developed at EA Technologies, now owned by C-Tech Innovations ([www.capenhurst.com](http://www.capenhurst.com)), which uses a combination of microwaves and gas or electric heating (Fig. 5). Advantages of this system include even heating, energy efficiency, and the capability to retrofit magnetrons to existing furnaces. The method has been tested, and initial scale up has been performed for many ceramic materials. The technology recently was licensed to a Japanese kiln manufacturer. Its availability in Europe and the U.S. still is an issue for the utilization of this technology. Ceralink is assisting C-Tech Innovations in licensing this technology to U.S. furnace manufacturers so microwave-assisted gas and electric furnaces will be manufactured in the U.S. (Contact Ceralink for more information.)

### Conclusions

Microwaves are finding their place in many high-temperature processes, such as heat treating, annealing, and firing. Feasibility, or proof of concept, is an important first stage that can be performed in house using a "homemade" or commercial microwave system, or it can be outsourced, e.g., to a university or microwave testing center.

Standardized microwave systems are useful for research, development, and initial scale-up. These systems save time over the "do-it-yourself" method of developing a microwave furnace. Many materials manufacturers eventually will need to have microwave furnaces custom built. Hiring a consultant to assist in the design of the microwave furnace and selection of microwave manufacturer can ensure that the most appropriate technology is used to get the best value from microwave heating.

For more information: Dr. Holly S. Shulman, president, Ceralink Inc., 200 North Main St., Alfred, NY 14802; tel: 607-587-9816; e-mail: [holly@ceralink.com](mailto:holly@ceralink.com); or Patricia M. Strickland, business manager; tel: 607-587-9816; e-mail: [patricia@ceralink.com](mailto:patricia@ceralink.com); Internet: [www.ceralink.com](http://www.ceralink.com).

Ceralink Inc. was founded in January 2000 by Dr. Holly Shulman to assist with locating and implementing important technologies that will bring **measurable short and medium term growth**. Ceralink works with inventors, investors, manufacturers, universities and government laboratories to bring new advancements to commercialization. Ceralink offers research capabilities, consulting experience and technical know-how with an understanding of business and human factors.

A unique function we call "Ceralinking", adds a new dimension to technology transfer, to get technologies off the ground (or shelf) and into the appropriate market place. Please visit our website ([www.ceralink.com](http://www.ceralink.com)) to learn more about us. We are interested in your industrial needs for new technologies. We are always looking for new innovations and products that need our service. Please contact us with your questions and comments.

Copyright 2003 Business News Publishing Co. Displayed by permission. All rights reserved. Obtain additional permission by typing <http://www.icopyright.com/3.5243.459948> into any browser. iCopyright Clearance License 3.5243.459948-121.