

MICROWAVE DRYING OF FRUITS AND VEGETABLES: A FOURTH GENERATION DRYING TECHNOLOGY

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ABSTRACT

Drying of fruit and vegetables is one of the oldest forms of food preservation techniques for off season use. Although the primary objective of drying and dehydration is food preservation, yet, it lowers the cost of packaging, storing and transportation by reducing both the weight and volume of the final product. Microwave drying is a rapid dehydration technique that can be applied to specific foods, mostly to fruits and vegetables. A significant reduction in drying time in microwave drying is often accompanied by an improvement in product quality, making it a promising food dehydration technology.

Keywords: Drying, Microwave dryer, Advantages, Drawbacks, Comparative study.

INTRODUCTION

Status of Fruits & Vegetables Production and Processing in India

India enjoys a rich diversity of horticultural crops covering large groups of fruits, vegetables, mushrooms, flowers, plantation and spices. This is possible because of the agro-climatic variations, enormous biodiversity, fertile soil, a large cultivable area and, above all, a long history of crop husbandry. It ranks second in fruits and vegetables production in the world, after China. As per National Horticulture Database published by National Horticulture Board, during 2012-13 India produced 81.285 million metric tonnes of fruits and 162.19 million metric tonnes of vegetables. The area under cultivation stood at 6.98 million hectares for fruits and at 9.21 million hectares for vegetables. India is the largest producer of ginger and okra amongst vegetables and ranks second in production of potatoes, onions, cauliflowers, brinjal, cabbages, etc. Amongst fruits, the country ranks first in production of Bananas (22.04%), Papayas (40.74%), Mangoes and guavas (32.65%). The vast production base offers India tremendous opportunities for export. During 2013-14, India exported fruits and vegetables worth Rs.8760.96 crores which comprised of fruits worth Rs.3298.03 crores and vegetables worth Rs.5462.93 crores. Mangoes, Walnuts, Grapes, Bananas, Pomegranates account for larger portion of fruits exported from the country while Onions, Okra, Bitter Gourd, Green Chillies, Mushrooms and Potatoes

contribute largely to the vegetable export basket. The major destinations for Indian fruits and vegetables are UAE, Bangladesh, Malaysia, UK, Netherland, Pakistan, Saudi Arabia, Sri Lanka and Nepal. Though India's share in the production of fruits and vegetables is very high, only 0.5 to 2% of the raw materials is processed, which compares very unfavourably with countries such as Brazil and the USA with 70% utilization, the Philippines with 78%, Malaysia with 83% and Thailand with 30%.

Introduction to Drying and Dehydration

Drying and dehydration offers a means of preserving foods in a stable and safe condition as it reduces water activity and extends shelf-life much longer than that of fresh agricultural produce. Drying is one of the most energy-intensive unit operations in the processing industries. In a drying process, a large amount of energy is needed for sensible heating and phase change of water. The high energy consumption is caused by both the energy needed for water removal via a phase change, as well as the low heat transfer efficiency during the falling rate period of a (hot-air) drying process. In the falling rate period, drying becomes inefficient because the dried product surface yields a layer with high heat and mass transfer resistance, and the temperature gradient could be in the opposite direction of the moisture gradient. In addition, in the falling rate period, the moisture content is low, the water molecules thus

have a higher evaporation enthalpy, and the removal of these molecules by evaporation requires higher energy input. When drying foods and agricultural products with conventional hot-air drying methods, this low heat and mass transfer efficiency coupled with a high energy demand for phase change results in prolonged drying time and hence a severe quality degradation in the final product. Many conventional thermal methods, including airflow drying, vacuum drying, and freeze-drying, result in low drying rates in the falling rate period of drying. The long drying times at relatively high temperatures during the falling rate periods often lead to undesirable thermal degradation of the finished products. So, microwave drying being fourth generation drying technology, offers opportunities to shorten the drying time and results in better quality dried product.

