State of the Art Microwave Vacuum Drying of Food

PÜSCHNER MICROWAVES

2010

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The article gives an insight into the latest development of microwave vacuum drying of foods for continuous and batch processing. Different microwave machine concepts are presented and explained for industrial production scale use.

Advanced Microwave Vacuum Drying of Fruits, Vegetables & Herbs

Drying is the oldest method of preserving food and accounts for the majority of processes in food industry. There are many known methods of drying food; microwave vacuum drying has been identified as an important method due to numerous benefits that it produces.

The use of vacuum has shown further improvement in quality of food products. Vacuum reduces thermal stress and sustains better colour and texture of dried products compared to those that were air-dried. Reduction of drying times in microwave is beneficial for the colour, porosity, the aroma, the shrinkage and improved rehydration.

The quality of microwave vacuum dried fruits and vegetables can be very similar to the results from freeze drying. Therefore microwave vacuum drying has the potential to be an interesting alternative to freeze drying in many applications as drying times are much shorter and running costs are less. But freeze drying has advantages regarding open porous structure, dissolubility, no migrations of active ingredients, flavours, vitamins and other volatiles. Therefore microwave freeze drying has the potential to cut down the drying time significantly compared to conventional freeze drying systems.

Behaviour of foods in microwave vacuum drying

Products like fruits and vegetables have a moisture content typically in the range of 70-90%. Therefore the dielectric losses are mainly determined by water and dielectric heating begins with selective heating of water, as the moisture content drops to less than 5-10%, dielectric heating will then pick up the product temperature. In the first drying phase until 5-10% the product can stand high energy densities and the temperature of the product is close to the evaporation temperature depending on the vacuum (typical 30 mbar and 30 °C). The second drying phase is critical and energy densities have to be reduced significantly as the product itself is absorbing energy and the temperature may rise over the evaporation temperature in vacuum. In order to keep the product properties like flavour, texture and ingredients etc. temperatures above 50 °C have to be avoided.

Conditions of microwave freeze drying

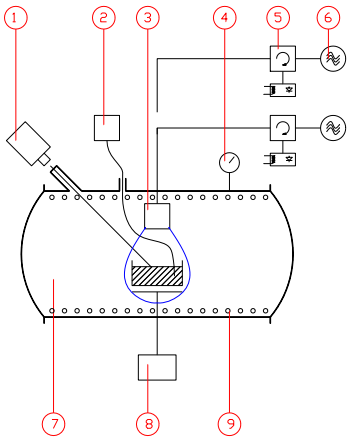
Due to the fact that water in frozen state has only low dielectric losses, the dielectric heating under freeze drying condition is mainly determined by the dielectric properties of the product itself. A positive effect is that the penetration depth of microwaves is much bigger under frozen conditions. But due to the low vacuum levels of only 1-2 mbar the problems of plasma and ionization require an optimal designed microwave system. In literature there are several studies, which have been carried out on this subject, but yet no industrial installations on microwave freeze drying have been reported. However due to the very long conventional freeze drying times there is a big interest from industry to produce freeze dried products in shorter times and in a more economical way.

Lab microwave vacuum dryer *µWaveVacxx50*

The front gate of the microwave vacuum dryer and microwave freeze dryer is shown by the batch microwave vacuum dryer, model **µWaveVacxx50** (see Figure 1a). The system is equipped with necessary measuring devices as well as the microwave applicator or/and microwave antenna system that can be adapted to various products under different process conditions. The drying profile is online monitored in a graphic form during the drying process (see Figure 2). The smallest dryer in the **µWaveVac0150-lc** family is ideal for lab-scale investigations and is easy to scale up to a bigger dryer with capacity according to production output.

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

Figure 1b. Members of the family ***µWaveVacxx50*** from left to right - ***µWaveVac0350*** with continuous dosing and discharging, ***µWaveVac0250-FD*** with 2kW/2450MHz freeze drying option.



