DOI: 10.1590/1808-1657v71p3992004

REVISION ARTICLE

THE EFFECT OF MICROWAVES ON MICROORGANISMS

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ABSTRACT

This work is a literature review on the use of microwaves for pasteurization processes and / or the reduction of the microbiological biota in foods. It presents background as well as latest information on the methodology being used in these processes, putting emphasis on the newest developments of the technology being used today.

KEY WORDS: Microwaves, pasteurization, microorganisms.

RESUMO

O EFEITO DAS MICROONDAS NOS MICRORGANISMOS. Este artigo apresenta uma revisão literária sobre o uso de microondas visando a pasteurização ou a diminuição da microbiota em alimentos, fornecendo informações fundamentais e atuais sobre a metodologia desse tipo de processo, bem como salienta avanços tecnológicos.

PALAVRAS-CHAVE: Microondas, pasteurização, microrganismo.

The granting to Mr. Percy L. Spencer, on January 24, 1950, of patent no. 2.495.429, applied for on October 8, 1945, gave no indication to the inventor that his invention would be used to benefit humanity so much.

Since the invention of the Volta cell in 1800, many medical applications of an electrical direct current were developed. D'Arsonval, as cited by DURNEY et al. (1986), was probably the first individual to study the physiological effects of alternating currents and oscillating electrical and magnetic fields.

Early in the 20th century, the thermal effects of fields of radio frequency (RF) were well known and were being applied in diathermia (DURNEY et al., 1986). Since then, the introductions of new devices and techniques utilizing electricity have always provoked the most varied types of reactions from individuals and groups. The most common biological effect from electromagnetic fields, well known and easier to understand, is the thermal effect. The sun heats up our skin. Food is cooked in microwave ovens.

In the 1930s and '40s, powerful generators of radio frequency (RF) were developed. The operators of such transmitters soon discovered that exposure to RF produced sensations of warmth. At the same time, systematic determinations of the dielectric properties of biological tissues were carried out aimed at understanding the mechanisms interacting in electromagnetic fields (SENIZE, 1996).

MICROWAVES

More recently, the use of microwave radiation became commonly used in the food industry, to brown, dry and cook foods, and as a tool to inactivate microorganisms (ROSENBERG & BOGL, 1987; KAKITA et al., 1995).

The word radiation is commonly associated with radioactivity, X rays and other dangers, while in fact it refers to "radiant energy", energy propagating even in vacuum, with no need of a physical conduit. "Electromagnetic radiation" in particular is a form of energy that propagates in the form of waves that are characterized by oscillating electric and electromagnetic fields that change in both time and space (SENIZE, 1996).

The increase in temperature of some materials when exposed to high frequency fields (above 108Hz) has been known since the 19th century and this

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characteristic has been widely utilized in applications since the early part of the 20th century (ZLOTORZINSKI, 1995).

The temperature of a body is the measurement of its caloric energy. To increase its temperature it is necessary to supply energy in a caloric form or in some other form of energy that will be transformed in caloric energy. In the so-called "conventional" processes, heat transfers are used, with the energy flowing from the warmer material to the cooler one that we are heating up.

Among the other methods to supply heat, including electromagnetic induction and dielectric hysteresis, the energy of the material is increased utilizing other forms of energy that are transformed in caloric energy within the material itself, with no heat transfer from an external source (SENIZE, 1996).

Energy transfers utilizing microwaves are quite different from these conventional heating processes. These transfer energy to the material to be heated-up by means of conduction, convection and irradiation while microwaves interact directly with the material, causing temperature increases due to the interaction of the molecular electric fields with the electromagnetic waves at their different phases and producing ionic conduction and dipolar rotation (KINGSTON & JASSIE, 1988).

Microwaves are all the non-ionizing electromagnetic radiations with frequencies ranging from 3 to 300,000 MHz and the most commonly used range from 915 to 2,450 MHz (TEJERA & DE LA TORRE, 1991).

