Application of radiation in food drying

Drying is the most widely used technique of food preservation. It is also used in materials production from agriculture, horticulture and other commodities each year. Several drying technique of its own characteristics have been developed. Sun drying, air drying, vacuum drying, and freeze-drying are traditional drying methods that have been applied industrially in the dehydration of various food items. Microwave drying and infrared drying are the two important methods which use radiation as source of heating method to dry the food products. These are discussed below:

1. Microwave drying

Microwaves are electromagnetic waves with the frequency varies from 300 MHz to 300 GHz. The frequency of the microwave oven is defined to avoid interference with communications. The lower the microwave frequency, the better the penetration. Generally speaking, to balance efficiency and cost, home microwave frequency is 2.45 GHz, while industrial microwave frequency is 915 MHz or 2.45 GHz. The microwave field is an alternating magnetic field, in which, polarity molecules from the original random thermal motion changes according to the orientation of the electric field direction (2.45 billion times per second). The ability of food material to convert microwave energy into heat can be understood by its dielectric properties. Dielectric properties show the nature of electrostatic energy saving and loss in the electric field, usually expressed as dielectric constant and dielectric loss. Non-uniformity is a characteristic of microwave processing. The microwave pattern is responsible for creating a hot spot and cold spot, and the hot spot is concentrated in a region where the electromagnetic field intensity is higher. Therefore, it is important to improve the uniformity during microwaving. Microwaving has been enormously applied in the field of food processing such as drying, heating or cooking, pasteurization and preservation of foods.

Like cooling and freezing, drying is a common processing method used in the food industry. In particular, microwave drying has many advantages, including lower shrinkage, lower bulk density, and higher rehydration ratio, dehydration rate and energy saving than traditional drying. However, more porous structure of foods caused by microwave drying occurs due to faster drying rate when compared with traditional drying. In addition, overheating normally results in scorching and the production of off-flavors especially during the final stage of microwave drying. Usually, in order to improve the drying rate and enhancing the quality of products, the microwave drying method and other traditional drying methods are employed in combination.

Microwave heating or cooking can retain high levels of bioactive components, antioxidant activity and attractive color of vegetables, when cooking without water or with a small amount of water. It can also decrease the antinutritional factors, meanwhile increase in in-vitro protein digestibility. However, microwave cooking with massive water can cause a great drop in nutrients due to leaching and thermal liability.

Microwave sterilization can not only effectively reduce the potential microorganisms in food to ensure food safety, but can also inactivate the enzyme to maintain the nutrition of food. Increase in microwave power and time increases the effectiveness. In addition, the non-uniformity of microwave sterilization can influence the quality of the product and shorten the shelf life.

Due to the above advantages, microwave processing techniques have been extensively used in the food industry. However, few reviews have been published in recent years summarizing the latest developments. Therefore, this review focuses on the applications of microwave processing technologies in the last few years. The technologies covered include microwave drying, heating or cooking, and sterilizing in vegetable, fruit and meat processing. Attentions are paid to the quality changes of food product after microwave processing and future research directions.

i. Mechanism of microwave drying

Microwave drying, such as vacuum-microwave drying, hot air microwave drying, microwave-far infrared combination drying, microwave-convective drying and microwave-freeze drying, is a complex process involving heat and mass transfer, which is based on the volumetric heating. Vapor is generated inside a food item and then spread through internal pressure gradient. Because of the strong penetrability of microwave, food inside and outside are heated at the same time and the temperature of food rises simultaneously.

Microwave drying translates the high frequency electromagnetic energy into heat, thus liquid moisture is intensively evaporated and transported toward the food material surface. In the process of microwave drying, two successive stages should be considered: liquid evaporation, and drying consisting of three stages including heating up, constant rate drying and falling rate drying.

ii. Moisture migration and distribution during drying process

During constant and falling rate-drying periods, effective moisture diffusion phenomenon shows an overall mass transport property of water in the food material, including liquid and vapor diffusion, vaporization-condensation, hydrodynamic flow and other possible mass transfer processes. The effective moisture diffusion coefficient is affected by many factors such as composition, moisture content, temperature, and the porosity of food material, which can be explained by the Fick's diffusion equation, and it is the only physical mechanism to transfer the water to surface.

In the process of microwave drying, effective moisture diffusion coefficient plays an important role as mass transfer is the key to the dehydration process. A higher microwave power usually results in a more porous structure and increases the temperatures of the food material. In addition, high temperatures usually cause the denaturization of cell membranes and phase transitions, greatly damaging the samples. Bound water in damaged tissues is easier to be removed as compared with that in less damaged tissues during microwave drying.

iii. Effects of microwave drying on food quality attributes

The quality of food products has some changes during microwave drying. These changes include optical properties such as color and appearance, sensory properties such as odor, taste and flavor, structural properties such as density, porosity and specific volume, textural properties, rehydration properties such as rehydration rate and rehydration capacity, and nutritional characteristics such as vitamins and proteins.

2. Infrared drying

Infrared (IR) radiation is a part of the electromagnetic spectrum as shown in figure below, and has both a spectral and directional dependence. IR has wavelengths ranging from 0.7 to 1000 μm and is classified into three different categories, near-IR (NIR), mid-IR (MIR), and far-IR (FIR), with corresponding spectral range of 0.75–1.4 μm, 1.4–3.0 μm, and 3.0–1000 μm, respectively. Water has very strong absorption of IR radiation at around 2.7–3.3, 6.0, and greater than 12.5 μm. The O–H bonds in water absorb IR energy and start to rotate with the same frequency as the incident radiation. This transformation of IR radiation to rotational energy causes the evaporation of water.

