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Microwaves for Drying Grain Maize

The trend in drying technology is toward bigger units. Conventional ones with warm-air systems, and especially those for grain maize, have reached their capacity limits. A remedy could be found in microwave energy, which can be applied additionally to the conventional process, and will improve dryer capacity. The process operations involved in grain maize drying were examined on a laboratory scale, to determine potential locations in the dryer and the right timing for applying the microwave energy.

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In principle, microwave- or dielectric properties exist in electrically non-conducting or poorly conducting materials. They are material-specific and based on electric dipoles.

Another kind are the so-called permanent dipoles. There, the charges are spatially separated without an external field like in the case of water, for example.

Under the influence of the dynamic effects of the alternating electric field, the dipoles move and generate heat. Heat generation is dependent on the frequency applied.

Dipolar or molecule polarisation or also orientation polarisation takes place at frequencies in the high frequency/microwave range. Due to their mass and their bonds in the molecule, charge carriers follow a field change after a certain time interval. At high excitation frequencies, only low-mass charge carriers respond, whereas all charge carriers respond at low frequencies..

In ε" - curves, the course of energy absorption is shown as a function of frequency [4]. At the maximum value of ε" , the largest amount of energy is absorbed. The frequency at which ε" reaches its maximum is also called relaxation frequency. For water, this value is f = 22 GHz combined with very low penetration depth, which is not desired. Therefore, the microwave frequency applied (f = 2.45 GHz) is suitable also under the aspect of drying technology because penetration depth is greater at this frequency.

The absorption of microwave energy is described by the following equation:

$$P_{Hf} = E^2 \cdot 2\pi f \cdot \varepsilon_0 \cdot \varepsilon_r'' \cdot V = E^2 \cdot 2\pi f \cdot \varepsilon_0 \cdot \varepsilon_r' \tan\delta \cdot V \text{ [W]} \quad (1)$$

In the considered volume V, the absorbed microwave energy is completely converted into heat.

Microwave properties also include the term penetration depth. It is defined as the depth at which the performance which reaches the product surface has decreased to the 1/eth part in the interior of the product. Penetration depth is dependent upon frequency and the dielectric properties [6].

$$d = \frac{c_0}{2 \cdot \pi \cdot f} \cdot \left(\left\{ 2 \cdot \varepsilon_r' \cdot \left[\left(1 + \left(\frac{\varepsilon_r''}{\varepsilon_r'} \right)^2 \right)^{0,5} - 1 \right] \right\}^{-1} \right)^{0,5} \quad \text{[m]}$$

In particular, this equation shows that penetration depth diminishes with increasing frequency from the surface towards the interior of the body.

Abbreviations

P_{Hf}	= absorbed power converted into heat [W]
E	= electric field intensity [V/cm]
f	= frequency [s^{-1}]
c_0	= light speed = $3 \cdot 10^8$ m / s
d	= penetration depth [m]
ε_0	= dielectric field constant = $8{,}85 \cdot 10^{-14}$ [As / V cm]
ε_r', ε'	= real part of complex permittivity, characterizes pure polarisation
ε_r'', ε''	= imaginary part of complex permittivity = dielectric loss value
tan δ	= $\varepsilon_r'' / \varepsilon_r'$ = loss factor (tangent of the dielectric loss angle), characterises the losses caused by the reversal of polarity
ω_m	= angular frequency at which the dielectric loss value is at a maximum (relaxation frequency)
V	= volume [cm^3]
m_{H2O}	= mass of water withdrawn
$m_{Nassmais}$	= mass of the material to be dried
F_A	= initial moisture content in %
F_E	= final moisture content in %

The two equations (1) and (2) show how an appropriate frequency can be chosen. On the one hand, high microwave performance in the product is desired for heat generation, which according to equation (1) can be reached through high frequency near the relaxation frequency and high field intensity. In the marginal area, the reduction of penetration depth with growing frequency leads to high temperatures and, hence, potential damage to the material. Microwave heating processes are intended to cover a large volume because this is a fast process which is less based on conventional heat transfer. The thermal conductivity of the products to be treated is low. This results in an undesired slowing down of the heating process. The technical limit is set by the dielectric strength of the air.

Experimental set-up

The studies were carried out using a household microwave oven converted for laboratory tests. The built-in magnetron was replaced by a more powerful one. At the existing microwave feed-in point, a hollow conductor with a magnetron head was installed. In addition to the magnetron and the feed-in hollow conductor, the magnetron head contains the heating transformer, the ventilator, and a temperature switch. At excess temperature, the latter shuts off anode tension.