Legends:

1) Infra-Red Camera (-50 to 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) 10 kg load cell, 10.000 digits
9) wall heating

Figure 1c. Block diagram of the ***µWaveVacxx50***

The microwave vacuum dryer allows investigation of drying and heating applications under atmospheric pressure or vacuum setting also below the triple point. Using an infrared and fiber-optical temperature measurement system, core and surface temperatures of the object can be measured within the chamber. Other process parameters such as the amount of forward and reflected microwave power and the changes of product weight are monitored during the process.

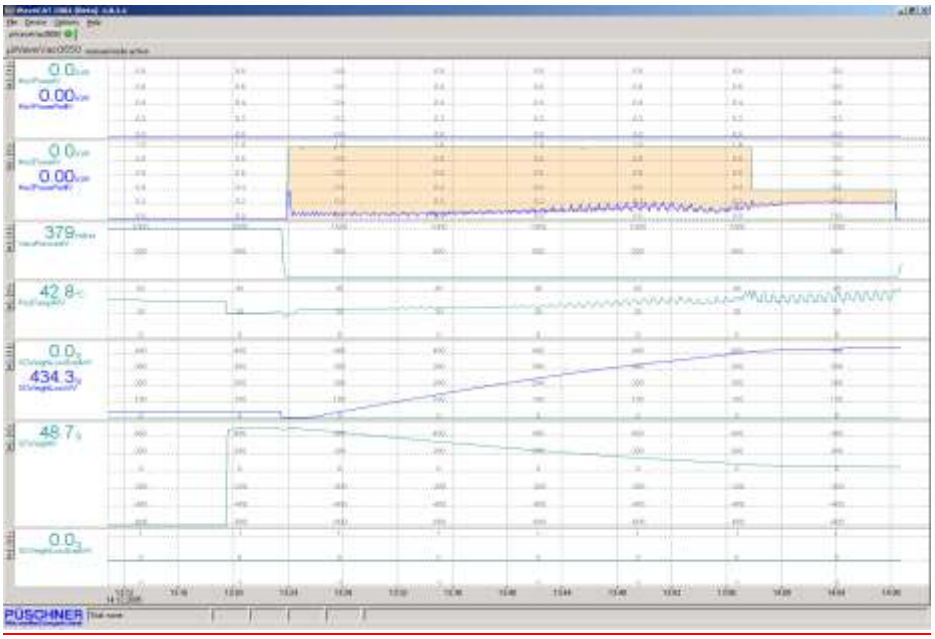


Figure 2. ScreenShot from process monitoring of a vacuum drying process using the WINDOWS program ***µWaveCAT***

As the ***µWaveVacxx50*** is a multi-purpose system various options can be offered such as

- Turntable operation with online load cell
- Open/closed product drums
- Spiral drum for continuous processing
- Conveyor belt (also monomode) for continuous products
- Flash options for feeding preheated viscous products
- Fluidized bed drying conditions in combination with vacuum (e.g. for drying of herbs)
- Freeze drying options

All options can be combined in one system. The results of the microwave vacuum lab dryer can be transferred and scaled-up to pilot and production microwave vacuum dryers based on four different concepts:

1. Multi Batch MW Vacuum System based on an open drum
2. Continuous MW Vacuum System based on a spiral drum
3. Continuous MW Vacuum System based on a conveyor belt
4. Semi Continuous MW Freeze Drying System based on rotating drums

Multi batch microwave vacuum system based on an open drum

The Microwave Vacuum Drum Dryer ***µWaveVacxx90*** is based on a plastic product drum, which is moved clock- and anticlockwise by max ±90°. 300 and 800 litre drum volumes are available. The filling level of the drum is normally 30-50% of the total drum volume (see Figure 3).