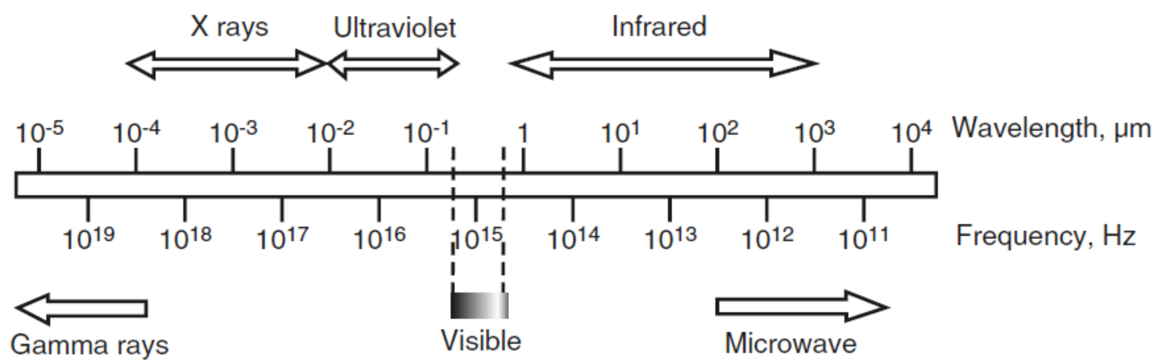

Fig. Electromagnetic wave spectrum

In IR heating, the temperature of IR emitter is directly related to the wavelength of the radiation. The relationship between the wavelength and temperature can be described by the basic laws for blackbody radiation, including Planck's law, Wien's displacement law, and Stefan–Boltzmann's law. The high temperature of NIR can result in rapid increase of product temperature and potentially reduce processing time, but risk overheating the product, causing product quality deterioration. If the operating temperature of the emitter is too low, it may not produce adequate radiant energy to meet the energy requirement for a thermal process of foods. Therefore, it is critical to select IR emitters with appropriate wavelengths and emissive power for different food processes.

In IR drying, also called thermal radiation drying, heat is transferred to the drying materials by radiant energy. In natural radiation drying (solar drying), radiation from the sun is tapped either directly or indirectly for drying purposes. Artificial IR drying involves the use of IR radiation generators or emitters. IR drying has been investigated as a potential method for obtaining high-quality dried foodstuffs, including fruits, vegetables, and grains. IR radiation drying is fundamentally different from convective drying because the material is dried directly by absorption of IR energy rather than transfer of heat from the air. IR energy is transferred from the heating element to the product surface without heating the surrounding air. The radiation impinges on the exposed material, penetrates it, and is converted to sensible heat. The penetration capability depends on the properties of the treated material and the temperature of the radiation source. The penetration provides more uniform heating in individual rice kernels and reduces the moisture gradient during heating and drying. In addition, due to radiation heating, the temperature of a rice kernel is not limited by the wet bulb temperature of the surrounding air and would become high in a short timeframe.

IR has several advantages over the conventional drying, including the high heat transfer rates, use of alternative energy source, increased energy efficiency, short drying time, easy control of material temperature, a reduced necessity for air flow across the product, high degree of process control parameters, space saving along with clean working environment, better product quality, and ability to achieve complete disinfestation and disinfection of foods. In IR drying, there is a very little absorption of heat by the space separating the product and emitter unless the intervening medium is saturated with water vapor. No direct contact with material is required as in conduction drying. IR radiation, similar to visible radiation (light), can be focused to increase heating intensity, provide fast treatments, or target a particular area. Energy efficiency of IR drying can be improved by placing IR source enclosed in a chamber with a highly reflective surface to take advantage of the multiple reflections within the enclosure. To achieve maximum uniformity of radiant flux density on the surface of foodstuffs being irradiated, there should be proper spacing between individual IR generators (if more than one unit is used) and the distance between the radiation sources and the foodstuff.

IR drying is not always easily applicable. Since foods usually come in complex shapes and sizes, the application of IR in such situations may be limited because energy impinging on the material will be different from place to place. Normally, IR modules are used to dry a thin layer of foods. The products to be dried can be in motion facilitated by a conveyor belt or a vibrating plate. Because IR radiation does not depend on the surrounding medium, the product surface can be quickly heated up to desired temperatures. However, allowing the temperature to rise too high and/or heating for extended periods of time is detrimental to the product quality. To prevent high product temperatures especially for heat-sensitive materials, intermittent heating and IR heating in combination with hot air drying or freeze drying have been practiced. Since, IR can be used to quickly heat rough rice in a single or thin layer to a relatively high temperature, it should be possible to use the sensible heat from the heated rice to remove more moisture during cooling, which could make the overall IR rough rice drying process more energy efficient.

Combination of IR and hot air drying has been used as an efficient and rapid drying method compared to hot air drying alone. The energy and operating costs of the combined drying mode are lower than convective drying systems for several food and agricultural products, particularly for the drying of heat-sensitive products. Use of tempering or holding treatment by maintaining the temperature of heated product after IR heating followed by natural cooling was found to reduce the moisture content of rice by up to 2.2% by using the sensible heat from heated rice without using additional energy and achieved high rice milling quality. In addition, IR heating followed by tempering and natural cooling inactivates lipase enzyme and significantly reduces the generation of free fatty acids in rough and brown rice. Controlling the IR radiation intensity or shortening the drying frequency by using intermittent IR drying has been used to minimize the changes in color and nutrients of dried product. Several studies proved that using IR for drying of food results in a better-quality product and saving of drying time and energy.