Between the magnetron head and the feed-in point of the working area, a water-cooled one-way conductor is installed to protect the magnetron against running-back microwaves. For the drying experiments, the recirculating air- and infrared heating installed in the working area was supplemented with flow heating.

A pipe mounted to a side wall contains a heater with a blower. The outlet, which also features a blower, is situated on the opposite side diagonally across the working area.

The entire system is housed in two mobile cabinets (*Fig. 1*). The one cabinet contains the microwave part with the control equipment for recirculating air, flow air, and infrared. Energy supply for the microwave oven is housed in the other unit in addition to the evaluation electronics for moisture measurement. A timer is used in order to set the impulse ñ break times for the microwave.

The system is supplied with three-phase current. A fault-current protection switch with a differential current of 30 mA serves as an additional protective measure.

The energy supply of the magnetron is current-controlled. With the aid of a potentiometer, power can be set between 0 and 100%.

Drying of grain maize

For the trial, 500 g of grain maize were used. They were placed in an open glass container which does not absorb microwave energy (no heating of the container). The initial moisture content of 25% w.b. was determined using a technique of capacitive measurement. The microwave power given off into the working area was 600 W.

Each batch of grain maize was exposed to microwave treatment for one minute. At five different places, the surface temperature was measured with an infrared thermometer. Based on these values, the arithmetic average was calculated. Afterwards, the grain maize was stirred in ambient air, its new weight was determined, and the surface temperature was measured again. The trial was ended after the final moisture content of ca. 13.5% had been reached. The water reduction required for this purpose was determined based on the initial moisture content using Duval's formula:

$$m_{H2O}=m_{Nassmais}\cdot\{(F_A-F_E)/(100\%-F_E)\} \quad (3)$$

Trial results

Fig. 1: View of the microwave batch type

The attempt to dry grain maize exclusively with microwave energy (*Fig. 2*) shows the typical drying course of capillary-porous materials. Therefore, it lacks the salient points known from the drying of capillary-porous-hygroscopic materials. After an initial phase, the water content diminishes relatively constantly. Immediately after each microwave treatment, the surface temperature remains virtually constant and then increases when a certain water content has been reached (15th minute). The water quantities removed per time unit are shown as rectangles. As of the 16th minute, measurements were carried out in 2-minute intervals. After an application time of 22 minutes, the final moisture degree was reached. The results show that grain maize is very suitable for drying with microwave energy due to its high initial moisture content and its physiological structure. Only under certain conditions can the results presented here be applied to large plants. The physical and technical properties of the conventional and the microwave system must be harmonized sensitively in order to be able to combine the individual processes and physical properties optimally. Other trials at a semicommercial and larger scale are required in order to make interactions within the drying process as a comprehensive system more describable and thus applicable in large plants.

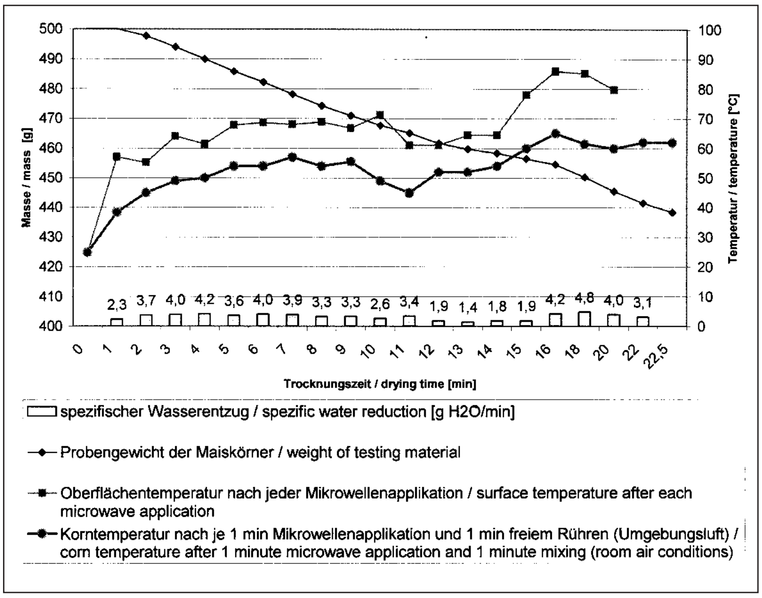

Fig. 2: Course of drying maize in microwave oven; initial moisture: 25 % w.b., end moisture: 13.5 % w.b.

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