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# RADIO FREQUENCY HEATING AND ITS APPLICATION IN FOOD PROCESSING: A REVIEW

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Radio frequency (RF) heating is an advanced and emerging technology for food application because of its higher penetration depth, heat distribution and low energy consumption. Due to this reason, RF has entered the food industry to sterilize, pasteurize, disinfect food and agricultural commodity like fruits and dry nuts, post baking and in many other applications. The demand for safe, hygienic, tastier, no fat and preservative free food has widened up RF application in the modern industries. The paper aims to review the RF heating and its status of application in food processing. It also emphasizes on application of RF heating highlighting the impact on general quality aspects of food and describes the advantage and drawback of the RF system.

**Key words:** RF heating, Food processing

## INTRODUCTION

Radio frequency heating forms a part of innovative techniques based on electromagnetic heating and other non-thermal methods have the potential of providing high quality foods economically. Electro heating can be sub-divided into either direct electro heating where electrical current is applied directly to the food (e.g. ohmic heating (OH)) or indirect electro heating (e.g. microwave (MW) or radio frequency (RF) heating) where the electrical energy is firstly converted to electromagnetic radiation which subsequently generates heat within the product. Radio frequency heating applications have been very successful in the non-food industry, including paper, lumber and plastic. Although quite limited in terms of its application in the food industry as a whole, the consumer demand for ever-tastier, ever-cheaper, low or no-fat, chemical free and safe products have recently extents its application in the food processing. RF heating in current scenario is the preferred method in modern industries for product cooking, baking, drying, pasteurization and other applications (Orsat *et al*., 2005).

The mechanism of radio frequency heating is that the molecules within a product placed in an RF environment re-orient themselves (27 million times/s at 27 MHz) continuously in response to the applied field. This response initiates volumetric heating within the entire product due to frictional interaction between the molecules, thus selectively heats only the product and not the air or equipment surrounding it. Radio frequency heating is accomplished through a combination of dipole heating and electric resistance heating resulting from the movement of dissolved ions present in the food. Although identical to the other electromagnetic heating methods, radio frequency with electromagnetic waves in 30-300MHz spectrum has the added advantage of uniform heating in homogeneous foods and most important of all, high penetration depth that could be used to pasteurize or sterilize liquid products. Rapid heating, as a primary advantage of RF heating allow faster line speeds and shorter line lengths for semi continuous as well as continuous unit operation in food industries (Rao *et al*., 2005). The potential use of RF technology for food processing was recognized after World War II. Sherman (1946) described 'electric heat' and suggested possible applications for the processing of food. These early efforts employed RF energy for applications such as the cooking of processed meat products, heating of bread, dehydration and blanching of vegetables. However, the work did not result in any commercial installations, predominately due to the high overall operating costs of RF energy at that stage. By the 1960s, studies on the application of RF energy to foods focused on the defrosting of frozen products, which resulted in several commercial production lines (Jason and Sanders, 1962). Demeczky (1974) also showed that juices (peach, quince and orange) sealed in bottles and carried on a conveyer belt through an RF applicator had better bacteriological and organoleptic qualities than the juices treated by conventional thermal methods suggesting potential applications in heat processing for preservation of foods. The next generation of commercial applications for RF energy in the food industry was post-bake drying of cookies and snack foods which began in the late 1980s (Rice, 1993; Mermelstein, 1998). Later in 1990s, the area of RF pasteurization was studied with attempts made to improve energy efficiency and solve technical problems such as run-away heating (Houben *et al*., 1991; Zhao *et al*., 2000). This in turn has led to recent investigations on RF applicator modifications and dielectric properties of food at RF frequencies (Laycock *et al*., 2003; Zhang *et al*., 2004a, 2006b, 2007c; Birla *et al*., 2004). The most recent focus is on drying, post-baking, pasteurization of juices especially apple juices and other high value produce, waste water treatment in diary industries, disinfection in agricultural produce especially walnut, red and black pepper, poultry and fish industries along with the future expansion of the technology were reported. (Geveke *et al*. (2008); Ukuku *et al*. (2010); Tiwari *et al*. (2011); Wang *et al*. (2012); Kirmaci *et al*. (2012).

