MICROWAVE VACUUM DRYING OF FRUITS & VEGETABLES

Peter Püschner and Louise Loh Siok Hoon PÜSCHNER GMBH + CO KG 28790 Schwanewede, Germany peter@pueschner.com

Microwave Drying has a big advantages compared with conventional drying, because in microwave drying, heat is generated by directly transforming the electromagnetic energy into kinetic molecular energy, thus the heat is generated deep within the material to be dried.

Especially in microwave vacuum drying this advantages has a big significance for bulk products with poor thermal conductivity.

The described microwave vacuum technology is used for high-end drying applications of thermal sensitive products like fruits and vegetables in order to achieve higher product qualities and shorter drying times.

1. Industrial Microwave Applications

There are many write-ups that established microwave heating showing promising potential in food manufacturing processes such as cooking, tempering, drying, heating, baking, , blanching and pasteurization. (2005; Decareau, 1985; Metaxas & Meredith, 1983; Metaxas, 1996; Roussy & Pearce, 1995; Buffler ,1993). While all processes are primarily about raising temperature, the heat management dictates the output quality, especially with thermal sensitive materials.

In microwave heating and drying process, heat transfer takes place speedily and this occurrence has to be understood, monitored and controlled so that a stable and reproducible process is guaranteed. For that reason process control in combination with good microwave design is the key point in successful microwave applications.

2. Dielectric Properties

As microwave heating is a form of dielectric heating, dielectric properties is thus the most important factors among all. For a substance to be microwaveable it must possess an asymmetric molecular structure, as in the case of a water molecule. The molecules of such substances form electric dipoles which, when exposed to an electric field (Figure 1), assume an orientation relative to the direction of that field. It is this orientation polarization that is responsible for energy generation.

The essential factors to produce heat capacity in a volume element are the electric field strength of the microwave field, the frequency, and the dielectric properties of the product represented by the loss factor of the material ε_r'' (equation (1)).

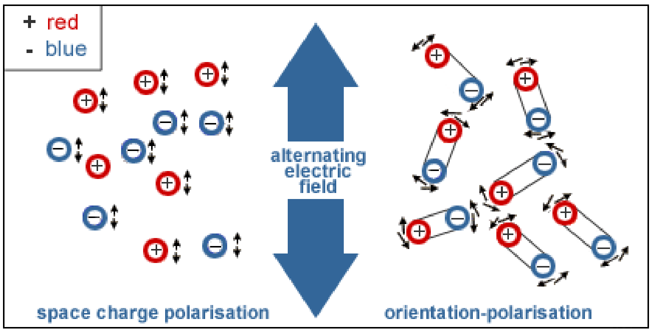


Figure 1. Molecular oscillations of polarizable substances under the influence of an alternating electric field

The loss factor is calculated as the product of the permittivity number and tangent of the loss angle δ. Both parameters depend on frequency and temperature.

$$P''' = 2\,\pi \bullet f \bullet \varepsilon_o \bullet \varepsilon_r' \bullet \tan\delta \bullet E \;=\; 2\,\pi \bullet f \bullet \varepsilon_o \bullet \varepsilon_r'' \bullet E \qquad (1)$$

- P''' bulk-wave energy density measured in W/m3
- f operating frequency measured in Hertz
- ε_o electrical field constant = 8.85 x 10-12 As/Vm
- ε_r' dielectric constant = real part of the complex permittivity number
- δ dielectric loss angle measured in degrees
- ε_r'' dielectric loss factor = imaginary part of complex permittivity
- E electric field strength measured in V/m (effective value)

The higher the loss factor of a substance is, the better the substance can be heated in a field of microwaves. Water and all aqueous substances possess a high loss factor and therefore absorb high frequent energy and microwave energy exceedingly well.
Depending on their absorption behavior towards microwave irradiation, materials can be classified into three groups:

- absorbers, e.g. water (ε_r''=12 at 25°Celsius), aqueous substances (practically all foodstuffs), diverse sorts of plastics
- transparent, e.g. porcelain quartz glass (ε_r''=0.0023), Teflon
- reflectors, e.g. metal, graphite

Down to a loss factor of about $\varepsilon_r'' = 0.01$ substances may still be heated in a microwave field. If the loss factor should be below this value, there still might be the possibility to blend in additives with higher loss factors which, however, should not change the desired properties of the substance.