Heating by microwaves usually refer to the use of certain electromagnetic frequencies to increase the temperature of a material (METAXAS, 1996; METAXAS & MEREDITH, 1988; ROUSSY & PEARCE, 1995). Non-ionizing radiations are all electromagnetic radiations with photon energy below 10eV. This is the minimum amount of energy required to displace electrons from biological molecules. Energies of 10eV correspond to the frequency of 2.4 x 10^{15} Hz, in the short ultraviolet region. The frequency in which microwave ovens operate (2.45 x 10^{9} Hz) the photon has 1,000,000 times less energy and it is impossible to ionize the food being processed, or animals or humans that may be exposed (GREENE, 1992).

In microwave ovens, the frequency of the radio wave commonly used is in the range of 2,500 megahertz (2.5 gigahertz). Water, fats and sugars absorb radio waves in this frequency. Once absorbed, the waves are converted directly into atomic motion thus generating heat. In this frequency microwaves have another property worth mentioning, the fact that they are not absorbed by the majority of plastics, glass and pottery (SENIZE, 1996).

Frequently, food is processed using microwaves in the frequencies of 915 and 2,450 megahertz. The use of 2,450 megahertz is more common and used for the home-type ovens and in industrial heating. The heating process involves primarily two mechanisms: dielectric and ionic. The water present in the food is frequently the preliminary component responsible for the dielectric component. Due to its dipolar nature, the water molecules have a tendency to follow the electric field associated with the electromagnetic radiation and these oscillations of the water molecules following the wave movements heat the water. The second-most important mechanism in heating using microwaves and RFs is the oscillatory migration of ions present in the food, generating heat under the influence of the electric field (US-FDA, 2000).

The rate of heat generation per unit volume "Q" in a given position in the food during heating by microwaves and RFs can be expressed by: $Q = 2\pi f \varepsilon_0 \varepsilon E^2$, where: "E" is the strength of the electric field at a given location, "f" is the frequency of the microwave or RFs, "ε_0" is the permissivity of the free space (a physical constant), and "ε" the factor of dielectric loss (a material property called dielectric property) that represents the ability of the material to absorb the wave. There is also another dielectric property called dielectric constant related to the strength of the electric field within the food itself (BUFFLER, 1993; DATTA & ANANTHESWARAN, 2000).

The dielectric properties are dependent upon the composition (or formulation) of the product being processed, with its humidity and salt content being the two determining factors of preliminary interest (MUDGETT, 1994; DATTA et al., 1994).

The utilization of microwaves can offer innumerous advantages over conventional methods of heat processing. The heating by microwaves can be faster and more uniform, and the distribution of heat throughout the product being processed can be done better than in conventional processes (CALVO & OLANO, 1992).

Relatively speaking and depending on the particular conditions of the heating process, heating by microwaves can be more uniform than conventional heating processes (DATTA & HU, 1992).

In the heating processes the time / temp relationship is not comparable for microwaves and conventional processes. The changes in material properties as the temperature goes up are more pronounced with microwaves. As the temperature of the material increases, its ability to absorb microwaves also goes up, increasing the rate of temperature increase. This coupled effect can lead to uncontrolled heating (ZHANG & DATTA, 2000).

The fast heating and the short time of exposure to radiation is less damaging to the food than the longer conventional heating processes (FUJIKAWA et al., 1992). The reduction in heating time is dependent upon the power of the microwave oven, the humidity present in the food, and the volume. The penetration efficacy of the microwaves is determined by the depth by which one half of the electromagnetic energy reaching the surface of the product being processed is converted into heat. This penetration has an inverse relationship with the frequency, so that, for processing larger masses, lower frequency waves should be used.

