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Radio Frequency Heating : Application in Food Processing and Preservation

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ABSTRACT

Radio frequency (RF) heating is an emerging technology in food processing and preservation due to its distinct advantages like uniform heat distribution, large penetration depth, low energy consumption, and providing safe and good quality food products. RF heating could be applied for baking, drying, thawing of frozen foods, pasteurization and sterilization, blanching of vegetables, post harvest insect control and aseptic processing of particulate food. A review of the major application of RF heating in food processing has been presented in this paper.

Introduction

Radio Frequency (RF) heating is done in the MHz part of the electromagnetic spectrum. The frequencies of 13.56 and 27.12 MHz are used for industrial heating applications. Foods are heated by transmitting electromagnetic energy through the food placed between an electrode and the ground. RF drying has been successfully used in the textile and furniture industries and its use has progressively grown in other industries such as food processing and paper manufacturing.

RF heating applications in the food processing industry has been recognized since the 1940s. The initial attempts to use RF energy were for cooked processed meat, to heat bread and to dehydrate vegetables. RF post-baking of biscuits, cereals and RF drying of foods are well-established applications. These RF systems have been recognized to be 70% efficient in removing moisture in comparison to 10% efficiency in conventional ovens (Mermelstein, 1997). RF drying is mainly used to boost drying capacity (to remove free water rapidly without generation of large thermal gradients in the material) or to remove the last few percentages of water, which comes out very slowly. RF drying applications in the food industry include the drying of food ingredients (e.g. herbs, spices, vegetables), potato products (e.g. French fries) and a number of pasta

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products. A rapidly growing application of RF in the food processing industry is for the bulk defrosting of meats and fish.

In conventional heating, once the food surface dries, they often form a thermal barrier layer, making it difficult to heat the inner parts. But in RF drying, there is uniform drying throughout the product, which improves product quality. The volumetric heating process in RF drying, removes the risk of overheating food surfaces while transferring heat to the inner parts. The efficiency of convection dryer drops significantly at lower moisture content because the dried surface behaves as thermal insulator whereas the RF dryer provides an energy-efficient means for achieving the desired moisture level.

There are three frequencies namely ohmic (50/60 Hz), radio (10-60MHz) and microwave (1-3 GHz), which are employed for direct heating of food. Energy is transferred from the electromagnetic source to the food without heating the heat transfer surfaces (processing equipment) in these methods. The RF heating offers simple uniform field patterns as opposed to the complex non-uniform standing wave patterns in a microwave (MW) oven. Both the RF and MW are considered a part of non-ionizing radiation because they have energy (< 10 eV) insufficient to ionize biological atoms. Since these waves lie in the radar range and can interfere with communication systems, only selected frequencies are permitted for domestic, industrial and scientific applications (Piyasena et al., 2003).

Radio Frequency Heating

In food processing and preservation, RF heating has the following advantages over the microwave and ohmic heating:

i. Contactless heating: The heating mechanism is same as ohmic heating, but RF does not require the electrodes to be in contact with the food. So RF heating can be applied to solid as well as liquid food materials.

ii. Increased power penetration: RF waves are longer than microwaves, allowing them to penetrate larger objects. This helps in avoiding surface overheating, as well as hot or cold spots, as found in microwave heating.

iii. Simple construction: Large RF applicator systems are generally simple to construct than the microwave ones. The longer wavelength of radio frequencies allows relatively large entry and exit ports (2m wide ports are common).

iv. Uniform moisture leveling: In RF drying, there is uniform drying throughout the product. The variation in the dielectric loss factor for food materials with moisture content is more in case of RF than MW. Hence, RF heating for drying leads to improved moisture leveling and accordingly, better quality products.

In RF heating, the RF generator creates an alternating electric field between two electrodes. The material to be heated forms a dielectric between the electrodes, which are alternatively charged positive and negative by high frequency electric field. The polarity changes rapidly (at 27 MHz, i.e., 27 million times/second), causing polar molecules in the water to continuously reorient them to face opposite pole. Reversing the charge causes the molecules to rub against one another. The friction causes the water in the material to rapidly heat up.

Knowledge of dielectric properties of food materials is necessary for development, improvement and scaling-up of RF treatment protocols for large scale processing plant. Permittivity is one of the dielectric properties that influence reflection of electromagnetic waves at interfaces and the attenuation of the wave energy within materials. The relative permittivity ε of a material is expressed as:

$$\varepsilon = \varepsilon' - i\varepsilon''$$

The real part ε' is the dielectric constant and is characteristic of the material that describes its ability to absorb, transmit and reflect energy from the electric portion of RF waves. The imaginary part ε'' is the dielectric loss factor, which determines energy absorption from electric fields passing through it and conversion into heat. Another important concept in the dielectric heating is the power penetration depth, defined as the distance an incident electromagnetic wave can penetrate beneath the surface of a material as the power decreases to $1/e$ of its power at the surface (Buffler, 1993). The heat generated in the food product depends on the frequency, the square of the applied voltage, dimensions of the product and the dielectric loss factor.

The factors affecting the dielectric properties of food materials are frequency, temperature, salt content, moisture content, the state of moisture (frozen, free or bound) and chemical composition. Many studies on dielectric properties of foods and agricultural products have been reported for MW heating (Ryynanen, 1995; Berbert et al., 2001) and RF heating (Nelson, 1992) at different frequency ranges, temperatures and moisture contents.