Concept of Microwave Drying

Microwaves are defined as a part of electromagnetic waves which have frequency range between 300 MHz and 300 GHz corresponding to wavelength from 1mm to 1m. Microwave frequencies of 915 MHz and 2.45 GHz can be utilized for industrial, scientific & medical applications. Microwaves have been applied in a broad range of food processing such as drying, tempering, blanching, cooking, pasteurization, sterilization, and baking. Microwave drying has considerable advantages over conventional drying methods, especially with regard to energy efficiency. Since heat is transferred from the surface of food to the interior by convection and conduction in conventional cooking method, it may result in a temperature gradient between outside and inside food. In addition, it requires higher energy consumption and relatively long processing time. In microwave drying, on the other hand, heat is generated (volumetric heating) inside the food in a short time when microwave penetrates through it. Microwaves have greater penetration depth, and this property coupled with volumetric heating can lead to rapid heating rate with short processing time, and also contribute to the minimization of temperature difference between the surface and interior of food material. As aforementioned, microwaves generate heat throughout the volume of food material rapidly because of the complete interaction between microwave, polar water molecules and charged ions in food. Microwave causes polar water molecules in

food to constantly rotate and couple with electromagnetic field. Molecular friction resulting from dipolar rotation of water molecule can generate heat. Water constitutes a major portion of most food products. Therefore, water is the primary component that interacts with microwaves due to its strong dipole rotation. Furthermore, heat can be generated through ionic migration that positive and negative ions of dissolved salts in food interact with the electric field by moving towards the oppositely charged regions of the electrical field and disrupt the hydrogen bonds with water.

Advantages of Microwave Drying

The advantages of microwave drying arise from the volumetric heating and internal vapour generation. Heating from the interior of a food product leads to the build-up of an internal vapour pressure that drives the moisture out of the product. This results in a significant reduction in drying time, leading to significantly improved product quality. A significantly reduced drying time, improvement in product quality, are the major advantages in microwave drying seem to have paved the road for potential widespread applications of this relatively new technology.

- Less start up time and faster drying.
- Slash energy consumption by up to 50% or more.

In microwave drying of foods, a reduction in drying time of up to 25–90% and an increase in drying rate of 4–8 times, when compared with convective drying, have been reported from many research studies. More importantly, microwaves should invariably be applied in the final stages of drying when drying rate is very slow resulting in reduced total drying time and reduced shrinkage. Microwave drying can reduce drying time for about 2-4 hours in the final stages of drying, if microwave drying is followed after mechanical drying. Commercial mechanical dryer usually takes 6-9 and 5-8 hours for drying at varying drying temperatures (50-70°C) of fresh and osmo-treated mushrooms respectively. Whereas, in microwave dryer, drying can be completed within 20 minutes. Table 1 shows the comparison of microwave, mechanical & mechanical-cum-microwave drying of oyster mushrooms on time saving.

Table- 1: Comparison of microwave, mechanical and mechanical-cum-microwave drying of oyster mushrooms on time saving

No.	Drying Time	Approx. Drying time	Saving in time (w.r.t) Mechanical drying
1	Mechanical Drying MC: 91.0 -7.0 %, db) Drying Conditions: T: 60°C, V: 3.86 m/s	360 min	-
2	Mechanical -cum-Microwave Drying		120 min= 2 h
	Convective Drying: 91 – 27 %, wb Drying Conditions: T: 60°C, V: 3.86 m/s	235 min	
	Microwave Drying: (27- 7.0%, wb) (Power levels: 415 W)	5 min	
3	Osmo-cum-mechanical drying (48-7%, wb) Osmotic Temperature: 45 °C Drying temperature: 60 °C	60 + 300 = 360 min	--
4	Osmo-mechanical-microwave drying Osmotic Temperature: 45 °C Mechanical: 60°C Microwave: 810 watts	60 + 180 + 6 = 246 min	114 min= 1 h and 54 min
5	Osmo-cum-microwave drying Osmotic Temperature: 45 °C Microwave power level: 810 watts	60 + 13 min = 63 min	287 min= 4 h and 47 min

- High energy efficiency in the falling rate period can be achieved. It is partially due to the fact that the energy is directly transferred to moisture, which eliminates the need to transfer heat from the low moisture surface into the high-moisture interior. It is also the result of an increased driving force for moisture transfer due to the generation of elevated internal vapour pressure.
- Case hardening may be avoided or lessened because of the surface moisture accumulation and the liquid pumping phenomena.
- An improvement in product quality can also be achieved. Better aroma retention, faster and better rehydration, better colour retention and higher porosity have been reported for microwave-dried food products.
- Reduce man-hours and downtime involved in cleaning.
- Minimize additional equipment such as heated jackets, boiling pans and heating and cooling vessels.
- Smaller equipment footprint.
- Eliminate warm up and cool down time.
- Microwave energy heats up only the food material, but not the entire chamber.
- Food product with better nutritional quality (No case hardening/ shrinkage and other surface damage), as moisture moves from inside out.