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## RF HEATING Vs CONVENTIONAL HEATING METHODS AND OTHER ELECTRO MAGNETIC METHODS

The Conventional heating methods involves conduction, convection and radiation heat transfer. In conventional heating at higher temperature the product is hot and can dry outside leading to relatively cold and wet inside surface and this cannot considered efficient because the dry outer layer acts as an insulating barrier and reduces the conduction heat transfer giving produce less quality and shelf life attributes. In contrast electro heating (e.g. OH, MW and RF) differs from conventional heating in that heat is generated volumetrically within the material by its interaction with, either

**Table: 1.Publications after 2003 which presents dielectric property of Radio frequencies**

| Author and Year | Frequency (MHz) | Product assessed | Temperature ($^0$C) |
|---|---|---|---|
| Wang *et al*., (2003) | 27 and 40 | Whey protein gel, Marconi noodles, cheese sauce | 15-120 |
| Zhang *et al*., (2004) | 27.12 | Luncheon roll and white pudding meat batter | 5-85 |
| Holy *et al*., (2004) | 27 | Caviar | 60-65 |
| Lagunas-Solar *et al*., (2005) | 0.01-120 | Fish Meal | 70-90 |
| Brunton *et al*., (2006) | 27.14 | Beef muscles | 5-90 |
| Luechapattanporn *et al*., (2008) | 27 | Mashed Potato | 20-52 |
| Geveke *et al*., (2008) | 0.02-27 | Pasteurization | 28-55 |
| Ukuku *et al*., (2010) | 0.02 | Apple Juice | 25-45 |
| Tiwari.G *et al*., (2010) | 0.012-27.12 | Dry foods | 56 |
| Casals .C *et al*., (2010) | 27.12 | Peaches and Nectarines | 15-75 |
| Uemura *et al*., (2011) | 28 | Soybean milk | 115 |
| Wang *et al*., (2010) | 27.12 | Lentils | 60 |
| Youn Kim *et al*., (2011) | 27.12 | Black and red pepper | 60 |
| Jian Wang *et al*., (2011) | 1-1800 | Meat Lasagna | 20-121 |
| Youn Kim *et al*., (2011) | 27.12 | Black and Red pepper | 60 |
| Kirmaci *et al*., (2012) | 27.12 | chicken breast meat | 74 |

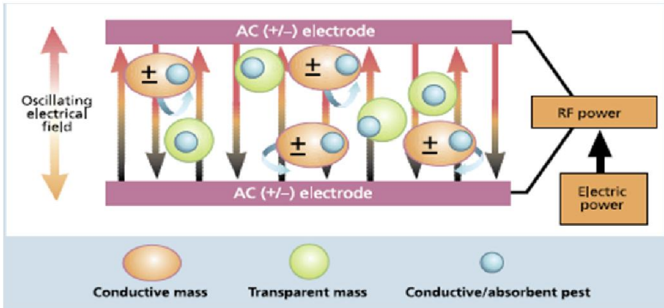
alternating electrical current (as in OH) or electromagnetic radiation MW (300–3000 MHz) or RF (1–300 MHz) frequencies (Marra., 2008). Electro heating technologies differ in terms of their methods of application (Orsat *et al*., 2005). In MW heating, the waves generated by a magnetron pass via a waveguide into an oven cavity in which they essentially bounce around off the metal walls of the cavity interior causing effect on the product from many directions. Whereas in ohmic heating, the product is placed in direct contact with a pair of electrodes through which generally a low frequency traditionally 50 or 60 Hz alternating current is passed into the food product. RF heating also involves the use of electrodes were the product being placed in the high frequency electric field causes polarization of the molecules. Thus, friction resulting from the rotational movement of the molecules and the space charge displacement causes the material to heat rapidly throughout its mass. The known difference between RF and ohmic heating is that RF heating does not require any direct contact between the product and electrodes i.e. RF waves will penetrate through conventional cardboard or plastic packaging were as in case of ohmic heating, the product needs to be either unpackaged or should be in direct contact with the electrodes. It is also important to understand the difference between radio frequency (RF) and microwave (MW), because both lies nearer in the electromagnetic spectrum of wavelength, providing conventionally similar characteristics, thus applied the difference lies principally on the technology. In RF, an electric field is developed between electrodes while in MW, it is a wave being propagated and reflected under the laws of optics (Marra *et al*., 2007). RF works well with large quantities having high ionic conductivity and MW works well with smaller quantities of a dipolar nature.