MICROWAVES AND MICROORGANISMS

Studies of the application of microwaves in commercial operations for pasteurization and sterilization have been reported for years. (PROCTOR & GOLDBLITH, 1951; JEPPSON & HARPER, 1967; HAMID et al., 1969; KENYON et al., 1971; MUDGETT & SCHWARTZBENRG, 1982; DECAREAU, 1985; KNUTSON et al., 1988; KUDRA et al., 1991; SCHLEGEL, 1992; HARLFINGER, 1992; CASASNOVAS et al., 1994; NASA, 1996; BURFOOT et al., 1988 e 1996; VILLAMIEL et al., 1997).

The use of microwaves to reduce the population of microorganisms in many different foods such as turkeys, meats, milk, corn on the cob, chickens, frozen foods and potatoes have indicated that radiation with microwaves help preserve food, reducing the presence of active microbiological cells. (CRAVEN & LILLARD, 1974; BOOKWALTER et al., 1982; SPITE, 1984; ALEIXO et al., 1985; DAHL et al., 1985; LIN & SAWYER, 1988; FARBER et al., 1998).

FUNG & CUNNINGHAM (1980), consider lower times and temperatures for pasteurization and sterilization of foods using microwaves as one of the most important aspects involved when compared to conventional processes.

Reports of inactivation of bacteria by microwave treatment include: *Bacillus cereus*, *Campylobacter jejuni*, *Clostridium perfringens*, *Escherichia coli*, *Enterococcus*, *Listeria monocytogenes*, *Staphylococcus aureus*, and *Salmonella* (CHIPLEY, 1980; ROSENBERG & BOGL, 1987b; KNUTSON et al., 1987; HEDDLESON & DOORES, 1994).

The effect of microwaves on microorganisms present in foods are influenced by the intrinsic characteristics of the products being processed (pH, humidity, Ox reduction potential, antibodies present, biological structures, chemical composition, amount and geometry of the food) and extrinsic factors (temperature, humidity, ambient gases, frequency and intensity of the radiation, time of exposure, position of the foods in relation to the effective radiation field, among others). Also important are: the chemical and physical composition of the microorganisms being irradiated, their stage of development (vegetative cell, spore or development phase, wet or dry, etc.) and their initial amount. Bacteria respond differently to inactivation by microwaves (FUNG & CUNNINGHAM, 1980).

The absorption of microwave energy can increase the temperature of foods rapidly, deactivating microorganisms and performing pasteurization or sterilization. Studies have shown that the thermal effect is essential in destroying microorganisms (GOLDBLITH & WANG, 1967; ROSEN, 1972; FUJIKAWA et al., 1992).

Since the first studies of microwave applications, there has been controversy over a possible non-thermal effect (MCKINLEY, 1936; BURTON, 1949; FUNG & CUNNINGHAM, 1980; GROSS & FUNG, 1982). Works reporting non-thermal effects never gave detailed explanations in the literature. Some of the proposed effects were: selective heating of microorganisms, rupture of the cell membrane and lysis of the cell due to absorption of electromagnetic energy.

HEDDLESON & DOORES (1994), reported consensual acceptance that the non-thermal effects are probably due to the lack of measurements of the time/temperature relationship and their spatial variations in microwave ovens.

KOZEMPEL et al. (1998) developed a system in which various liquids were exposed to microwave energy followed by refrigeration to keep the temperatures of the liquids at 40º C. The liquids were inoculated with strains of the *Pediococcus* bacteria prior to being exposed. Apple juice showed the highest reduction of cells (4.6 log) when exposed to a sequence of exposures and the lowest reduction (0.7 log) in a 10% glucose solution subjected to a single exposure. The destruction of the cells was not constant for multiple exposures. For some food products the rate of cell destruction diminishes after the first exposure. Almost no reductions in the number of cells were reported for low-fat milk, pineapple juice, tomato juice, apple cider or beer. Besides the influence of the food product itself, the culture media used for the *Pediococcus* also appeared to affect the cell count. Nevertheless other characteristics of the food product such as solids in suspension, pH and conductivity could satisfactorily explain the varying results. The authors concluded that they had demonstrated the existence of a significant number of dead cells in some liquids when using microwave energy at sub-lethal temperatures.

