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Microwave Heating Applications in Food Processing

Okeke. C. (M. Eng. B. Eng.) [1] Abioye, A. E. (B. Eng.)[2] Omosun Y. (B. Eng.)[3]
[(123)]Department of Electrical /Electronics Engineering, Michael Okpara University of Agriculture, Umudike, Abia State, Nigeria

Abstract: *Microwaves refer to the electromagnetic waves in the frequency range of 300MHz to 300GHz. Once microwave energy is absorbed, polar molecules and ions inside the food will rotate or collide according to the alternating electromagnetic field and heat is subsequently generated for cooking. The use of microwave oven provides a convenient way to thaw, cook and reheat foods. However, the safety of the microwaved food has on and off aroused some public interest. This paper reviewed the basic principles, structure and characteristics of microwave heating. The biological effect and safety on users is also examined.*
Keywords: *Electromagnetic field, Food, Microwave, Microwave Heating, Safety.*

I. Introduction

Microwaves are defined as a part of electromagnetic waves which have frequency range between 300 MHz and 300 GHz corresponding to wavelength from 1mm to 1m.
Microwaves heating can be applied in a broad range of food processing such as drying, tempering, blanching, cooking, pasteurization, sterilization, and baking. Microwave heating has considerable advantages over conventional heating.
In a conventional oven, a gas or charcoal fire, or an electric heating element, generates heat outside of the material by convection and inside by of the material by conduction. In microwave heating, by contrast, the inside of the material is heated first. The process through which this occurs primarily involves the conduction losses in materials with large loss tangent.
An interesting fact is that the loss tangent of many foods decreases with increasing temperature, so that microwave heating is to some extend self regulating. [1]
This result is that microwave cooking generally gives faster and more uniform heating of food, as compared with conventional cooking. The efficiency of a microwave oven, when defined as the ratio of power converted to heat (in the food) to the power supplied to power supplied to oven, is generally greater than the cooking efficiency of a conventional oven. [2]
A common misconception is that microwave heating is always more expensive than heating by conventional techniques. This will actually depend on the application and utility costs. However, in some cases, microwaves can be 50% or more efficient than conventional systems, resulting in major savings in energy consumption and cost. [3]

II. Methodology

Qualitative sourcing of information from the library and online surfing was adopted in the preparation of this paper based on the emerging development in microwave heating techniques in food processing. This paper brings together findings from both local and international research in microwave Technology.

III. The Principles Of Microwave Heating

Dipolar interaction
Once microwave energy is absorbed, polar molecules such as water molecules inside the food will rotate according to the alternating electromagnetic field. The water molecule is a “dipole” with one positively charged end and one negatively charged end. Similar to the action of magnet, these “dipoles” will orient themselves when they are subject to electromagnetic field. The rotation of water molecules would generate heat for cooking. [4] Hence the composition of a food will affect how it will be heated up inside the microwave oven. Food with higher moisture content will be heated up faster because of the dipolar interaction.

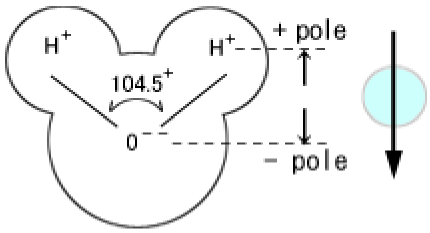


Figure 1: The structure of water molecules (left)
and Image of permanent dipole (right)

Then as shown in Figure 2, when there is no external electric field, it has set a balance. But when placed in external electric field, dipole will turn towards the electric field.

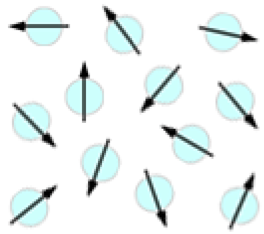
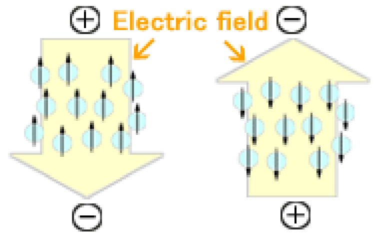


Figure (2) When there is no external electric field



(3) When there is an external electric field

Figure 3 show the Direction of dipoles influenced by external electric field

Figure 4 shows a case where a too much lower frequency of radio wave is irradiated to the permanent dipole of water. In this case, the permanent dipole will immediately follow the directions of electric field. So in this case, water doesn't generate heat. On the other hand, Figure 5 shows a case where a too much higher frequency of radio wave is irradiated to the permanet dipole. In this case, since electric field changes its direction too fast, dipole won't be able to follow. Then, water does not generate heat in this case also.

