Drying and Heating of Bulk Materials by Microwaves

Microwave heating is known for several decades now, but its industrial use is limited to a few areas only. Heating and drying with microwaves shows several substantial benefits, e.g. fast and homogeneous heating, an optimisation of the drying process, and consequently the reduction of the drying time. This technology has a high potential which was insufficiently exploited until now.

Linn High Therm GmbH designed a microwave belt drying system, which is suitable for heating and drying of bulk materials. The system allows a fast, homogeneous and effective processing.

Drying and heating processes are necessary during the production of many materials. Quite often, such drying processes take relatively long time, and are a limiting factor, if the production capacity needs to be increased and/or production time reduced. In many cases the conventional heating technology sets a limit, as the homogeneous heating of the product restricts the heating- respective drying speed. Special products with a low heat conductivity and procedures where rather thick layers of a material are to be heated homogeneously, need a lot of time with conventional methods.

The technology to improve such processes is microwave heating. This technology is known for decades and is successfully applied in the industry. It was discovered by a radar technician who had accidentally left his lunch in the radiation field of the radar transmitter.

Before the physical principle of the microwave technology is discussed, we should look briefly at the conventional heating process. Typical heat sources are gas- or oil burners, resistance or infrared heating elements, all of which are located in the proximity of the material to be heated. The energy is applied to the surface of the material by radiation and convection and must penetrate from there to the inner layers in order to achieve an uniform heating of the material. The heating process is mainly determined by the thermal conductivity and heat resistance of the material.

Sensitive materials will often not allow high temperatures, and, if the material has poor thermal conductivity, a time consuming heating process is unavoidable, so that conventional heating is subject to strict limitations in the manufacturing process of many products.

Microwaves are electromagnetic waves similar to those used in radio, television and radar technology. Differences are in the frequency range and in the power density. The frequency range 88-108 MHz is used, for example, for VHF radio. GSM phones utilize a higher frequency band, e.g 1800 MHz (in Europe), whereby the power output is about 2 Watts.

There are three main frequencies available for microwave technology, which may vary according to the regulations in different countries. The highest frequency is 28 and 30 GHz, resp., whereby low-cost industrial application does not yet appear on a large scale. For the time being microwave generators for these frequencies are very expensive and sensitive. This is also valid for the low frequency of 915 MHz. The "least-expensive" frequency is 2,45 GHz which is already used worldwide in millions of household microwave ovens. Almost everyone uses this technology, without knowing how the heating process actually works.

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The conversion of electromagnetic energy into thermal energy is realized utilizing the electromagnetic characteristics of the materials. It depends principally on the material, temperature and microwave frequency. Generally, only a single frequency is used for the heating process, and, furthermore, the temperature dependency of the material characteristics is not known. Therefore an observation can only be carried out in terms of the material itself.

Whether a material can be heated by microwaves or not depends on its molecular structure. Polar (i.e. asymmetrical) molecules as, e.g. water, can be well heated with microwaves. Excited through the high frequent alteration of the microwaves, the polar molecule starts oscillating and, thus, converts the electromagnetic energy into heat. As every molecule generates heat and the microwaves penetrate deep into the material (depending on material), all the volume is heated. This is an essential advantage against conventional heating, where heat is penetrating into the material through the surface only.

It is obvious that a high heat conductivity is not necessarily needed for microwave heating as it is a volumetric heating. This process is described through the equation shown below, which is valid for non-magnetic materials only [1]:

$$P = 2 \cdot \pi \cdot f \cdot \varepsilon_0 \cdot \varepsilon'' \cdot E^2 \cdot V \qquad (1)$$

where P: power taken up by the material
f: frequency of the microwaves
ε_0: electrical field constant
ε'': imaginary part of the complex dielectric constant
E: electrical fieldstrength
V: material volume

During volumetric heating, every volume element receives the same amount of heat, provided the material layer is thin compared to the penetration depth of the microwaves. For homogeneous materials this means that first the body has the same temperature everywhere. As the surface of the material is in contact with the environment which is not heated up by the microwaves, the surface gives heat to the ambient atmosphere and is cooled this way. This results in the fact that with microwave heating, the inside of a material is hotter than the surface. Thus the temperature profile is inverse to that for conventional heating. This effect is desirable in many cases, as the surface is protected and the heat can be built up more quickly in the inside.