3. General application categories

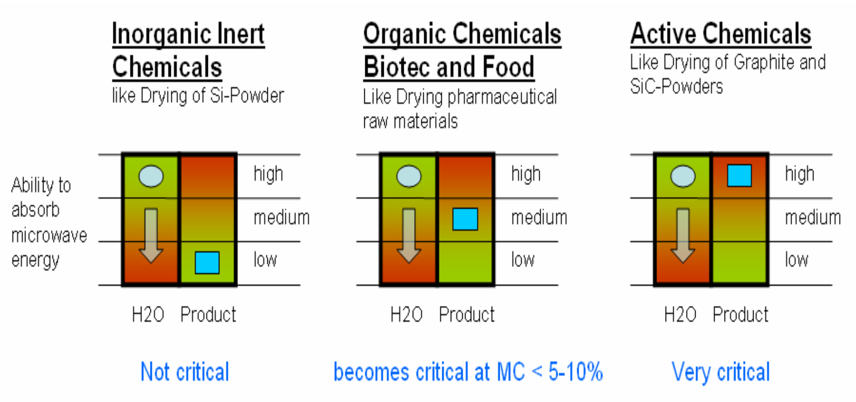


Figure 2. Three general application categories

3.1. *1. Products with low dielectric losses*

When drying products like Si-powder, the product has a relatively low loss factor as compare to water. In such case, dielectric heating is selectively specific towards water; hence dielectric heating has least impact over the material.

3.2. *2. Products with medium dielectric losses*

When the products like fruits possess a medium range of loss factor as compare to water, the control becomes more critical during the process. Dielectric heating begins with selective heating on water, as the moisture content drops to less than 5-10%, dielectric heating will then be pick up by the products. Therefore it is crucial to intercept the various parameters when approaching the end-drying.

3.3. *3. Products with high dielectric losses*

When heating product like Silicon Carbide or Graphite, which has high dielectric losses, the control of temperature becomes very difficult. Uneven energy distribution creats hot spots. Therefore the power densities have to be reduced and a good microwave design to maintain even energy distributions is essential.

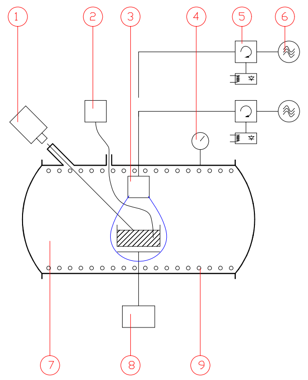
Drying of Fruits & Vegetables using Püschner Microwave Vacuum Dryer, µWaveVac 0150

Drying is the oldest method of preserving food and account for majority of processes in food industry. There are many known methods of drying food; microwave vacuum drying is identified due to numerous benefits it produces.

The use of vacuum has shown further improvement in quality of food products. Vacuum reduces thermal stress and showed better colour and texture of dried products over ones that was air-dried. Reduction of drying times in microwave is beneficial for the color, porosity (Krokida & Maroulis, 1999), the aroma (Raghavan & Koller, 1995), the shrinkage and improved rehydration (Khraisheh et al, 2004).

The industrial batch microwave vacuum dryer, model **µWaveVac0150** (In figure 1), is equipped with necessary measuring devices as well as the microwave applicator or/and microwave antenna system for monitoring parameters. The drying profile is captured in a graphic form by the process control. The smallest dryer in the **µWaveVacxx50** family is ideal for lab investigation and is easily scale up to bigger dryer with capacity according to production output.

Figure 3. Members of the family **µWaveVacxx50** from left to right - **µWaveVac0150-lc** with 1kW/2450MHz and **µWaveVac0650** with 6kW/2450MHz.



Legends:

1) Infra-Red Camera (0-250°C)
2) Fibre-optical temperature measurement system
3) Microwave antenna
4) Pressure measurement
5) Circulator (magnetron protection) incl. Measurement of the reflected power
6) 1-6kW/2450MHz Magnetron incl. DC high-voltage power supply.
7) Vacuum vessel ca. 200l
8) 10kg load cell, 10.ooo digits
9) wall heating

Figure 4. Block diagram of **µWaveVacxx50**

The microwave vacuum dryer installed with 1KW/2450MHz microwave power, allows investigation of drying and heating applications under atmospheric pressure or vacuum setting. Using an infrared and fiber-optical temperature measurement system, core and surface temperatures of object can be measured within the chamber. Other process parameters are such as the amount of forward microwave and reflected microwave and the changes of product weight over the process.

