Microwave Heat treatment for Milk Processing

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Thermal processing has been a major processing technology in the food industry ever since the discovery of the process by Nicholas Appert and its subsequent commercialization. The purpose of thermal processing was to extend the shelf life of food products without compromising food safety. Variousthermal treatments such as pasteurization and sterilization can be selected on the basis of severity of theheat treatment and the intended purpose. Apart from inactivation of pathogens, thermal treatmentcan also result in some other desirable changes, such as protein coagulation, texture softening, and formation of aromatic components. However, the process has also got some limitation by way of partialdestruction of quality attributes of food products, especially heat-labile nutrients, and sensory attributes. (Ahmed, and Ramaswamy, 2014)

The technological revolution, nutritional awareness, and continuous demand of the new generation havenecessitated search for new or improved food processing technologies. Presently, several new food processingtechnologies, including microwave and radio frequency heating, pulse-electric field treatment, high-pressure processing, ultrasonic applications, irradiation, and oscillating magnetic fields, are beinginvestigated to improve, replace, or complement conventional processing technology.

Microwave heating of foods is attractive due to its volumetric origin, rapid increase in temperature, controllableheat deposition, and the easy clean-up opportunities. It is currently being used for a variety ofdomestic and industrial food preparations and processing applications. Microwaves are electromagnetic radio waves that are within a frequency band of 300 MHz to 300 GHz. Microwave oven operated at 915 and 2450 MHz, allocated by the International Telecommunications Union. Domestic ovens operate at 2450 MHz. (www.en.wikipedia.org)

Principle

Microwave heating refers to dielectric heating due to polarization effects at a selected frequency band in a nonconductor. Microwave heating in foods occurs due to coupling of electrical energy from an electromagnetic field in a microwave cavity with the food and its subsequent dissipation within food product. This results in a sharp increase in temperature within the product. Microwave energy is delivered at a molecular level through the molecular interaction with theelectromagnetic field, in particular, through molecular friction resulting from dipole rotation of polarsolvents and from the conductive migration of dissolved ions. Water in the food is the primary dipolar component responsible for the dielectric heating. In an alternating current electric field, the polarity of the field is varied at the rate of microwave frequency and molecules attempt to alignthemselves with the changing field. Heat is generated rapidly as a result of internal molecular friction.

The second major mechanism of heating with microwaves is through the polarization of ions as a resultof the back and forth movement of the ionic molecules trying to align themselves with the oscillatingelectric field. (Oliveira and Franca, 2002)

Advantages

i. Microwave penetrates inside the food materials and, therefore, cooking takes place throughout the whole volume of food internally, uniformly, and rapidly, which significantly reduces the processing time and energy

ii. Since the heat transfer is fast, nutrients and vitamins contents, as well as flavor, sensory characteristics, and color of food are well preserved.

iii. Minimum fouling depositions, because of the elimination of the hot heat transfer surfaces, since the piping used is microwave transparent and remains relatively cooler than the product

iv. High heating efficiency (80% or higher efficiency can be achieved)

v. Perfect geometry for clean-in-place (CIP) system

vi. Suitable for heat-sensitive, high-viscous, and multiphase fluids

vii. Low cost in system maintenance (www.en.wikipedia.org)

Factors Affecting Microwave Heating

Some physical, thermal, and electrical properties determine the absorption of microwave energy andsimultaneous heating behavior of food materials in microwave processing. These properties/factors arebriefly discussed below.

Frequency

For food application, only two frequencies are allocated for microwave heating (915 and 2450 MHz) and,therefore, these frequencies are of special interest. The corresponding wavelengths of these frequenciesare 0.328 and 0.122 m, respectively. The wavelength has special significance as most interactionsbetween the energy and materials take place in that region and generate instantaneous heat due to molecularfriction. Food constituents except moisture, lipids, and ash are relatively inert to prescribedmicrowave frequencies. In addition, frequency (or wavelength) dictates equipment components such asmagnetron, waveguide, and to some extent heating volume.

Dielectric Properties

The electrical properties of materials in the context of microwave and radiofrequency heating are knownas dielectric properties, which provide a measure of how food materials interact with electromagneticenergy. Biological materials may be viewed as nonideal capacitors in that they have the ability to storeand dissipate electrical energy from an electromagnetic field and the properties can be expressed in terms of a complex notation. The complex notation is characterized by dielectric permittivity with a real component, dielectric constant, and an imaginary component, dielectric loss (Von Hippel, 1954).

