Power Dissipation Pattern and Specific Absorption Rate of Wheat Grains Inside Capacitive Field in the Radio Frequency Range

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***Abstract*—The capacitive field treatment on the wheat grains designed in the Radio Frequency (RF) region is discussed in this paper. The pattern of power dissipation and Specific Absorption Rate (SAR) value within the wheat grains is determined using the designed model of capacitor and the wheat grains in COMSOL. Major problem in the Agriculture are the pests which infest the seeds, crops and end products like fruits, vegetables and grains. SAR and the power dissipation within the grains are found using COMSOL MULTIPHYSICS. Result of simulation shows that power dissipation and the SAR varies with the variation in the terminal voltage at the capacitor plates. RF treatments are very effective for protecting the grains from the possible infestations. This methods can also be implemented for post-harvest storage of the grains. The RF or Microwave (MW) treatment is an area of research for attractive quarantine treatment because it is quick and safe, and operation costs are comparable to chemical fumigation.**

Keywords*—Specific Absorption Rate, Power Dissipation Pattern, Capacitive Heating, Capacitive field, RF range, Infestation of grains.

I. INTRODUCTION

In the recent years, interactive relations between various branches of science and technology have improved interdisciplinary fields of science. The relationship which can be developed between the fields of electromagnetism and the agricultural science can provide some interactive and useful solutions to increase the productivity and minimize the loss of crops and end products like fruits and grains due to the infestations. The major suffering problems with which a farmer faces are the damages caused by the harmful pests as well as the product freezing in unexpected cold weather. The promising available biological methods of treatment have decreased the need for new treatment methods effectively. Electromagnetic radiation as tools in the field of agriculture have been used in many applications such as remote sensing, imaging, and dielectric heating in a pre-harvest or post-harvest environment. RF waves are very effectively used as thermal heating to kill pests. This is the effective method for prevention and protection of the crops from possible infestations. It can be used to disinfest various foods and non-food materials including soil [1].

The importance and usefulness of the dielectric properties of agricultural products and their use in the rapid sensing and measurement of moisture content in grain and seed and in governing the behavior of materials subjected to RF and microwave electric fields for dielectric heating applications [3]. This paper throws light on the influence of capacitive field strength on the wheat grains. The capacitor is designed at the 27 MHz ISM frequency band [6].

In this paper we discuss a novel method of controlling agricultural pest by the use of electromagnetic energy over the conventional chemical methods which are harmful to plants and the human beings consuming them. Section II discusses measurement of the effects of electromagnetic radiations on the biological tissues. The dielectric and the dielectric properties of wheat grains are discussed in section III. In Section IV simulation and results are discussed.

II. MEASUREMENT OF THE EFFECTS OF ELECTROMAGNETIC RADIATIONS ON THE BIOLOGICAL TISSUES

A. Measurement of SAR in biological tissues

The interaction of electromagnetic fields with biological tissues can be defined in terms of Specific Absorption Rate (SAR). It is a measure of the rate at which energy is absorbed by the biological tissues when exposed to a Radio Frequency (RF) electromagnetic field. SAR is usually averaged either over the whole object or over a small sample volume (typically 1 g or 10 g of tissue) [2]. At lower Frequencies of EM radiation (by but not below approximately 100 KHz) many biological effects are quantified in terms of the current density in tissue and this parameter is most often used as a dosimetric quantity. In general, exposure to a uniform (plane-wave) electromagnetic field results in a highly non-uniform deposition and distribution of energy within the body, which must be assessed by dosimetric measurement and calculation [4].

B. Microwave Heating Phenomena

Dielectric heating depends on the interaction between polar groups in molecules of non- conductive materials and the alternating electric field of electromagnetic oscillation. The atomic carriers of charges are not able to move upon imposing an electric field E, instead, they may only be slightly dislodged from their initial position. The effective force is proportional to the electric field strength, and due to this displacement, negative and positive surface charges arise at the terminal sites. This phenomenon is referred to as polarization P and is related to the electric field by Eq.1.

$$P = (\varepsilon' - 1)\,\varepsilon_0 E = D - \varepsilon_0 E \qquad (1)$$

Where, E represents Electric Field vector measured in V/m. P represents Polarization vector measured in C/m^2. D represents Dielectric displacement and ε_0 represents Permittivity of free space.