µWaveVac 0150 presents the use of microwave in drying fruits and vegetables under vacuum, achieving the various desirable characteristic of dried products. Due to the difference in texture and sizes, the vacuum dryer uses different devices to hold the products in the chamber. The products are presented along with the four main configurations listed below (In figure 3):

1.Configuration with PP Container on Turntable
2.Configuration with Cavity

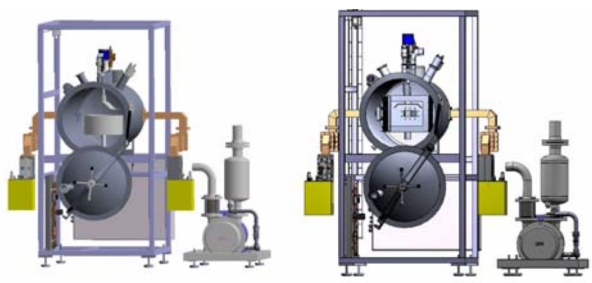


Figure 5. Different Configurations of the family **µWaveVacxx50**

3.4. *Püschner Vacuum Dryer using Container on Turntable*

The most common device used in microwave heater or dryer is the use of container on the turntable. Products place in the container remain static in position while moving through the microwave field which prevent any mechanical friction or stress experience in a movable device.

3.4.1. *Strawberry*

Strawberries are a popular fruits and dessert. The drying process successfully retained the form, appearance, color and the outstandingly strong aroma of the highly perishable fruits.

Figure 6. Strawberries before and after Microwave

Figure 7. Complete Vacuum Dried Strawberries (LEFT: After drying; RIGHT: Inside of dried strawberry) maintains its appearance, color and strong aroma.

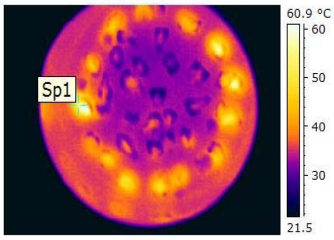


Figure 8. Image Thermograph after Microwave Vacuum of Strawberries

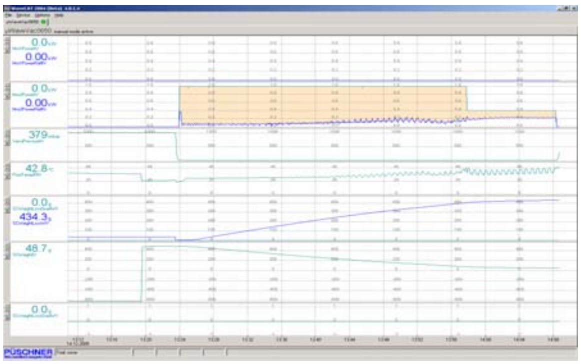


Figure 9. Drying Curve of Strawberries monitored with ***WaveCAT***

3.4.2. *Broccoli*

More and more vegetables are dried as an ingredient in instant noodle where both noodles and the ingredients are reconstituted. Other than the size, microwave drying maintain the structure and the rich color of broccoli.

Figure 10. Broccoli before and after Microwave Vacuum Drying

Figure 11. Fiber Structure of Broccoli after Drying

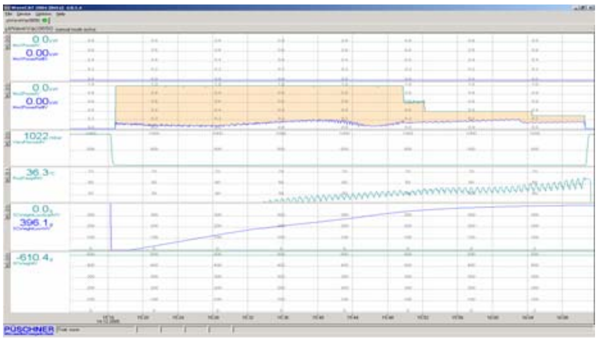


Figure 12. Drying Curve of Broccoli monitored with ***µWaveCAT***

3.5. *Summery*

The article shows the abilities of the multi purpose microwave vacuum system of the Püschner Microwave Vacuum Dryer, model WaveVac 0150. It demonstrated the use of different configurations to adapt to different application examples for Foods industry. The scale up of microwave vacuum dryer is easily bridged by the models of µWaveVacxx50 product line. There is certainly a great potential in employing microwave for Foods industry in the next future.

In summary, the following advantages of microwave drying are drawn as compared to conventional drying methods.

- low temperature drying provides gentle treatment for the product due to low vacuum pressure.
- a temperature gradient directed towards the surface, i.e. temperatures inside are higher than on the outside, giving rise to a pressure gradient which drives the evaporating liquid to the surface

- consequently, the superficial layer does not dry out completely and the surfaces remain permeable
- the liquid evaporating inside the product is emitted through the pore structure of the solid material's macro-capillary system, resulting in a high drying velocity
- the heating of water and most organic solvents occurs selectively - due to the greater dielectric losses of water as compared to the product to be dried
- swift and thorough drying of moist products with low thermal conductivity
- stationary drying of thick layers without frictional losses
- high total efficiency of energy application
- high-speed control of the energy transport
- short processing times, i.e. suitable for automated manufacturing

3.6. *Reference*

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