# Microwave Drying of Refractory Materials

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**Abstract**

Microwave heating is known for several decades but its industrial use is limited to some very specific applications (rubber, wood, chemicals, food). As heating and drying with microwaves shows several substantial benefits, the technology has a high potential which is still unrealized.

The advantages of microwave heating and drying technology for refractory materials are:
- fast and even heating
- acceleration of drying
- and the resulting reduction of the drying time.

Additionally, material defects caused by overly fast drying (i.e. microcracks) can be reduced or even avoided entirely.

Linn High Therm offers a wide range of newly developed microwave dryers, both as continuous and chamber systems. These dryers are well suited for drying shaped refractory materials and green bodies.

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## 1 The Principle of Microwave Drying

Microwaves are electromagnetic waves, just as cellular phone or radar waves. They are governed by the same physical principles as these waves, and therefore can be reflected, transmitted, or absorbed by the material they interact with. Most ceramic/refractory materials belong to the group of microwave absorbing materials. The absorbed microwave energy is converted into heat in the whole volume of the material, hence the temperature of the material increases homogeneously. Microwaves heat the material itself, along with any water remaining. In fact, the water does absorb the microwave energy better than most refractory materials. The water is therefore primarily heated in a wet material. This effect makes microwave heating especially suitable for drying purposes. Microwaves can penetrate all materials, as long as they are not reflected by them. This allows the material to be heated in its complete volume, including the centre. The penetration depth depends on the specific material properties. For most ceramic/refractory materials it is so deep that the refractory products can be completely penetrated by the microwaves, resulting in a simultaneous heating of the inside and the outside. Theoretically, this generates a nearly even temperature profile inside the material with the same temperature at every point. But the surface radiates heat to the ambient, and is consequently cooled. The interior cannot radiate heat to the ambient and therefore has a slightly higher temperature than the surface. This results in an effective temperature profile that is inverse to the one obtained by conventional heating due to thermal conductivity (i.e. surface hottest, inside coldest). For products sensitive to drying cracks, the microwave chamber can be insulated and heated by conventional methods, e.g. hot air, to prevent the cooling of the surface. This measure allows an even temperature profile inside the material. This process is called microwave hybrid or microwave assisted heating. It can also be used for the debindering of injection moulded ceramics/refractories (Fig. 1). The debindering time can be dramatically reduced with such a system. A newly developed method is multi-frequency microwave heating. The concept is based on the use of microwaves with two or three different frequencies simultaneously to heat the material. This system generates a high microwave field strength inside the chamber without risking inhomogeneities in the field. Thus materials can be heated even faster than with single-frequency microwaves but with the same homogeneity.