Applications of RF Heating

1. Baking. The post-baking of biscuits (Holland, 1974) is one of the most accepted and widely used applications of RF heating in the food processing industry. This technology is uniquely suited to removing moisture from products where it is most difficult for the conventional oven heat to reach. It thus provides the benefits of increased productivity and improved quality to a broad range of bakery products. An RF post-baking dryer gives the baker a greater ability to control final moisture content and uniformity throughout the product, which provide the benefits like up to 40% increase in productivity, virtual elimination of checking, control over product color and longer shelf life. This process has also been found effective for cereal, pastry and bread products. More recently, the RF system has been incorporated directly into the hot air oven, allowing RF-assisted baking of a wide range of products to be carried out in a very compact unit.

2. Drying. The limitation of heat transfer in conventional drying with hot air, particularly during falling rate period, can be overcome by combining RF heating with convective drying. RF generates heat volumetrically within the wet material by the combined mechanisms of dipole rotation and conduction effects, which speed up the drying process. Since water moves through the product in the form of a gas rather than by capillary action, migration of solids is avoided. Warping, surface discoloration and cracking associated with conventional drying methods are also avoided. Closer tolerance of the dielectric heating frequency, 13.56 MHz ± 0.05%, 27.12 MHz ± 0.60% and 40.68 MHz ± 0.05%, significantly improves the control over internal drying and is best for the industry that requires precision moisture removal. The simultaneous external and internal drying reduces the drying time to reach the desired moisture content. A smaller heat pump can double or triple the drying capacity, with the help of supplementary heating by RF (Chou and Chua, 2001). RF heating combined with convection or vacuum drying can reduce the energy consumption (Mujumdar, 2004). RF drying is intrinsically self-leveling, with more energy being dissipated in wet regions than in dried ones (Jones and Rowley, 1997).

3. Thawing of frozen foods. The growing application of RF in the food processing industry is its use for the bulk defrosting of meat and fish. Cathcart et al. (1947) used a unit at 14-17 MHz and 3 kW RF to thaw frozen eggs, fruits, vegetables and fish. The RF thawing times were in minutes compared to hours in conventional thawing and quality of product was better in the former due to minimum color and flavor loss. The RF thawed product was found to have better odor, flavor and less drip loss. The volumetric nature of RF heating allowed the thawing process to be faster, while maintaining the temperature distribution within the food product.

4. RF pasteurization and sterilization. RF heating for pasteurization and sterilization are preferred to conventional heating because they require less time to come up to the desired process temperature, particularly for solid and semi-solid foods. In addition to the shorter heating time, less changes in the quality attributes of the product were noticed in the RF treated product compared to the retort-sterilized product (Wang et al., 2003). RF pasteurization of moving sausage emulsions was reported by Houben et al. (1991). Sausage products using RF heating had a good appearance, smooth surface, and did not show moisture or fat release.

As public concern over food safety issues is continuing to grow, and the demand for convenience food is on the rise, RF pasteurisation and sterilisation processes are likely to gain more importance. An RF-based sterilization heating process has been suggested for low acid foods such as macaroni and cheese.

5. Blanching of vegetables. It is possible to blanch greater bed depths of vegetables with RF blanching compared to steam and water. Steam and water blanching require the product to have contact with the steam or water in order to heat but not in case of RF blanching. Blanching vegetables using RF heating limits the loss of nutritive value but results in poor flavor and color. A variety of vegetables have been reported to be blanched using a self-excited oscillator with a potential power output of 750 W at 150 MHz (Moyer and Stotz, 1947).

6. Post harvest insect control. There has been an increasing interest in using RF heating as a new thermal treatment method for post harvest insect control in agricultural commodities (Tang et al., 2000). Thermal treatments for insect control using RF leave no chemical residues on products, have acceptable quality and have minimal impacts on the environment. Nelson (1996) had summarized research on the application of RF and microwave treatments to kill selected pests in many crops.

7. Aseptic processing of particulate food. Conventional heating of particulate foods usually starts by a convective heat transfer between a carrier medium and a particle surface followed by the conduction inside a particle. Therefore, temperature at a particle surface is always higher than that at a particle center. So for particulate products, aseptic processing using conventional heating method is still questionable due to uncertainties associated with particle residence time distribution and associated heat transfer. Ohmic heating and MW heating are considered as alternatives to conventional heating for particulate foods.

Ohmic heating was tried for liquid containing particles because the applied electric field heated the liquid and particles simultaneously (Khalaf and Sastry, 1996). But technical complexities such as faster heating of particles, runaway heating, and reformulation of the product to obtain the desired electrical conductivity, have limited its industrial application in aseptic processing. Microwave heating of liquid containing particles could also cause significant temperature gradients inside particles, depending on particle geometry and microwave frequency (Ohlsson and Risman, 1978).

Future Research Needs in RF Heating

The problem in RF heating is dielectric breakdown (arching), if the electric field strength across the sample is too high and thermal runaway heating, which can lead to both packaging failure and product destruction. Burning of packaging material was observed during RF heating of vacuum packaged seafood (Kolbe, 1996). The use of RF heating to pasteurize packaged food products causes packaging failure. However, this could be avoided by proper selection of packaging materials. But this requires detail studies of dielectric properties of various packaging materials over a wide range of frequencies and temperatures. There is also a need of detail studies of RF dielectric properties of various foods as functions of frequency, temperature, water content, viscosity and composition.

The detail economic study is needed to evaluate the cost of applying RF technology in food processing and preservation to get wider commercial application. Although some studies have been done to estimate energy efficiency and cost but mainly on old technologies. So there is a need of updated economic analysis of RF heating considering latest technologies available and its economics in comparison to other technologies available for food processing and preservation. There is also a lack of detail studies of RF dielectric properties of various foods as functions of frequency, temperature, water content, viscosity and composition.

Conclusions

RF heating could be successfully used as food processing and preservation technology. Further research work is needed to evaluate the dielectric properties of food and packaging materials for better utilization of RF technology. Evaluation of cost economics of applying RF technology is also needed.

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