Fig. 1: Microwave continuous belt furnace. Microwave power 60 kW, length 15 m

Fig. 2: Microwave continuous belt furnace. Microwave power 55 kW, length 20 m

Microwaves travel at the velocity of light. As soon as the microwave source is switched on, energy penetrates into the body to be heated. The energy conversion immediately starts. When the source is switched off, the heating process is immediately stopped. Therefore long heating up and cooling down cycles are not necessary with a microwave heating system.

Non-polar materials, (e.g. air, Teflon, quartz glass) cannot convert microwave energy into heat and therefore do not consume any energy. The microwaves pass through these materials and are not weakened. The material which can do the energy conversion, may be described as "heating element", as the material itself represents the "heat source". The metallic microwave chamber is only needed to reflect the microwaves back to the material, in order to prevent microwave leakage and prevent the operator from exposure to microwave radiation.

The inverse temperature profile is an advantage of microwave drying, as a high pressure is built up inside the material pushing the water to the surface where it vaporizes, keeping the surface constantly wet, until almost all the water from the inside is removed. Thereafter the surface also starts to dry. Normally, the water takes up the biggest part of the microwave energy, a lower energy conversion takes place in the parts of the material that are already nearly dry. At these places microwaves can penetrate deeper into the material and can be used at other places which are still more wet. So an effective drying with elimination of all water residues is possible.

Basically, different processes are possible, due to the varying energy consumption of the materials to be dried. At a humidity content greater than 15 % an essential difference does not exist. Here the water determines the process run solely. In the range of 5% - 15% the dry material can play an increasingly important role. If the material itself is able to convert microwave energy into heat, the temperature of the material can rise, whereby the material's dielectric coefficient determines the process.

Below 5% microwave drying may become ineffective with decreasing humidity contents, when the material itself cannot be heated up by microwaves, due to its dielectric characteristics. For dry materials or materials with low humidity, the coupling behavior of the dry material is important for the heating process.

A rule of thumb may be applied to microwave drying to determine the required microwave power: For vaporization of 1 kg water per hour a microwave power of approx. 1 kW is required. This rule is valid as long as a sufficient humidity is available at the beginning of the process.

Microwave belt drying systems are used for heating and/or drying of bulk materials. The conveyor belt consists of microwave transparent material, and so the microwave can pass the belt without losses and heat up the material also from the bottom side.

The height of bed of the material should be at least approx. 5 cm in order to have a sufficient material volume available to take up the microwave energy. As the microwave heating is a volumetric heating, more microwave energy can be taken up with increasing material volume.

The maximum height of the material bed is limited by the penetration depth of the microwaves. The penetration depth is approx. 5-10 cm for most materials; as the microwaves penetrate into the bulk from all sides, a height of the bed of approx.10-20 cm can be heated without problems. In case of drying, there is another limitation of the material bed height due to the fact that humidity inside the bulk has to be led to the surface (the bulk density is an important factor). In case of large heights of the bed, the drying time can be extended as the material represents a higher resistance against the flow of the vapor.

The microwave belt driers of the *MDBT* series can be applied for the drying, resp. heating, of bulk materials (see Figs. 1-3). A modular design was chosen and, therefore power and flowrate can be extended at any time without problems. The microwave generators (magnetrons) are arranged in a spiral around the longitudinal axis of the cylindrical chamber to achieve a more uniform field distribution.

The conveyor belt is led over bottom plates which are equipped with secondary radiators (slot antennas) releasing a further field influence (field concentration). The inlets / outlets are lined with a special absorber material in order to stay within the allowed maximum leakage limitation values. Depending on the size of the opening, additional absorber zones will be integrated to effect a further reduction. The magnetrons used are air-cooled, whereby the heated cooling air flows into the heating zone and takes up humidity. Thereafter the humid air is drawn out of the drier by a suction system. These microwave belt driers can be equipped with a microwave power up to 100 kW.

Microwave rotary tube systems can be used as special systems for the heating of bulk materials.