Moisture Content

The moisture content significantly affects the dielectric properties of the food product and consequently penetration depth of the microwaves. Uneven heating rate is observed in high-moisture foods because of low microwave penetration depth. Low-moisture foods will have more uniform heating rate because of the deeper microwave penetration. The initial moisture content of the product and the rate of moisture evaporation play important roles during microwave heating. The heating behavior of water is phase dependent (liquid water versus solid ice phase) and also depends on the available free water content (Mudgett, 1989).

Mass

A direct relationship exists between the mass and the amount of absorbed microwave power, which should be applied to achieve the desired heating. For a smaller mass, batch oven is suitable, while a larger through put would often be better in large capacity equipment with conveyor. Such equipment has the added advantage of providing greater heating uniformity by moving the product through the microwave field. Each microwave oven has a critical (minimum) sample mass for its efficient operation. It is usually around250 ml water load in a 1 kW oven. Below this level, significant amount of microwave power is notabsorbed into the product, and at very low loads they may damage the magnetron.

Temperature

Microwave heating is significantly affected by the level of sample temperature. Dielectric properties mayvary with temperature, depending upon the material. Both temperature and moisture content can changeduring heating and therefore, those may have a combined effect on the dielectric constant, dielectric lossfactor, loss tangent, and subsequently on the heating behavior. The initial temperature of the food product being heated by microwaves should either be controlled orknown, so that the microwave power can be adjusted to obtain uniform final temperatures. If themicrowave oven is preset to increase the product temperature from 20°C to 80°C, it will practically reacha target temperature of 95°C with an initial product temperature of 35°C. To compensate the effect of higher initial temperature, the power of MW oven should be reduced or a higher sample mass should beused or the product should be heated for a shorter duration. (Mudgett, 1989)

Geometry and Location of Foods

The shape of the food product does play an important role in the distribution of heat within the productheated in a microwave oven. It affects the depth of microwave penetration, and the heating rate anduniformity. Irregular-shaped products are subjected to nonuniform heating due to the difference in productthickness. The closer the size (thickness) is to the wavelength, the higher will be the center temperature.Smaller particulates require less heat than larger ones. In addition, the more regular the shape,the more uniform will be the heat distribution within the product. A food of a spherical or cylindricalshape heats more evenly than a square. A higher surface-to-volume ratio enhances the heating rate.Therefore, the heating rate for a sphere will be different from that of a cylinder with the same volume. Placement has the most significant effect.

Thermal Properties

The heating characteristics of foods are dependent to a greater or lesser extent on some thermal propertiessuch as thermal conductivity, density, and heat capacity. Thermal conductivity of food plays a significantrole in microwave heating. Materials with higher thermal conductivity dissipate heat faster than the ones with lower conductivity during microwave heating. Food with high thermal conductivity will take lessertime to attain uniform temperature during holding. (Ahmed and Ramaswamy, 2014)

Application in food industry

The major industrial applications of microwave heating are tempering of frozen meat and poultry products;precooking of bacon for foodservice; sausage cooking; drying of various foods; baking of bread,biscuit, and confectionery; thawing of frozen products; blanching of vegetables; heating and sterilizingof fast food, cooked meals, and cereals; and pasteurization and sterilization of various foods.(Khattarpaul, 2005)

Application in Dairy Industry

Milk is traditionally pasteurized in a heat exchanger before distribution. The application of microwave heating to pasteurize milk has been well studied and has been a commercial practice for quite a long time. The success of microwave heating of milk is based on established conditions that provide the desired degree of safety with minimum product quality degradation. Since the first reported study on the use of a microwave system for pasteurization of milk (Hamid *et al.*, 1969), several studies on microwave heating of milk have been carried out. The majority of these microwave-based studies have been used to investigate the possibility of shelf-life enhancement of pasteurized milk, application of microwave energy to inactivate milk pathogens, assess the influence on the milk nutrients or the non-uniformtemperature distribution during the microwave treatment (Koutchma *et al.*, 1998)

Batch Heating

In the batch process, the magnetron-based microwave ovens are commonly used for the heating purpose. The food sample is placed in the oven for a predetermined time to achieve a target temperature. The power level is normally adjusted to achieve a certain desired temperature difference in a given time frame.