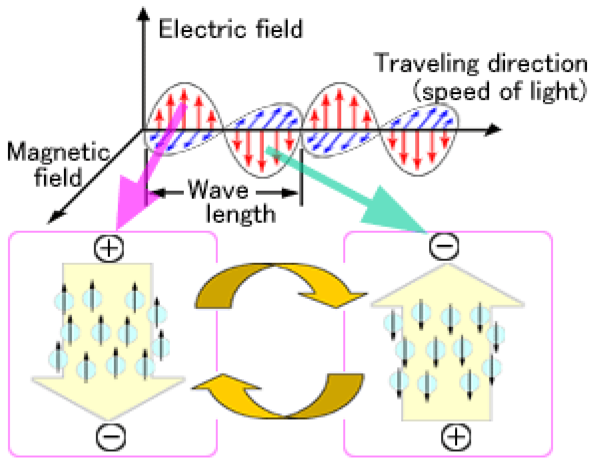


Figure 4 At too lower frequency of radio wave

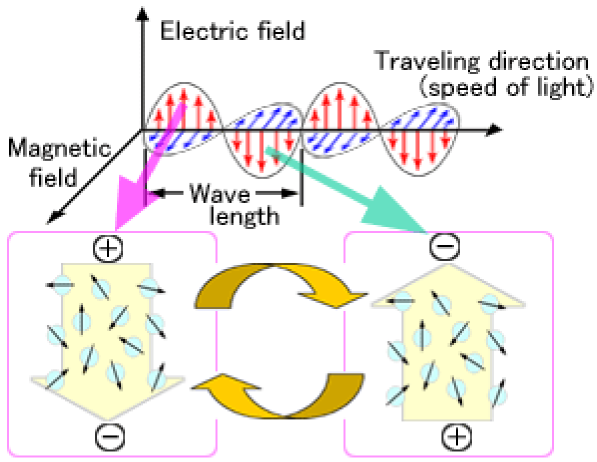


Figure 5 At too higher frequency of radio wave

In contrast to these, Figure 6 shows a case where moderate frequency of radio wave is irradiated to the permanent dipole. In this case, the permanent dipole changes a little behind the electric field. During the time delay, water is absorbing energy from radio wave and generates heat. And, this moderate frequency is the microwave. [5]

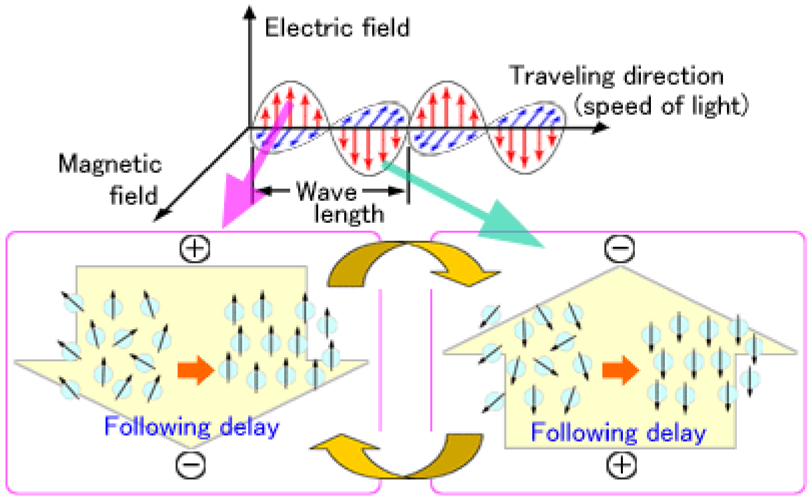


Figure 6 At moderate frequency of radio wave (microwave)

IV. The Basic Structure Of Microwave Heating Device

Below, a microwave oven is relatively simple system consisting of a high power source, a wave guide feed, and the oven cavity. The source is generally a magnetron tube operating at 2.45GHZ. Although 915MHZ is sometimes used when greater penetration is desired. Power output is usually between 500 and 1500W. The oven cavity has metallic walls, and is electrically large. To reduce the effect of uneven heating caused by standing waves in the oven, a mode stirrer, which is just a metallic fan blade, is used to perturb the field distribution inside the oven with a motorized platter. The food is also rotated with a motorized plate