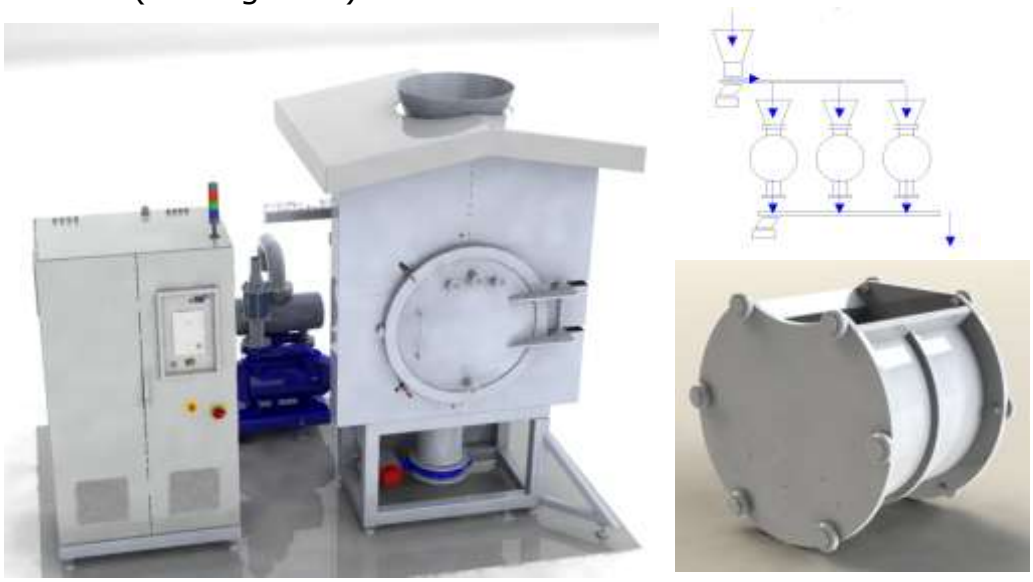


Figure 3. 100kW/915MHz Production Machine ***µWaveVac10090***, left: system setup, right: Plastic product drum of 300 or 800 litre volume, top: multi parallel systems working in a continuous production flow.

The movement of the drum is used to mix and tumble the product during drying which guarantees an even energy distribution throughout the volume of the product load in the drum. Also mixing allows a good temperature monitoring using IR pyrometers for measuring the bulk temperature of the product.
The microwave vacuum dryer is charged using an inlet hopper on the top.
After drying the drum is turned by 180° and a butterfly valve at the bottom is discharging the dried product and the machine is ready for the next drying cycle. The concept allows to scale up parallel machines to meet higher production rates. The maximum installed microwave power per unit is 100kW.

Continuous microwave vacuum system based on a spiral drum

For continuous production requirement the ***µWaveVacxx70,*** *(see Figure 4)* based on a spiral drum is available. Compared to the vacuum belt dryer, the spiral drum dryer has a better ratio of product load versus vacuum volume of the vacuum vessel and also allows a better mixing during drying in order to cope with critical products.

Figure 4. 100kW/915MHz Production Machine **µWaveVac10070**

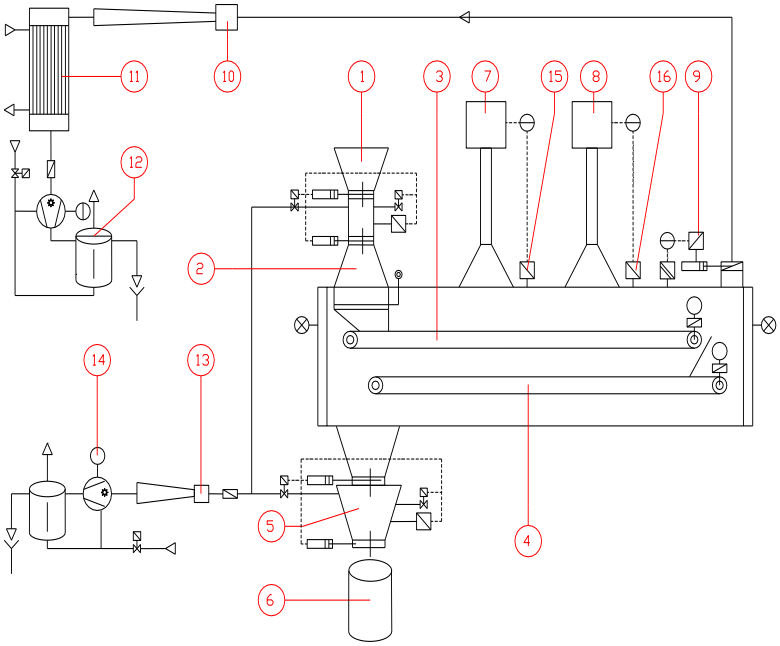
Feeding and discharging is similar to the operation described for the vacuum belt dryer. The typical residence time is in the range of 10-40 min. The installed microwave power is in the range between 20 to 100 kW.
In comparison to vacuum drum dryer the continuous spiral drum dryer is used when almost only one product is dried within a production line. The vacuum batch drum dryer has advantages when there are a wide range of different products to be dried under different settings.