Drawbacks of Microwave Drying

The rapid and volumetric heat generation of microwaves has been utilized to improve conventional drying processes. But strictly speaking, a stand-alone microwave drying does not exist. Microwaves are used to assist or enhance another drying operation. The most widely used is a combination of microwave heating with hot-air drying.

- If microwaves are used in the initial stage of a drying, a rapid heating and evaporation often results in a high porous-dried product. Higher heating temperature owing to high moisture at initial stages results in colour darkening.
- Industrial adoption of this technique, nevertheless, has been slow. It may be partially due to some unique engineering problems associated with design of microwave drying chambers.
- A major drawback is the heating non-uniformity, stemmed from the uneven microwave field distribution in the cavity caused by the

superposition of the sinusoid microwaves. This is an inherent characteristic of microwaves.

- The control of the mass transfer rate raises another issue. In some cases, the mass transfer rate is too high, causing puffing and even disintegration of the product.
- Another factor negatively impacting the adoption of microwave drying is the relatively high cost and low life span of the magnetron.
- Another major drawback is the penetration depth of the microwave field into the products. Although microwave power at 915 MHz penetrates to a greater depth than does at 2450 MHz, in large-scale drying applications, the penetration depth is still much smaller compared to that attained in radio frequency (RF) heating at 10-300 MHz.
- One more drawback is that too rapid mass transport by microwave power may cause quality damage or undesirable changes in the food texture by 'puffing'. However, this may or may not be a limitation, depends upon the desired quality attributes of the final products.

Methods have been developed over the years to improve microwave heating uniformity. The remaining obstacles for the application of microwave drying could be a lack of understanding of the microwave interaction with product, a scarcity in dielectric property data, and a lack of an effective means to predict the moisture and temperature history and distribution during microwave drying. The reluctance of industry to adopt new technology also plays an important role hindering the application of microwave drying. Efforts have to be made to advance our understanding of the interactions between microwaves and food products. Means to predict the temperature and moisture distributions using coupled heat and mass transfer analysis has to be developed, which will help to enhance our understanding of the underlying physics and develop better strategies for the control of microwave drying processes.

Nutritional Benefits of Dried Food

Dried foods are tasty, nutritious, lightweight, ready-to-prepare, and easy-to-store and use. The energy input is less than what is needed to freeze or can, and the storage space is minimal compared with that needed for canning jars and freezer containers. The nutritional value of food is only minimally affected by drying. Vitamin A is retained during drying; however, because vitamin A

is light sensitive, food containing it should be stored in dark places. Yellow and dark green vegetables, such as peppers, carrots, winter squash, papaya, mango and sweet potatoes, have high vitamin A content. Vitamin C is destroyed by exposure to heat, although pre-treating foods with lemon, orange, or pineapple juice increases vitamin C content. Dried fruits and vegetables are high in fiber and carbohydrates and low in fat, making them healthy food choices. Dried fruit has a higher concentration of carbohydrate than fresh fruit and therefore serving sizes should be smaller. Half a cup of dried fruit is equivalent to one cup of fresh fruit. Diabetic individuals must especially take into consideration smaller serving sizes when planning meals and snacks to avoid elevated blood glucose levels.

Concluding remarks

India's diverse climate ensures availability of all varieties of fresh fruits and vegetables. But, it has lacuna in the processing front. There are many newer technologies available for the processing nowadays. But, making use of these technologies is of today's concern. In recent years, microwave drying has been gaining much popularity all over the world, for modern household food processing applications. Moreover, microwave drying technique has gained a renewed interest in both academia and industry. The unique volumetric heat generation and the increased mass transport rate in microwave drying are proven to be advantageous over traditional drying technologies, and as a result, microwave drying is featured by an enhanced drying rate and improved product quality. Progress has been made in recent years to expand the life span of magnetrons and lower the capital investment. Techniques to overcome the heating non-uniformity have also been developed. The techniques and instrumentation for the measurement of dielectric properties have been fully developed, and more and more dielectric properties have been measured and reported. Built upon these progresses, the heat and mass transport in microwave drying can be simulated with both simplified and comprehensive mathematical models. The models developed and validated with one food product can be used to investigate the drying of similar products, or in the design and optimization of the drying process. The use of fiber optic technique enables us to measure the temperature and pressure changes during drying, which can be used to validate the models developed. It is foreseeable that the further development of microwave drying technology, as well as more investigations into how to better simulate a microwave drying process, will stimulate the adoption of this relatively new generation drying method in the food industry.