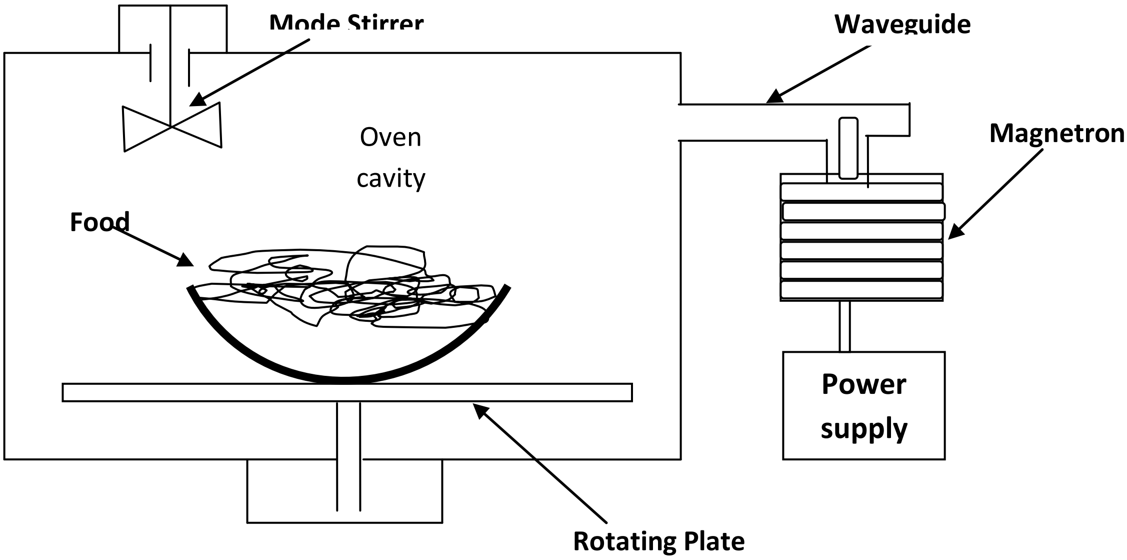


Figure 7: Structure of Microwave Heating Device

V. The Functional Parts Of The Microwave Heating Device

(5.1) **Generator (Magnetron)** : Magnetron is a device built inside the Generator that oscillates microwave. The microwave that is oscillated by the Generator is called the traveling wave (or incident wave).The theory of operation of the magnetron is based on the motion of electron under the influence of combined electric and magnetic fields. The direction of the electric field is from the positive electrode to the negative electrode. The magnetron can produce oscillations at microwave frequency by virtue of the current induced electrostatically by moving beams of electrons. This frequency is determined by the type of cavities used. [6] The microwave which is generated by magnetron propagates in waveguide to be emitted from the nozzle.

(5.2) **Isolator**: This is device, sends traveling wave directly to the Applicator, and absorbs reflected wave by built-in dummy load to avoid returning back to the Generator. Reflected wave which occurs by rotation of the Turntable and the Stirrer. Isolator can reduce the influence of reflected wave fluctuation. Without this fluctuation, magnetron can continue stable operation. In other words, Isolator functions to protect magnetron

(5.3) **Power Monitor**: This is a device that monitors traveling and reflected waves of microwave power propagating through the rectangular waveguide. Must be careful when reflected wave becomes large, there is an increase in error.

(5.4) **Waveguide**: Waveguide is a hollow metal pipe use to conduct electromagnetic waves through its interior. A wave guide can be of any shape. The most popular shape is rectangular, circular and even more exotic shapes. Microwave (electromagnetic wave) propagates in the interaction of electric and magnetic fields. Microwave is transmittable when metal pipe with cross section is used. In general, for the microwave heating equipment, 2GHz standard rectangular waveguide of rectangular cross section is used. (Standard waveguide: WRJ-2/WRI-22, Flange: BRJ-2/FUDR22) [7]

(5.5) **EH-Tuner:** There are two kinds of tuners, which are three stub and EH. By adjusting E- or H-tuner, changes the phase and magnitude of microwave reflection at the tuner section. It is also adjustable to set the display value of reflected power to zero by adjusting E- or H- tuner. This means that, by adjusting E- or H- tuner generates a same magnitude reverse phase wave to counter the reflected wave. And as a result, the reflected wave has been denied. When the reflected power wave value is zero on the display of Power Monitor, power consumption of after tuner to inside applicator is maximized. This condition is called "The matching.