Continuous-flow microwave treatment

Continuous-flow microwave treatment has been proposed for milk pasteurization due to its potential advantages over the conventionaltubular and plate heat exchangers. Continuousmilk pasteurization at 2450 MHz using asimple waveguide heat exchanger was firstreported by Hamid *et al.*(1969). Raw milk waspassed through a glass tube fitted across awaveguide, and milk was exposed to microwave energy during gravity falling. The plate counts were found to be negative whilethe temperature reached 82.2°C. Jaynes (1975) developed an experimental continuous-flowmicrowave pasteurizer using a Teflon tube(12 cm/0.635 cm) placed across a 2450 MHz microwave guide. The system had 15 seconds holding time. The adequacy of pasteurization was considered on the basis of inactivation of phosphatase enzyme, standardplate, and coliformcounts.

HTST sterilization

HTST sterilization of raw milk has also been tested under microwave field at 2450 MHz. The process was done in free-falling stream of milk with pressure application. Heating was reported to be extremely rapid with a temperature rise of 200°C; holding was less than a second while the cooling was done by turbulent mixing with cold sterilized milk. However, the process was not considered economically feasible. Kudra *et al*. (1991) used a domestic Microwave oven for continuous-flow pasteurization of milk and its constituents. The protein in milk was found to be the contributing component to dictate the heating pattern in milk pasteurization, while effects of fat and lactose were considered negligible.

Coronel *et al*.(2003)experimented on continuous-flow microwave heating of milk at 915 MHz using a cylindrical microwave applicator. The microwave field inside the applicator generated a parabolic field distribution inside the tube for a fluid with constant dielectric properties, like those of milk at 25°C. The system was designed in such a fashion that the fastest moving particles residing at the center would receive maximum power for a shorter period, whereas the slowest moving particles at the wall side would receive minimum power for a larger period. The system was reported to exhibit a relatively even distribution of temperature for milk in the cross-sectional area of the tube at the exit of the applicator.

Temperature distributions data revealed that the hottest temperature was found at the center of the tube, while the cooler temperature was close to the walls of the tube.

Effect on Milk Nutrients

Milk is a rich source of vitamins and heat treatment affects some of these nutrients. The effects of microwave heating on several vitamins in cows' milk have been studied by many researchers.

- ✓ Sierra *et al.* (1999) research in milk B1, B2 and B6 vitamins studied continuously operating microwave and conventional (tube heat exchanger) heating methods. They found that 3.4 % and 0.5 % fat milk at 90 °C with a heat treatment method did not cause vitamin loss.
- ✓ Moststudies report an insignificant loss in vitamin A,carotene, vitamin B1 or B2 in microwave-pasteurizedmilk, while losses of approximately 17% for vitamin E and 36% for vitamin C have been found. Compared the heat stability of vitamins B1 and B2 in milk between continuous microwave heating and conventional heating having the same heating, holding, and cooling steps. No significant losses in the vitamins were reported during microwave heating at 90°C without holding period, while vitamin B2 was found to decrease by 3%–5% during 30–60 s of holding.
- ✓ Microwave pasteurization of milk was reported to result in lower levels of denaturation of whey proteins compared to conventional thermal processes and that the denaturation of β-lactoglobulin was almost similar in both processes. Moreover, the process yielded lower microbial counts and lower lactose isomerization. (Lopez-Fandino *et al*., 1996)
- ✓ The inactivation of *Streptococcus faecalis, Yersinia enterocolitica, Campylobacter jejuni*, and *Listeria monocytogenes* in milk by microwave energy has been reported by (Choi *et al*., 1993 a, b) The complete inactivationof *Y. enterocolitica, C. jejuni,* and *L. monocytogenes* occurred at 8, 3, and 10 min when the cells were heated at a constant temperature of 71.1°C using microwaves.

Conclusion

Microwave energy has advantages over conventional heating. Continuous-flow microwaveable pasteurizers could be used for milk as Commercial size microwave equipment is now readily available for pasteurization and sterilization applications.

The main obstacles to industrial setup of MW heating processes are the difficulties in controlling the process and the high energy costs associated with this technology.

Moreover the food industry and the consumer are very conservative about the use of new technologies.

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