## PRINCIPLE AND MECHANISM OF RF HEATING

The RF portion of the electromagnetic spectrum occupies a region between 1 and 300 MHz although the main frequencies used for industrial heating lie in the range 10–50 MHz (Tang. J *et al*., 2005), within the latter range only selected frequencies namely 13.56 ± 0.00678, 27.12 ± 0.16272 and 40.68 ± 0.02034 MHz are permitted for industrial, scientific and medical applications (Marra *et al*., 2007). In general food materials are poor electric insulators. They have the ability to store and dissipate electric energy when subjected to an electromagnetic field. The principle of absorption of this energy is described by Maxwell's equations. In practice, a relative complex permittivity $\varepsilon^*=\varepsilon/\varepsilon_0$ is used where $\varepsilon_0=8.8542\times10^{-12}$ F/m is the permittivity of free space. This relative complex permittivity $\varepsilon^*$, is composed of two properties $\varepsilon$ (called the dielectric constant) and $\varepsilon''$ (called the dielectric loss factor), are the component responsible for dielectric heating. This dimensionless number measures the ability of the material to interact with the electric field of RF.

The dielectric constant is the measure of the food material's ability to store electromagnetic energy; whereas dielectric loss factor is the material's ability to dissipate electromagnetic energy. The relation between relative complex permittivity, dielectric constant and dielectric loss factor is explained equation (1).

$$\varepsilon^* = \varepsilon' - j\,\varepsilon'' \quad \text{-------------} \quad (1)$$




**SOURCE**: (Lagunas-Solar MC *et al*., 2005)

**Fig. 1. RF heating mechanism**

The working of a simple RF heater can be explained as the RF energy generated is applied to material via a pair of electrodes (Rowley *et al*., 2001). In a radio-frequency heating system, the RF generator creates an alternating electric field between two electrodes. The material to be heated is placed in between the electrodes where the alternating energy causes polarization of the molecules, thus continuously reorient themselves to face opposite poles. In another words, the energy absorption involves primary two mechanisms - dipolar relaxation and ionic conduction. Water in the food is often the primary component responsible for dielectric heating. Due to their dipolar nature, water molecules try to follow the electric field associated with electromagnetic radiation as it oscillates at very high frequencies, thus producing heat. Secondary mechanism of heating is through the oscillatory migration of ions in the food that generates heat. The amount of heat generated in the product is determined by the frequency, the square of the applied voltage, dimensions of the product and the dielectric loss factor of the material, which is essentially a measure of the ease with which the material can be heated by radio waves. RF power is produced when electricity is applied to an RF generator whose signal is amplified and delivered to a parallel electrode system (RF cavity), in which the selected material is placed.

## APPLICATION OF RF IN FOOD INDUSTRY

RF heating in food processing applications are less common than that of MW heating, though a number can be found in the literature works.

Zhao *et al*. (2000) and Piyasena *et al*. (2003) extensively discussed RF heating applications. Since then, more work has appeared in the literature showing several additional applications for RF heating in food processing. In living matter, thermal sensitivity is in inversely proportional to biological complexity and therefore, organisms with a high degree of biological complexity have similarly high sensitivity to thermal energy. Based on this postulate, the following trend has been tested and demonstrated:

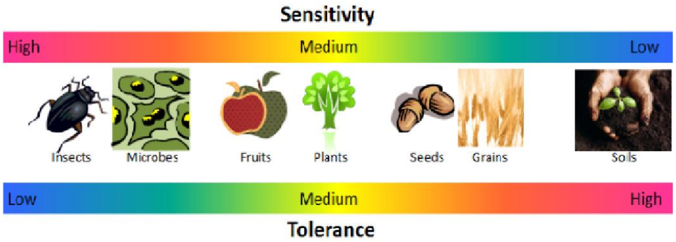



**Fig. 2. Thermal and tolerance on living matter**

## MEAT AND FISH PRODUCTS

Meat and fish are perishable produce similar to that of fruits and vegetable which requires higher preservation techniques. These produce are usually conventionally heated, sterilized, canned and stored. Both have problems associated with conventional methods during heating and storage. The research work using RF heating mechanism in meat and fish product processing have significant effect on nutrition, quality, quantity and storage of the produce. Wang *et al*., (2012) reported that the RF heating at 27MHz and applying an alternating current of 6kW can be used to process pre-packaged heterogeneous foods (meat lasagna in large polymeric containers (295 x 253 x 42 mm)) to retain product quality better compared to conventional method of heating. Computer simulations were also conducted to evaluate the influence of the dielectric properties of each food component on the electric field distribution and heating pattern during RF heating. Many recent advances have been developed in the RF heating of meat and fish products, such as fish meal, used widely as a feed ingredient in balanced diets for aquaculture and animal production because of its high protein content and in vivo digestibility. The RF process operated in the 70-90ºC range and with high efficiency (50%), which compares well with the 10-15% efficiency for conventional surface heating methods has shown the uniform and deep penetration of RF waves resulting in rapid and homogeneous heating provide greater than 99.999% reduction in infection levels for *Salmonella sp*., and for *Escherichia coli O157:H7* when compared to the sample kept at control. Simultaneously, the natural flora was reduced by greater than 99.9% adding quality attribute to the treated products (Lagunas-Solar *et al*., 2005).