Continuous microwave vacuum system based on a conveyor belt

The vacuum batch drum dryer as well as the continuous spiral drum dryer are used for vacuum drying processes where mixing and tumbling gives an advantage to the process. Also due to the better ratio of product load versus vacuum volume both dryer types are used for high evaporation rates and drying product from 90% down to below 5-10%. For these products a certain mechanical stability is required to resist mixing and tumbling. For some product a static continuous drying on conveyor belt is required. This can be done using the ***µWaveVacxx95*** vacuum dryer system (see Figure 5 and Figure 6).

Figure 5. 100kW/915MHz Production Machine ***µWaveVac10095***

These dryers are available as a one or two-stage dryer. The block diagram below shows a two-stage microwave vacuum belt dryer where feeding and discharging is done by airlocks based on two butterfly valves.



Legends:

1	Granular product inlet
2	Distribution system
3	Microwave Belt Drying Zones
4	PTFE coated conveyor belt
5	Product outlet
6	Hopper with dried product
7,8	Microwave system (2x)
9	Vacuum control
10	Steam injector
11	Condenser
12	Water ring vacuum pump
13	Gas steam injector
14	Water ring pump in-/outlet
15, 16	IR-camera (2x)

Figure 6. Block diagram two stage vacuum dryer **µWaveVac6095**

The vacuum belt dryers are used for products, which require static drying and also have a short dwell time of approx. <20 min to ensure economical drying results.

Semi continuous microwave freeze drying system based on rotating drums

Heat transfer is the limiting point with conventional freeze drying processes. Investigations with microwave freeze drying systems have shown that e.g. banana slices dried in vacuum system within 20 min can be dried with the same drying kinetics under microwave freeze drying conditions. Whole pealed bananas which were dried within 60 min in microwave vacuum systems can also be dried within the same time under microwave freeze drying condition. In frozen condition also the material handling problem is solved for mechanically sensitive products like berries etc. Due to this fact, microwave freeze drying process will be used more often in the future also in the food industry. The machine concept based on a ***µWaveVacxx50*** shown in Figure 7 shows a 3 stage 24kW/2450MHz freeze drying system with the use of 50 litre product drums.