KOZEMPEL et al. (2000) designed a new system capable of separating the thermal from non-thermal effects of microwaves. With this system they did not find any inactivation of the innoculum at sub-lethal temperatures for *Enterobacter aerogenes*, *E.coli*, *Listeria* and *Pediococcus*, or for an for a yeastlike suspension of various liquids which included water, egg white, whole eggs, tomato juice and beer. They concluded that, when other stressing factors such as pH or heat are not present, the energy from microwaves do not deactivate microorganisms, leading them to suggest that microwave energy can complement or amplify the thermal effects.

In laboratory tests using *Saccharomyces cerevisiae* and *Lactobacillus plantarum* present in apple juice, RAMASWAMY et al. (2000) also found that the non-thermal effects of the microwave energy at sub-lethal temperatures are of no significance. Nevertheless, they determined that, when treatments of equivalent heat, the microwaves promoted the inactivation of the microorganisms.

Homogeneous materials can be pasteurized or sterilized by microwaves without overheating the superficial edges or underheating the center in contrast to conventional methods having slow penetration of heat. Thus, elevated superficial temperatures do not occur when heating with microwaves and the temperature required to destroy microorganisms at the center is reached faster. The above leads to designing processes utilizing microwaves that will yield foods with a higher content of heat sensitive nutrients, vitamins and flavor components. All of this can be accomplished with only 5-10% of the time required by conventional heating methods. Water suspensions can be processed either in batches or continuous processes (MUDGETT & SCHWARTZBERG, 1982).

For pasteurization and sterilization, microwave heating is preferred over conventional heating because it is faster and thus requires less time to reach the required process temperature. Other advantages of microwave heating are that it permits turning on and off and that the product can be pasteurized after packaging. The processes utilizing microwaves can also be more energy efficient (US-FDA, 2000).

There are conflicting works in the literature with respect to the lethal effects of microwaves on microorganisms: if they are exclusively of a thermal nature or not (CUNNINGHAM, 1980; AKTAS & OZILGEN, 1992).

Even after all the studies that have been done, the mechanisms promoting microbiological destruction are still not yet totally understood. It is somewhat generally accepted that it is the result of the thermal effect from exposure to microwaves (STILES, 1963; FUNG & CUNNINGHAM, 1980).

Many researchers tried to determine if there was a non-thermal effect on microorganisms from these radiations (CARROLL & LOPEZ, 1969; CULKIN & FUNG, 1975; KOZEMPEL et al., 1998).

MUDGETT & SCHWARTZBERG (1982) reported that the energies from high frequencies were looked into extensively by many researchers in trying to determine if the effects were of a thermal or non-thermal nature.

Fleming, cited by MUDGETT & SCHWARTZBERG (1982), believed that the microbial destruction was due to some non-thermal effect since it had been demonstrated that the lethal effect of the microwave energy is only of a thermal nature.

This microbial lethality is now understood as the result from the penetration of electromagnetic waves into a biological wet material, heating up the intra- and extracellular fluids by the transfer of energy from polar water molecules and dissolved ions. This results in the generation of heat within the material itself due to molecular activity (SENIZE, 1996).

Other researchers believe that non-thermal electromagnetic effects from microwaves are responsible for the microbial deactivation. YOUNG & JOLLY (1990), state that microwaves can certainly have non-thermal effects on chemical reactions.

AKTAS & OZILGEN (1992) evaluated the damage and the killing of *E. coli* by microwaves using a continuous tubular pasteurizing reactor and determined that between 15 and 25% of the surviving microorganisms had been injured. This percentage increased dramatically at conditions near total sterilization.

At some American universities as well as at the US Army Laboratories at Natick, MA, research of commercial microwave use in sterilization is underway with the intent to improve the quality of the food made available to soldiers. (US-FDA, 2000). Some of the studies are directed towards the effect that microwave heating has on pathogenic microorganisms present in foods.

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Received on 28/6/04
Accepted on 12/8/04