Comparison study on conventional and RF heating of *Listeria monocytogenes* in ready-to-eat aquatic foods such as caviar concluded that RF pasteurization carried at 25MHz providing 60˚C, 63˚C and 65˚C variation in temperature, reported that at higher temperature of 65˚C *L. innocuacells* microorganisms are completely inactivated and the visual quality of the caviar products treated by RF was good and acceptable compared to the conventional pasteurization processes affect the texture, color, and flavor of these foods (Holy *et al*., 2004). Kirmaci *et al*., 2012 reported the effect of RF cooking on the quality, temperature distribution and heating rate of chicken breast meat at 27.12 MHz until the center of the breasts reached to 74 °C. When the method of heating is compared to the conventional heating methods it is explained that the time to reach end point temperature in the RF oven was significantly less compared with water bath (conventional method), where as the cook yield, moisture content, pH, expressible moisture, shear value of RF and water bath (WB) cooked chicken breast meat were statistically the same. The most extensive investigations on the processing and the quality of RF cooked meats were published between 2004 and 2007 (Brunton *et al*., 2005; McKenna *et al*., 2006; Tang. X *et al*., 2005, 2006; Zhang *et al*., 2004a, 2006b; Lyng *et al*., 2007) by a team from UCD Dublin, Ireland, who heated products using a 27.12 MHz RF applicator with a maximum power output of 600W included RF as the best and upcoming method to be considered in meat and fish processing industries.

## LIQUID FOODS

Research in RF technology has stated the possibility of sterilizing or pasteurizing a food product at time-temperature values much lower than those now required using conventional heating techniques. Commercially, the benefit of using RF energy comes from a potential selective killing effect on microorganisms along with the rapid heating and high penetration of RF energy. Heating of starch and guar solutions in continuous flow was investigated respectively by Awuah *et al*. (2002) and Piyasena and Dussault (2003), in order to evaluate the effect of system parameters that is the flow rate and RF power at 1.5 kW, 27.12 MHz. Awuah *et al*. (2005) used a 2 kW, 27.12 MHz, RF applicator in order to find best conditions to inactivate surrogates of both *Listeria* and *E. coli* cells in milk under continuous laminar flow conditions. The impact of RF treatment on microbial inactivation in orange and apple juices and in apple cider was assessed by Geveke and Brunkhorst (2004, 2008) and by Geveke *et al*. (2007). The main focus of their work was on microbial inactivation and microbial quality of beverages processed using the system which provides a RF heating source of 15 kHz to a maximum of 41 kHz which varied with the product type and increasing the product temperature to maximum of 65˚C at the outlet. Under the experimental conditions, it is demonstrated that the potential of RF towards the inactivation of *E. coli K12* in apple juice, orange juice and apple cider respectively is effective than the conventional methods. In addition to maximum microbial inactivation the RF treated samples are found to be similar in its color and flavor property to the natural juices with nil loss in ascorbic acid or enzymatic browning in RF treated juices. Another application was proposed by Geveke and Brunkhorst (2004, 2008) and by Geveke *et al*. (2007), who considered RF heating as a potential alternative to conventional heating for liquids containing particulates, using an alternating current of 30 kW and frequency of 40.68 MHz. Uemura *et al*. (2011) reported the inactivation of *Bacillus subtilis* spores in soybean milk by radio-frequency flash heating at 28MHz by heating up to 115ºC for 0.4sec. Fouling of the electrode surface by the protein from the soybean milk became a problem with high electric- field on continuous treatment, which was later rectified when the electrode surface was covered with a Teflon film.