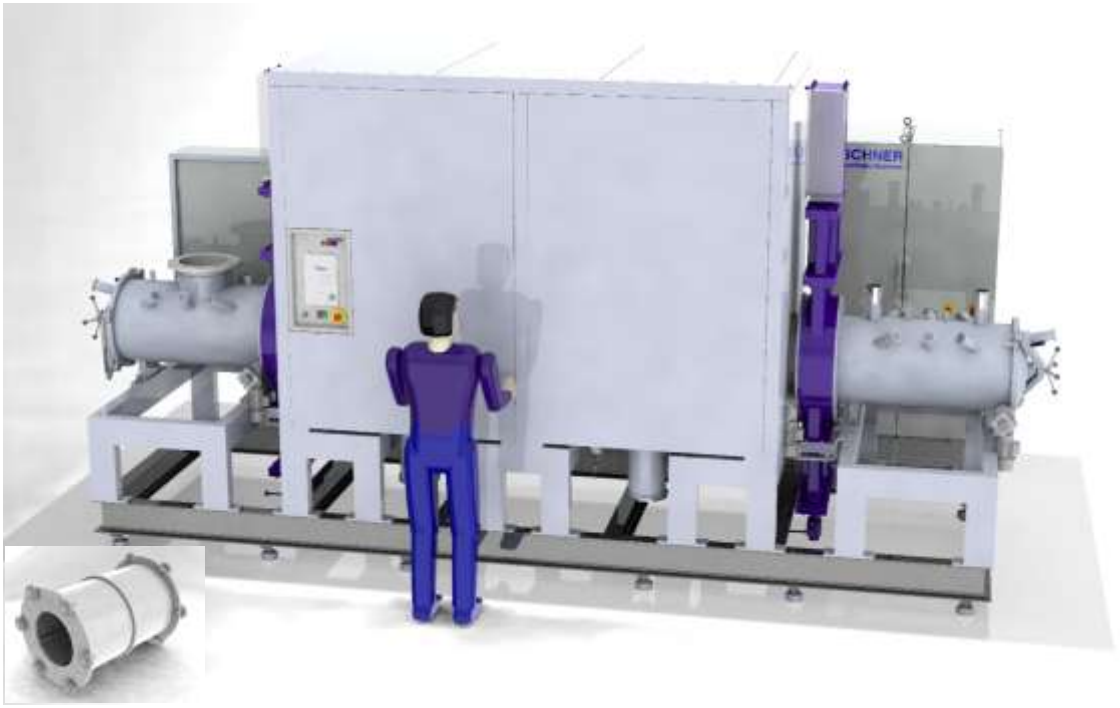


Figure 7. Three stage microwave freeze dryer **µWaveVac2450** based on 50 litre drums.

Examples of Advanced Drying Applications

Strawberries

Strawberries are a popular fruit and dessert. The drying process successfully retains the form, appearance, colour and the outstandingly strong aroma of the highly perishable fruits (see Figure 8).

Figure 8. Whole vacuum dried strawberries (left: after drying; right: inside of dried strawberry) maintains its appearance, colour and strong aroma.

Broccoli

More and more vegetables are dried as an ingredient in instant noodle where both noodles and the ingredients are reconstituted. Additionally to the size, microwave drying maintains the structure and the rich colour of broccoli. Broccoli is regarded as a difficult product as it contains fine fiber bundles with a stem. Both are very sensitive to overheating and browning (see Figure 9).

Figure 9. Fibre structure of broccoli after drying

Bananas

Banana products are very popular on the market, but regarded to be a difficult product for gentle and fast drying. Whole pealed bananas can be dried keeping the shape and structure. Low vacuum drying below 20 mbar ensures that there is no exposure to oxygen and the skin remains almost white which gives a nice appearance for consumers. Shrinking can be avoided with microwave puffing assistance (see Figure 10).

Figure 10. Whole bananas after microwave vacuum drying

Herbs

Herbs are high value products on the food market. Most of the offered products in supermarkets are dried based on fluidized bed dryers, where temperatures of above 60-70°C destroy most of the volatiles. As a more gentle and fast alternative a combined microwave fluidized bed dryer under vacuum can dry the complete range of herbs in a short time keeping form, color and aroma (see Figure 11).

Figure 11. Drying of 10 kg basil in 40min using a combined microwave fluidized bed dryer under vacuum

Summary

This article shows the potential of microwave vacuum drying for future high value dried fruits, vegetables and herbs. Results from the lab using the ***µWaveVacxx50*** can be up-scaled into production scale. Different production plant concepts were explained

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 the product 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
- short processing times, i.e. suitable for automated manufacturing
- microwave freeze drying on certain products is more than 10 times faster than conventional freeze drying

Industrial microwave vacuum systems will become more common in food applications in the near feature. Footprint of the microwave vacuum dryers are small compared to conventional dryers and the higher efficiency will dry food faster with better quality results at lower costs.