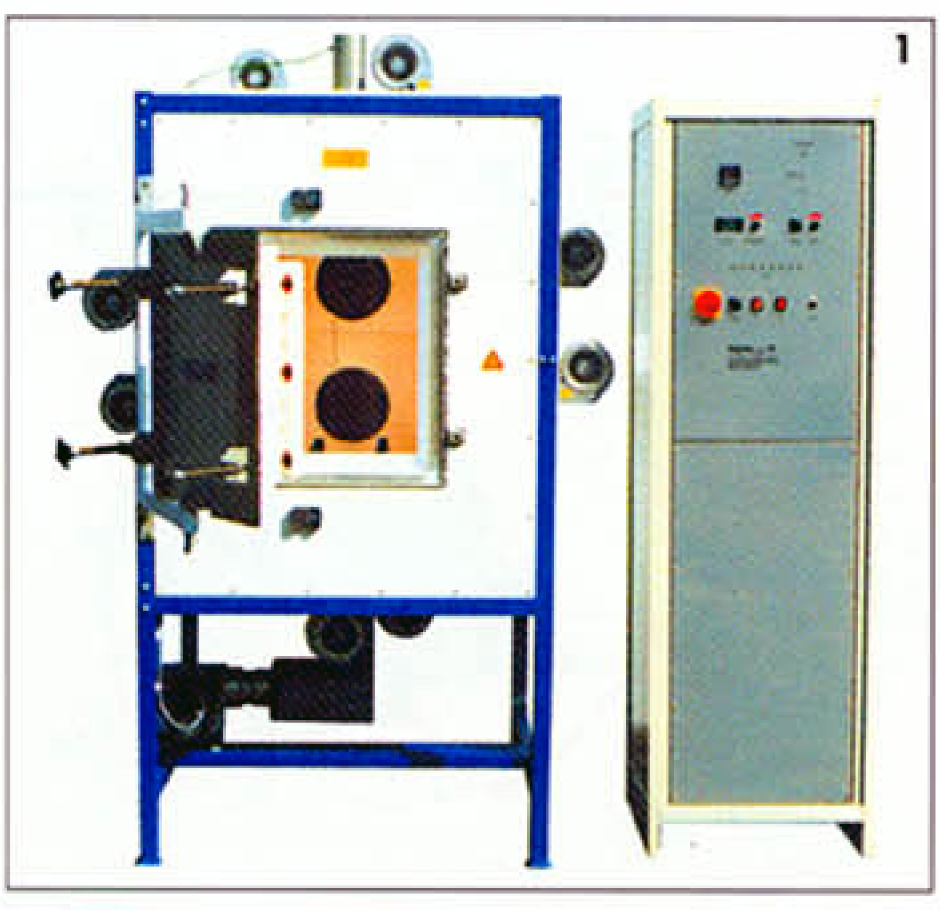

Fig. 1 Microwave hybrid chamber dryer de-bindering furnace, 600 °C

## 2 The Advantages of Microwave Drying

### 2.1 Fast Heating

Heat is generated inside the material, hence it is not necessary to wait until the heat is conducted from the surface to the inside.

### 2.2 Heating of Materials with Low Thermal Conductivity

There is no need to conduct the heat from the surface to the inside, since it is generated inside. Materials with a low heat conductivity can be easily heated and dried.

### 2.3 Fast Drying

Due to the inverse temperature profile created by the microwaves, the drying is considerably faster compared to conventional drying. On the inside of the material, the water temperature quickly increases to the boiling point, even for water that is contained in capillaries and thus has a higher boiling temperature than free water. The water pressure inside the material increases and forces the water to the outside. The surface is kept relatively cold by losing heat to the ambient and the evaporation of water. Since the water is pressing from the inside, there is no danger for the pores near the surface to dry out and close before the water from the inside is removed.

### 2.4 Minimized Loss of Stored Heat

The dryer casing and the air inside the microwave chamber are not heated, so nearly no heat is lost to the ambient.



