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MARKOM MICROWAVES

EFFICIENCY OF MICROWAVE DRYING AT LOW PRESSURE

MARKOM MICROWAVES is a company specializing in the design and construction of microwave devices and systems. Drying with microwaves, and even more so with microwaves at reduced pressure, is still a topic little known to a wider group. The efficiency of this type of microwave devices (vacuum dryers) is the most important information that allows you to decide on the implementation of this technology. This article describes the basic relationships associated with microwave technology used to dry materials at reduced pressure.

1 INTRODUCTION

The speed at which electromagnetic waves propagate in a vacuum is $v = 299792458\ m/s$ (rounded 300000000 m/s). Microwaves are part of the electromagnetic radiation in the range from 300 MHz to 300 GHz. The l wavelength with a f frequency is calculated from the formula $l = f/v$.

The principle of the influence of microwaves on water molecules is well known. Let us only recall that water molecules in the microwave field begin to vibrate (rotate) in accordance with the changes in this field. In this process, heat is released which raises the temperature of the water, causing it to boil and evaporate.

There are several frequency ranges used in industrial equipment. In the following, all aspects related to drying will only pertain to the range 2450 MHz $\pm$ 50 MHz.

2 MAGNETRON

The magnetron is a vacuum electron tube that generates microwaves. The microwave energy is led outside through a dipole antenna. In specialized solutions (e.g. radars) the microwaves are led out through a waveguide.

Unfortunately, the process of producing microwaves generates a lot of heat. The magnetron must be protected against excessive heat build-up, otherwise it will be damaged. The magnetrons are therefore either air or water cooled. This part of the energy is practically wasted.

The efficiency of the magnetrons is rated at 70-80%. Some manufacturers declare efficiency at the level above 90%, however, one should be quite skeptical about this. Generally, to generate microwaves of 1 kW, 1,25 kW power should be provided.

3 WATER

Due to its dielectric properties, water absorbs microwaves very well. It is also a good heat conductor. The boiling point under normal pressure is 100°C. At 40 mbar, the boiling point of water drops to about 29°C. This is important due to the fact that in the microwave drying process it is necessary to take into account the phase change (phase transition).

Phase change is a thermodynamic process in which water is changed from a liquid state to a gas (water vapor). The latent heat is a measure of the energy required for the transition of water from a liquid to a gas. In this example, for water it is 2433 kJ/kg.

4 ENERGY TRANSFER

In order to estimate the efficiency of the microwave system in the process of water evaporation, we will assume that the source produces microwaves of 1 kW power. This is an amount of energy equivalent to 1 kJ/s.

Recall that the latent heat of water is 2433 kJ/kg. We determine the rate of water evaporation from the ratio of latent heat to the supplied energy

$$\frac{2433\frac{kJ}{kg}}{1\frac{kJ}{s}} = 2433\frac{s}{kg}$$

This means that when using a microwave power of 1 kW, 1 kg of water can be evaporated in 2433 seconds, which is about 41 minutes.

5 AIR DRYING

There are other methods and technologies for drying materials (water evaporation). One of the most popular is hot air drying. Air drying, for obvious reasons, is difficult to accomplish under reduced pressure. So this is only an example to which microwave drying in vacuum will be compared.
1 m^3 of dry air, at a temperature of 20°C, contains about 17 g of water. However, let's make assumptions where:

- the air intended for drying does not contain water (relative humidity 0%),
- is fully saturated after passing through the material or over its surface (relative humidity 100%),
- the amount of air flowing is 100 l/min.

In 1 minute, the air will 'take away' approx. 1,7 g of water (moisture). By increasing the air temperature to 60°C, the process yield can theoretically be increased to about 13 g/min. Unfortunately, upon contact with a cooler material (e.g., at a temperature of 29°C), the air temperature drops, thereby reducing the productivity to about 10 g/min. In 41 minutes, only about 410 g of water will be collected.
So, in order to receive 1 kg of water, it takes about 100 minutes.

6 TYPES OF MATERIALS

Without going into scientific considerations, we can distinguish between three types of humidity:

- surface,
- capillary,
- molecular.

In hygroscopic materials, water is mainly found on the surface.
In hygroscopic materials, water can penetrate into the interior of granules or tiles.
Molecular humidity is water bound at the level of the molecules of the material.
Microwaves at reduced pressure can dry virtually all materials and products, even those sensitive to high temperature. Additionally, the ability of microwaves to penetrate deeply into the structure of the material facilitates drying its deeper layers, and thus drying hygroscopic materials.
For comparison, hot air must be intensively blown into the layer of dried material. Even so, it is extremely difficult to remove moisture from hygroscopic materials.

7 EXPERIMENT

The above-mentioned dependency apply to ideal conditions. However, the difficulties in drying hygroscopic materials under real conditions were mentioned.
An example is the experiment carried out by GEA on drying lactose (powdered milk). The experiment was carried out in tanks with a capacity of 10 to 1200 l.
Approximately 40 minutes was enough to remove 1 kg of water using 2,4 kW microwaves, regardless of the tank capacity.
For drying with hot air of 60°C at 100 l/min, 120 to 270 min was required to remove 1 kg of water. The volume of the reservoir was important in this case.

8 CONCLUSIONS

Many aspects related to the evaluation of the effectiveness and efficiency of microwave systems have not been addressed in this study. However, the information presented and the comparison to the traditional method of drying allows the future user to assess whether this type of solution will be applicable in his system.