When the material with water molecules is subjected to an electromagnetic field that rapidly changes direction, the water molecules rotate into alignment with the direction of electrical field changes direction. The water molecular friction produces the internal heat of the material. The frequency in a range of 12 MHz-2450 MHz is usually used in food engineering. Dielectric materials, such as most agricultural products, can store electric energy and convert electric energy into heat. The increase in temperature of a material by absorbed electromagnetic energy can be expressed by Eq.2.

$$\rho Cp \frac{\nabla T}{\nabla t} = 2\pi f \varepsilon_0 \varepsilon'' E^2 \quad (2)$$

C_p represents Specific Heat of the Material in J/Kg°C. ρ represents Density of Material in Kg/m^3. E represents Electric Field Intensity in V/m^3 and f represents Frequency in Hz.

From Eq.2 the raise in temperature depends on the power, frequency, heating time and the materials dielectric loss factor. Higher temperatures in commodities can be achieved by long heating duration and high power input. If the dielectric loss factor is relatively constant, rapid dielectric heating using higher frequencies can be achieved with much lower field intensities.

III. DIELECTRIC CONSTANT AND DIELECTRIC PROPERTIES OF WHEAT GRAINS

A. Dielectric Constant

1) A common example of a dielectric is the electrically insulating material between the metallic plates of a capacitor. Every dielectric material has a dielectric constant, which describes the extent to which the material concentrates electrostatic lines of flux.

2) Dielectric properties are highly correlated with moisture content, permittivity of water greatly exceeds that of the dry matter of agricultural products.

3) The dielectric constant Ɛ' influences the electric field distribution and the phase of waves travelling through the material, whereas, the energy absorption and consequent attenuation is influenced principally by the loss factor Ɛ".

4) One of the most important properties of a dielectric material is how the value of the material's dielectric constant varies with the frequency of the applied electromagnetic field. The dielectric properties of a material can also be used to estimate the thermal energy converted from electric energy at microwave frequencies [5].

B. Relative Permittivity

The relative permittivity of a material under given conditions reflects the extent to which it concentrates electrostatic lines of flux. In technical terms, it is the ratio of the amount of electrical energy stored in a material by an applied voltage, relative to that stored in a vacuum. The real part is expressed in terms of the dielectric constant (energy stored) which influences the electric field distribution and the phase of waves traveling through the material. Dielectric loss factor, which is the imaginary part, mainly influences energy absorption and attenuation. The relative permittivity is given by the Eq.3.

$$\varepsilon = \varepsilon' - j\,\varepsilon'' \quad (3)$$

Ɛ represents permittivity, Ɛ′ represents dielectric constant and Ɛ″ represents dielectric loss factor.

C. Dielectric Properties of Wheat Grains

Along with Relative Permittivity, several other properties viz. Permeability, Electrical conductivity, Density, Thermal Conductivity and Specific Heat Capacity are included under dielectric properties. Here, some of the dielectric properties of wheat grains listed in Table I which are very useful for the simulation.

TABLE I. DIELECTRIC PROPERTIES OF WHEAT

Parameter	Values
Relative Permittivity (ε_r)	3
Permeability (μ)	1
Electric conductivity (S/m)	0.07
Density (Kg/m^3)	0.13
Thermal Conductivity (W/m*K)	769
Specific heat capacity (J/Kg*K)	1800

Extensive research is made and the values are collected which are required for carrying out the simulation [7].

IV. SIMULATION & RESULTS

A. Steps for Implementation

1) To design a parallel plate capacitor at 27 MHz which falls in the ISM band frequency.