(5.6) **Applicator**: A heating tank that heats the object placed inside by irradiation of microwave. Depending on the application, there are a variety of shapes, such as batch type, conveyor type, waveguide type, etc.
However, the most critical issue in the design of a microwave oven is safety. Since a very high power is used, leakage levels must be very small to avoid exposing the user to avoid exposing the exposing the user to harmful radiation .Thus, the magnetron, feed waveguide, and oven cavity must all be carefully shielded. The door of the oven requires particular attention; besides close mechanical tolerances, the joint around the door usually employ Radio frequency (RF) absorbing material and a $\lambda/4$ choke flange to reduce leakage to an acceptable level.

VI. The Characteristics Of Microwave Heating

There are some characteristics of microwave heating that other heating methods (conventional heating method) do not have. The following are the features

(6.1) The Internal Heating: Microwave energy will reach the object to be heated at the same speed of light. Then it enters into the object as a wave, and by getting absorbed, the object generates heat. Therefore as shown in Figure 8, microwave heating is internal heating.

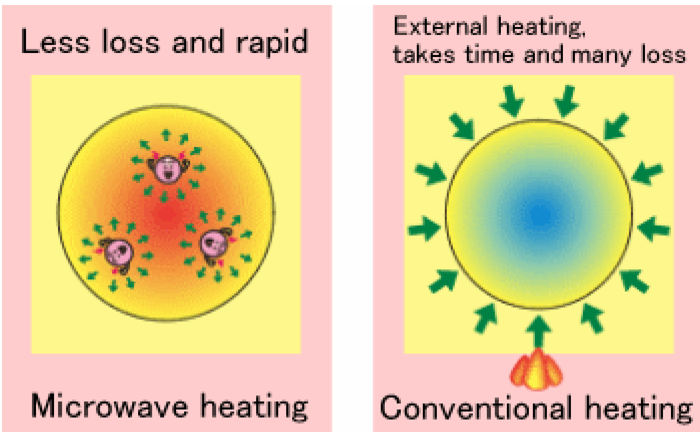


Figure 8: Microwave heats object internally

(6.2) Rapid Heating: As shown in Figure 8, in conventional heating, the object's temperature rises by spreading heat energy from the surface to inside (external heating) On the other hand, by microwave heating, the object will generate heat on their own by the penetration of the microwave. Not necessary to consider about the heat conduction. That is why rapid heating is possible by microwave. Although the object has to be large enough for the microwave to penetrate, the smaller objects will also be heated from inside as the depth of microwave penetration.[8]

(6.3) High Heating Efficiency: Microwave penetrates into the object at the speed of light. You get high heating efficiency because no need to consider the heating losses of air inside the heating furnace.

(6.4) Rapid Response and Temperature Control: Microwave penetrates into the object at the speed of light. So it allows rapid response. For example, you can start and stop the heating instantly. In addition, by the adjustment of microwave output, you can control the amount of heat energy generated inside the heated object.

(6.5) Heating Uniformity: Each part of the heated object generates heat, so even for those objects with complicated shape, it can be heated relatively uniform. To keep the heating uniformity, stirrer, turntable, and belt conveyor is used for heating blur related to wave length.
(6.6) Clean Energy: Microwave doesn't require a medium, because it propagates only by changes of electric fields and magnetic fields. It can propagate in a vacuum. It reaches the object and penetrates without heating the air. The heated object generates heat by absorbing microwave energy to convert it to heat energy. Therefore, it can be said as clean energy because it doesn't heat the air during process.
(6.7) **Good Operation and Work Environment**: Conventional heating requires a heat source, and the temperature rises not only of heated object, but also of heat source and the heating furnace. So the temperature of room equipped heating furnace goes high because of radiant heat. This is an operation and work environment issue. On the other hand, microwave heating only uses electricity to generate heat of the object. The temperature of the object only raises, not the furnace. And there is no radiant heat, so it's possible to keep operational and good working environment.

VII. Biological Effects And Safety

The proven dangers of exposure to microwave radiation are due to it thermal effects. The body absorbs RF and microwave energy and converts it to heat, as in the case of a microwave oven this heating occurs within the body, and may not be felt at low level. [9] Such heating is most dangerous to brain, the eye, the genitals and the stomach organs. Excessive radiation can lead to cataracts, sterility or cancer. Thus it is important to determine a safe radiation levels. The most recent safety standard for human exposure to electromagnetic field is given by IEEE Standard C95.1-1991. [10]