## DRYING IN AGRICULTURAL PRODUCE

RF drying, with regards to food, has mainly been used for post-bake drying of cookies, crackers and pasta (UIE, 1992; Mermelstein, 1998). Cookies and crackers, fresh out of the oven, have a non-uniform moisture distribution which may yield to cracking during handling. RF heating can help even out the moisture distribution after baking, by targeting the remaining moisture pockets. Recent development trends are investigating hybrid drying systems involving radio frequency to cater for the special needs of heat-sensitive food stuffs (Zhao *et al*., 2000; Chou and Chua., 2001; Vega-Mercado *et al*., 2001). Tiwari. G, Wang. S, Tang. J, Birla., (2011) were studied the effects of the RF heating on wheat flour, placed in three cuboidal boxes were subjected to study on the sample size, shape, its relative position between the RF electrodes and frequency of 27.12 MHz. Simulated results showed that the RF heating uniformity could be improved using larger sample sizes placed in the air between the electrodes. Monzon *et al*. (2007) evaluated the impact of RF heating protocols used to control Mexican fruit fly larvae on fruit and found the treatments used at 48–52˚C followed by holding times of 0.5–18 min had no significant effect on firmness, soluble solids content, titratable acidity or product weight loss with RF treated products attaining a deeper orange red peel than control fruits. Other authors proposed the use of RF technology in high value and highly perishable commodities like walnut for the purpose of drying as well as disinfection of the agricultural commodity.

### DISINFECTION IN AGRICULTURAL PRODUCE

A large-scale treatment for conveyor walnuts was designed based on a 25 kW, 27MHz RF system to achieve an average walnut surface temperature of 60˚C and minimum temperature of 52˚C for 5 min. The treatment caused 100% mortality of fifth-instar navel orange worm larvae, the most heat tolerant target pest, in both unwashed and air-dried walnuts, and was effective over a relatively wide range of walnut moisture contents (3–7.5%). Walnut quality was not affected by the RF treatments. The kernel color, peroxide values and fatty acid values of treated walnuts were similar to untreated controls after 20 days at 35˚C simulating 2 years of storage under commercial conditions at 4˚C. The RF treatment slightly reduced the moisture content of the walnuts, especially the shells (Wang. S, Monzon., Johnson. J.A, Mitcham, Tang. 2007). Radio frequency heating to control brown rot on peaches and nectarines, the RF treatment at 27.12 MHz, with 17mm distance between fruit and upper electrode and 18 min exposure time were studied by Casals. C *et al*., 2010, the results indicated that RF treatment conducted for 22.5 min had a significant effect on brown rot control in peaches artificially inoculated with *M. fructicola*., when the exposure time was reduced to 15 min, the incidence of brown rot was only reduced in all the varieties tested. Youn Kim *et al*., 2011 reported the RF heating to inactivate *Salmonella Typhimurium* and *Escherichia coli O157:H7* on black and red pepper spice by RF heating for 50s resulted in 2.80 to 4.29 log CFU/g reductions of *S. Typhimurium* and *E. coli O157:H7* in black peppers and RF heating of red peppers for 40 s reduced pathogens by 3.38 log CFU/g to more than 5 log CFU/g without affecting the color change, provided 27.12MHz RF heating system. This report suggested the RF heating has the potential for novel thermal process to control food borne pathogens in spices.

### MERITS AND DEMERITS OF RF HEATING

The advantages of RF heating system include overcoming many heat transfer problems thus preferred over conventional heating for the primary reason that they are rapid and require less time to come up to the desired process time. The major benefits of Radio-frequency heating includes the ease of targeting the product, not the air surrounding it, tends to drive the moisture from inside out, and hence leveling the moisture, considerably decreasing the processing time, avoiding overheating and dehydration on the surface of the product. Other advantages of radio frequency heating system include are they can be turned on or off instantly (Orsat *et al.*, 2005) and can be provided with temperature measurement systems (thermocouple). RF heating is restricted by limited understanding of RF photons interact with materials and by high cost of its source electronics. Subject to fluctuations of electrical costs is another drawback of RF heating. The major obstacle in RF technology is that the factors such as product dielectric properties, size, shape, position between the RF electrodes and the electrode configuration may affect temperature uniformity thus providing non uniform heating of food produce. The RF heating system should be provided such that all generators and applicators must be properly shielded and specially designed to meet the product specific requirements. The lack of in-depth information on area such as its impact on all aspects of product quality is another factor of concern, the recent focus are only on meat product but this needs to be replicated across a wider range of food commodities.

### Conclusion

The RF heating technology is in research for many decades, the industrial application of it is still limited towards heterogeneous food stuff like meat, disinfection of agricultural commodities and post baking, where as there is a large potential source available in utilizing RF technology. The study on material factors which include dielectric properties of the host material and contaminants, material geometry and thermal sensitivity of the host material and RF process factors like frequency, electric and electromagnetic field intensity, RF power provides a greater challenge to the engineers to develop a large scale production unit for the industrial application. Introduction of any newer technology requires skilled labors and higher initial capital cost of equipment through its steady and further focus on health benefits and comparative study with conventional heating RF heating system can take the modern market on food processing without any reason of concern.

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