2) To design an agricultural product in COMSOL and observe the radiation effects at ISM band frequency.

3) To measure SAR for this product and also the power dissipation pattern.

4) To observe the variation in the SAR values and the power dissipation in the grains with varying the plate voltage.

In the RF frequency range, at 27 MHz the capacitor is designed. Simulation over the grains is observed to obtained, also total power dissipation over the volume is calculated.

B. Design of the parallel plate capacitor

The parallel plate capacitor is designed at 27 MHz, equation of capacitive reactance is as in Eq.4.

$$X_C = \frac{1}{\omega C} = \frac{1}{2\pi f C} \quad (4)$$

Here, f = 27 MHz & Xc = 50 Ω

So, the calculated value of C = 118 pF and the observed value of C = 113.87 pF using the software. Using the formula of capacitance in Eq.5, the area of the plate is calculated keeping the distance between the plates equal to 20 cm and the further results are calculated.

$$C = \varepsilon_r \varepsilon_0 \frac{A}{d} \quad (5)$$

C. Simulation results of power dissipation

The capacitor is designed at 27 MHz and is operated by assigning 10 kV potential as one terminal voltage. Very high values of the potential are chosen because the considerable value of SAR is observed at higher plate potential. The design of the plates, voltage distribution plot and grains inside the plates is as shown in Fig.1.

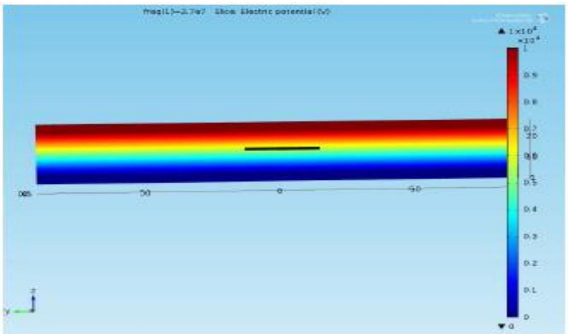

Fig. 1. Voltage distribution and the capacitor, grains design

The total value of power dissipation over the entire volume of grains is integrated and is found to be 20 W. It is observed that power dissipation increases as the volume of grains inside is increased. The power dissipation density in W/m^3 inside the grains is as shown in Fig.2.

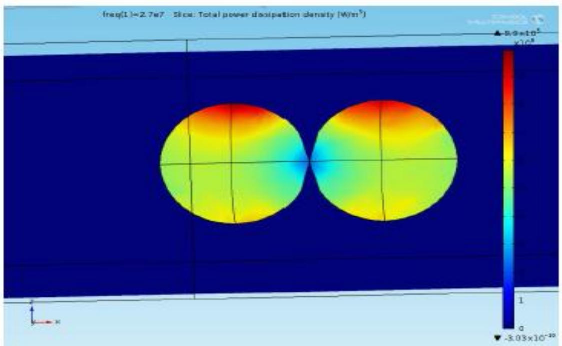

Fig. 2. Power dissipation density inside the grains

Some interesting results have been observed regarding the power dissipation density inside the grains. The power dissipation density is the most (nearly 10^6 W/m^3) on the side of the grain which is near to the positive plate of the capacitor. Throughout the grain, the power dissipation is nearly $5*10^5$ W/ m^3. The value is found to be the least where there is the contact between the grains.

The Power dissipation is measured in the grains placed between two parallel plates of a capacitor. A capacitor is designed at 27 MHz, SAR and power dissipation are obtained by varying input voltage applied to capacitor. The values are tabulated in Table II. The voltage range chosen is from 100V to 5000V.