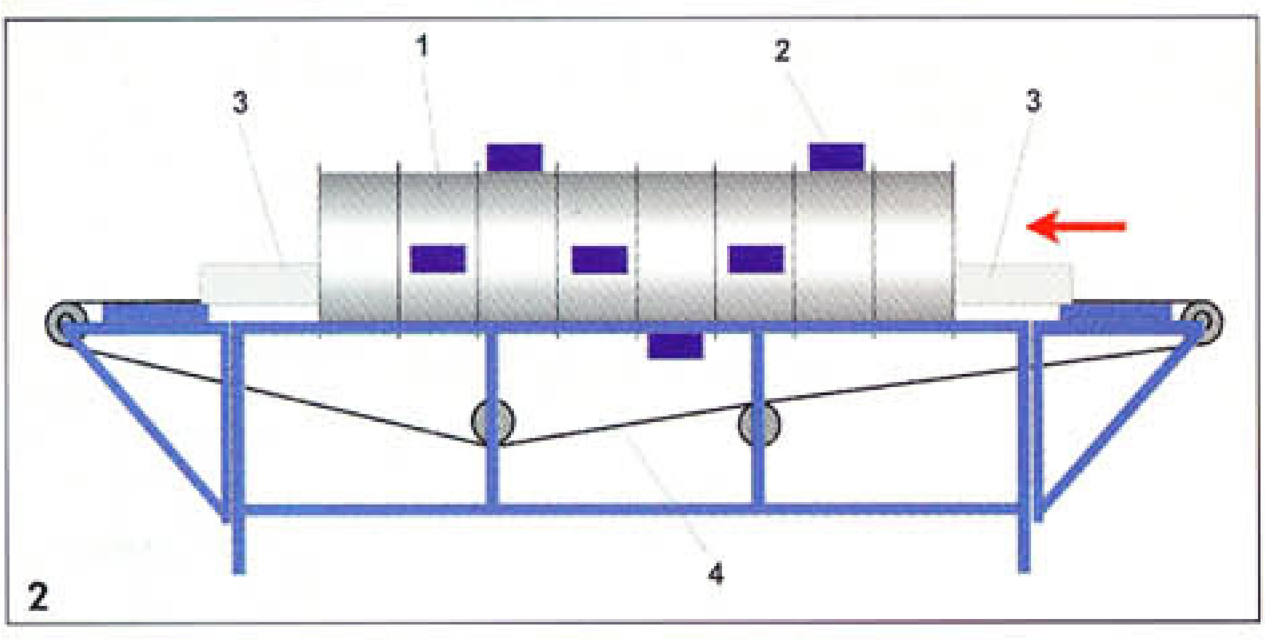


Fig. 2 Concept of a continuous microwave dryer

Fig. 3 Continuous microwave dryer for building materials

### 2.5 Delay-Free Control and Flexibility

The microwave power and the generated heat can be continuously controlled and measured by optical pyrometers or fibre pyrometers, depending on the process parameters.

### 2.6 No Heat-Up Phase of the Furnace

After switching on the microwave, energy is immediately available. It is not necessary to heat up the dryer before starting production. After switching off the microwave, no further heat is generated, the dryer does not need to cool down.

## 3 Application of Microwave Drying

Microwave drying is most effectively used for materials that are difficult to dry with conventional methods. For example materials that have a very low green strength or porosity easily crack if the conventional drying process for it is too fast. With microwaves, the drying time for these materials can be reduced without risking cracks or other defects to the product. For example shaped parts of low-cement or cement-free castables have a low toughness before the sintering process. Even comparatively large bodies of these materials can be dried with microwaves due to the high penetration depth of the electromagnetic waves. The drying of these castables is much faster than with conventional means, but of course still substantially longer compared to microwave dried castables with a high cement content. Microwave heating has come a long way, but cannot negate the laws of physics.

## 4 Basic Design of a Microwave Dryer

The basic part of every microwave dryer is the microwave chamber (1). In Fig. 2, the microwave chamber is cylindrical with openings/channels at both end Connected to the microwave chamber are the microwav generators (magnetrons) (2). In this case the microwav energy is conducted from the magnetron through waveguide (not shown in the picture) fixed to th microwave chamber. The microwave dryer is equippe with several magnetrons (one each under the hoods show in the picture) which are fitted in a spiral around th microwave chamber. This configuration ensures an eve distribution of the microwave field inside the chambe an effect not achievable with traditional microwave drye available on the market. The microwave chamber is close on both ends by channels (3), which are equipped wi specially designed microwave absorbing material reduce microwave leakage the allowed 5 mW/cm² the outside. The heated material is transported on microwave transparent conveyor belt (4) through the ove The belt is also air permeable, the material can dry eve from below. Microwaves can reach the material also fro below because of secondary radiator equipped plat on the bottom of the belt. An innovative design, th hole-structured plates allow the microwaves to mo through them without losing energy. This concept drawi of a microwave continuous dryer has only fe magnetrons, to show the basic design of such a syste Production scale units have longer microwave chambe and more magnetrons for a higher microwave pow for example up to 30 m and 200 kW (Fig. 3).

**References**

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