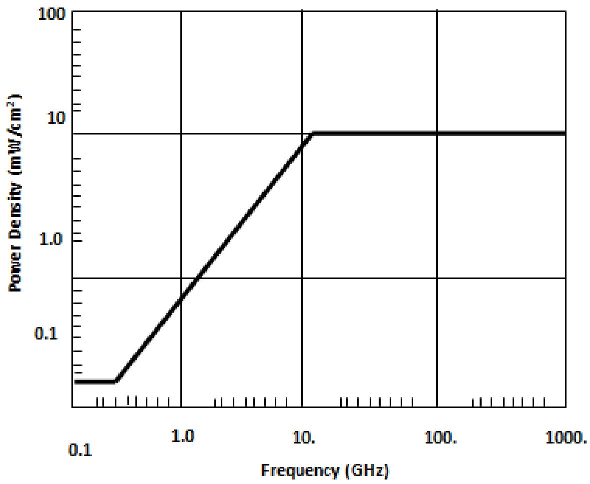


Figure 9 IEEE Standard C95.1-1991recomended Power density limits for human exposure to RF and microwave electromagnetic fields

In the RF microwave frequency range of 100MHZ to 300GHZ , exposure on the limits are set on the power density (W/cm^2) as frequency, as shown in figure 9. The recommended safe power density limit is as low as $0.2mW/cm^2$ at the lower end of this frequency range, because fields penetrate the body more deeply at lower frequencies. At frequencies above 15GHZ the power density limit rises to $10mW/cm^2$, since most of the power absorption at such frequencies occurs near the skin surface. By comparison, the sun radiates a power density of about $100mW/cm^2$ on a clear day, but the effect of this radiation is much less severe than a corresponding level of lower frequency microwave radiation because the sun heats the outside of the body, with much of the generated heat reabsorbed by the air, while microwave power heats from inside the body. At frequencies below 100MHZ electric and magnetic fields interact with the body differently than higher frequency electromagnetic fields and so separate limits are given for field components at these lower frequencies.

VIII. Conclusion

The successful applications of microwave heating technology for processing of various foods have been discussed in the present review. The microwave heating technology for pasteurization and sterilization contributed to effectively destroy pathogenic microorganisms and significantly reduce processing time without serious damage in overall quality of liquid food as compared to traditional methods. The use of microwave heating for food processing applications such as blanching, cooking, and baking has a great effect on the preservation of nutritional quality of food. Microwave technology is now being seriously considered as a viable energy source in process heating. It's been a slow development process over the last two centuries. However,

the timing is right to achieve significant economic benefits for those who are now considering a change. All the myths have been dispelled and various safety issues have been overcome.
The use of microwave oven provides a convenient way to thaw, cook or reheat foods nowadays. Many studies have been conducted to assess the safety as well as possible nutrient loss associated with microwave cooking. The best available evidence supports that the use of microwave cooking resulted in foods with safety and nutrient quality similar to those cooked by conventional methods, provided that the consumers followed the given instructions.

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ABOUT THE AUTHORS

Engr. Okeke C., B.Eng, M.Eng, MNSE, holds a Bachelors Degree in Electrical/Electronics Engineering, Enugu State University of Science and Technology, Enugu, Nigeria in1998. A Masters Degree in Electrical/Electronics Engineering, majoring in Electronics and Communication from the same University in 2006. He is a member of Nigerian Society of Engineers (NSE) and Council for the Regulation of Engineering in Nigeria (COREN). He is also a member of International Research and Development Institute (IRDI).Engr. Chukwuma Okeke is currently lecturing in Michael Okpara University of Agriculture, Umuduke, Abia State.

Abioye. Abiodun E. (B. Eng.) received his B.Eng. degree in Electrical Engineering from University of Ilorin, Ilorin, Kwara State Nigeria in 2010, and currently undergoing a Master of Engineering degree in Electronics and Communication Engineering, at Michael Okpara University of Agriculture, (MOUAU) Umudike, Abia State Nigeria. He is a member of Institute of Electrical Electronics Engineers (IEEE) and International Association of Engineers (IAENG). His research interests are in the fields of Communication Systems, Digital Electronics, Power Electronics and Design of Microcontroller based systems.

Omosun Yerima (B. Eng.) received his B.Eng. degree in Electrical/Electronics Engineering from Ambrose Ali University, Ekpoma, Edo State, Nigeria in 2007, and currently undergoing a Master of Engineering degree in Electronics and Communication Engineering, at Michael Okpara University of Agriculture, (MOUAU) Umudike, Abia State Nigeria. He is a member of Institute of Electrical Electronics Engineers (IEEE). His research interests are in the fields of Communication Systems, Digital Electronics, Computer Engineering and Information Communication Technology.