TABLE II. POWER DISSIPATION DENSITY AND SAR WITH VARYING INPUT VOLTAGE

Input Voltage (V)	Power Dissipation Density (W/m^3)	SAR (W/Kg)
100	114.301	0.148
200	457.203	0.594
300	1028.711	1.377
400	1828.817	2.378
500	2857.527	3.716
..	..	..
..	..	..
1000	11430.106	14.864
3000	1.028e5	133.68
5000	2.857e5	371.52

CONCLUSION

In this paper the concept of Specific absorption rate, power dissipation in wheat due to capacitive field is determined. The capacitor is designed which operates in ISM band frequency 27 MHz and the power dissipation pattern is analyzed within the grains. It is also observed that a very high voltage is to be applied at the capacitor plate to obtain considerable SAR within the grains. About 500 V terminal voltage is required to obtain 3.7 W/Kg SAR. Unlike, exposure to the radiations from an antenna, the effects due to the capacitive field is throughout the volume and not just only on the surface. The model is simulated using COMSOL MULTIPHYSICS and the result of simulation shows that SAR and power dissipation increases with the variation in input terminal voltage. RF and MW heat methods may be an alternative to control insects in agricultural products during a short time period without product quality damage. Anechoic chambers are required for the practical implementation.

REFERENCES

[1] S. Wang and J. Tang, "Radio frequency and microwave alternative treatments for insect control and nuts," *Agricultural Engineering Journal, vol. 10(3&4), 105-120, 2001.*

[2] Teerapot Wessapan, Siramate Srisawatdhisukul, Phaungsak Rattanadecho "Numerical analysis of Specific Absorption Rate and heat transfer in human head subjected to mobile phone radiation at different frequencies" *Journal of Heat on mass Transfer 55 (2012) 347-359.*

[3] International Commission on Non-Ionizing Radiation Protection (ICNIRP), Guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (upto 3000GHz), *Health Phys. 74(1998) 494-522.*

[4] Riagh W. Y. Habash, Rajiv Bansal, Daniel Krewski, Hafid T. Alhafid, "Thermal Therapy, Part IV: Electromagnetic and Thermal Dosimetry, *Critical Reviews in Biomedical Engineering, Vol. 35, 123-182(2007).*

[5] Kuang and S. O. Nelson, "Dielectric Relaxation characteristics of fresh fruits and and vegetables from 3 to 20 GHz," *Journal of Microwave power and Electromagnetic Energy, Vol.32, No. 2, 1997.*

[6] Jing Peng a, Juming Tang Yang Jiao, Stewart G. Bohnet a, Diane M. Barrett "Dielectric properties of tomatoes assisting in the development of microwave pasteurization and sterilization processes." *LWT - Food Science and Technology 54 (2013) 367e376 ELSEVIER*

[7] A.Kraszewski S.O.Nelson "Composite model of complex permittivity of cereal grains", *J.Agric Engng Res. (1989) 43211-219.*

[8] Constantine A. Balanis, Antenna Theory: Analysis and Design, 2nd Edition; John Wiley Sons Inc. New York

[9] S. Wang, J. Tang, R. P. Cavleiri , D. C. Devis, "Differential heating of Insects and Fruits associated with radio Frequency" *TRANSACTIONS OF THE ASAE*

[10] J. N. Ikediala, J. Tang, S. R. Drake, L. G. Neven" Dielectric properties of apple cultivars and codling moth larvae," *TRANSACTIONS OF THE ASAE VOL. 43(5): 1175-1184.*

[11] L.S. Xu, Max Q.-H. Meng, and B.P. Li, "Effects of Dielectric Values of Human Body on Specific Absorption Rate (SAR) Following 800 MHz Radio Frequency Exposure to Ingestible Wireless Device," *31st Annual International Conference of the IEEE EMBS Minneapolis, Minnesota, USA, September 2-6, 2009.*

[12] Concettina Buccella, Senior Member, IEEE, Valerio De Santis, Member, IEEE, and Mauro Feliziani, Senior Member, "Prediction of Temperature Increase in Human Eyes Due to RF Sources," IEEE , *IEEE TRANSACTIONS ON ELECTROMAGNETIC COMPATIBILITY, VOL. 49, NO. 4, NOVEMBER 2007.*