Applying these systems the microwave energy is submitted from outside through the microwave transparent rotary tube. Due to the rotary tube made of quartz glass or ceramic the length and the diameter of these units are limited.

References

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[2] Suhm, J.: Mikrowellentechnik zur schonenden Trocknung keramischer Materialien, Keramische Zeitschrift, Vol. 52 (2000) Nr. 8.

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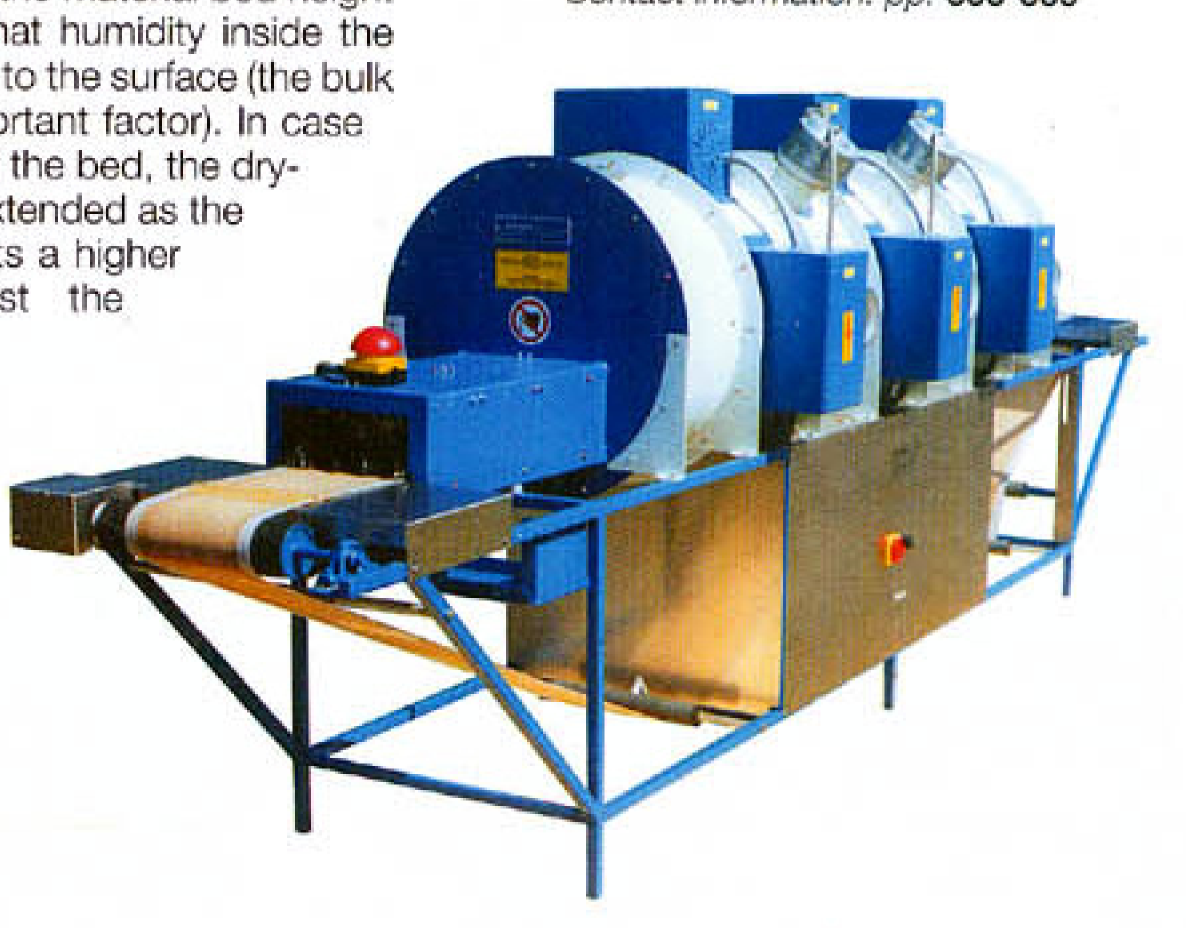

Fig. 3: Microwave continuous belt furnace. Mobile test unit, power 8 kW, length 4,5 m