DESIGN AND DEVELOPMENT OF A PROTOTYPE RADIO FREQUENCY APPLICATOR FOR POST BAKING OF BISCUITS

[1*]Jeni Anto.F, [2]A. Sumathi
[1*]Anna University, Chennai - 600025, Tamil Nadu, India. [1]jensonjenisha@gmail.com
[2]Department of ECE, Adhiyaman College of Engineering, Hosur - 635109, Tamil Nadu, India.
[2]sumathi_2005@rediffmail.com

Abstract: *- Indian Biscuits Corporation appears to be the biggest among all the food corporations and has a turnover of around ₹.3000 corers. Indian subcontinent is known to be the second biggest maker of biscuits, the first being USA. The biscuits per capita utilization in India is 2.0 kg and ranked 3rd after USA and China amongst the global biscuits producers. Biscuit making process have stages like mixing, forming, baking, cooling and packaging. The baking method is the main energy overwhelming and quality deciding procedure. In conventional baking process, checking emerrges because of the development of worries in the item piece. These burdens are caused by differential dampness content between the external surface and the middle bone of the biscuit and causes breakage. Radio Frequency Post Baking is a proven result to this difficulty. RF heaters are like microwave ovens where items (food, biscuits, paper, materials etc) going through the microwave oven (heater), are subjected to an immediate or volumetric warming process as a radio frequency (RF) energy source. In the simplest type of RF tool, the material to be warmed is placed between two metal plates which make an electrical capacitor. The material turns into a lossy dielectric and attracts energy from the RF Generator which is associated over the two plates. Main aim of this study was to design, development and testing of a prototype RF applicator for post baking of biscuits by studying dielectric properties of biscuits and numerical modelling using COMSOL MULTIPHYSICS software.*

Keywords: *applicator, baking, checking, dielectric properties, radio frequency heating*

1. Introduction:

A biscuit (pronounced “biskit”) in the United States, and widely used in popular American English, is a small bread made with baking powder or baking soda as a chemical leavening agent rather than yeast. The origin of the word "biscuit" is from Latin via Middle French and means "cooked twice" (similar to the German Zwieback). Some of the original biscuits were British naval hard tack. That was passed down to American culture, and hard tack (biscuits) was made through the 19th century.

Indian Biscuits Industry came into major existence and started gaining a sound status in the bakery industry in the later part of 20th century when the urbanized society called for readymade food products at a tenable cost. Biscuits were assumed as sick-man's diet in earlier days. But today it has become one of the most loved fast food products for every age group. Biscuits are always easy to carry, tasty to eat, cholesterol free and reasonable at cost. Maharashtra and West Bengal are the most industrially developed states; hold the maximum amount of consumption of biscuits. Even, the rural sector consumes around 55 % of the biscuits in the bakery products.

Indian Biscuits Industry is by all accounts the biggest among all the food industries and has a turnover of around ₹.3000 crores. The bread rolls per capita utilization in India is 2.0 kg and India is positioned third after USA and China among the worldwide biscuit rolls manufacturers. The fare of biscuits is around 17% of the yearly production, the export of sweet biscuits for year 2007-08 was ₹ 145.93 crores and for year 2008-09 (April-Dec) was ₹ 280 crores, the major exporting regions were Haiti, Angola, USA, Ghana, UAE. The imports are not major amount as compared to the total expenditure. Government has set up The Federation of Biscuit Manufacturers of India (FBMI) which has affirmed a great future of India Biscuits Industry in the year 1953. As per FBMI, an enduring development of 15 % per annum in the following 10 years will be accomplished by the biscuit business of India. Moreover, the biscuits export will likewise surpass the target and hit the worldwide market effectively.

2. Objectives:

Of all these steps the procedure of baking is the main energy consuming and value deciding action. In current baking action, Checking emerges due to the development of worries in the product piece. These burdens are caused by differential dampness content between the external surface and the inside bone of the biscuit. In baking, heat is spreaded to the surface of the material only, by excellence of conduction, convection or radiation. This implies the heat energy needs to go from the surface by conduction to the inside of the material. Regularly this can show an issue, because the product itself is a good protector and all things considered it is hard to get the heat to go through to the focal point of the product. In this manner the surface dries out, while the centre or focal point of the piece stays high in moisture. Radio Frequency Post Baking is a demonstrated solution for this issue.

Radio frequency waves are the electromagnetic radiation of range 1 to 300 MHz. The radio frequencies reserved for industrial use by the Federal Communications Commission are 13.56MHz ±0.05%, 27.12MHz ±0.60%, and 40.68MHz ±0.05%.
RF heaters are like to microwaves where items (food, wafers, paper, materials etc) going through the microwave oven (warmer), are subjected to an immediate or volumetric warming procedure as a radio frequency (RF) energy source. In the last complex type of RF implemnt, the material to be heated is located between two metal plates which frame an electrical capacitor .The material turns into a lossy dielectric and assimilates energy from the RF Generator which is associated over the two plates.

Keeping these in view, the following objectives are undertaken for further study

1. Measurement of dielectric properties of biscuit dough at 27.12 MHz
2. Numerical modelling of Radio Frequency (RF) heating process for post baking of biscuit.
3. Design of Radio Frequency applicator for post baking of biscuit.
4. Testing of Radio frequency applicator for post baking of biscuits.

3. Numerical Modelling of RF Heating:

3.1.1 Software Tools:

COMSOL Multiphysics, Version 4.2 (COMSOL Multiphysics Pvt Ltd, Bangalore, India) was used for the numerical modelling of RF heating.

3.1.2 Theory:

The substance to be heated is considered in terms of its compound dielectric constant. The actual part of the dielectric constant finds the speed of the RF wave in the material while the pretend part indicates the losses. When a dielectric material is positioned between two parallel metallic plates, the applied RF field warms up the material. The key source of heat comes from the RF power density (losses) in the object given as follows,

$$Q = 2\pi f \epsilon_0 \epsilon_m'' |\mathbf{E}|^2 \quad (1)$$

Where,

Q = RF power loss density in W/m^2
f = frequency of RF field in Hz
ϵ_0= dielectric constant of free space
ϵ_m''= loss factor of food material
E = electric field inside the applicator per unit dimension in V/m.

3.1.3 Physical and Simulation model:

A 12 kW, 27.12 MHz parallel plate applicator system was used. The dimension of the RF cavity was 1.8m X 1.4m X 1.0m. A design of the arrangement is depicted in Fig. 3.1 since the wavelength of the wave at 27.12 MHz (~11m) is large in relationship to thecavity size, a quasi static approximation of the electric field was assumed. This was obtained by solving Laplace equation:

$$\nabla\left(\sigma + j2\pi f \varepsilon_o \varepsilon_m\right)\nabla V = 0 \quad (2)$$

The RF power density thus obtained acts as the heat basis for the conductive heat transfer in the substance. The solved heat transfer equation is given as:

$$\frac{\partial T}{\partial t} = \nabla \alpha \nabla T + \frac{Q}{\rho C_p} \quad (3)$$

The heating uniformity of the food sample was measured in terms of Power Uniformity Index (PUI) defined as:

$$PUI = \frac{\frac{1}{V_{vol}} \int_{V_{vol}} \sqrt{(Q - Q_{av})^2}\, dV_{vol}}{Q_{av}} \quad (4)$$

Where,

$$Q_{av} = \frac{1}{V_{vol}} \int_{V_{vol}} Q\, dV_{vol}$$

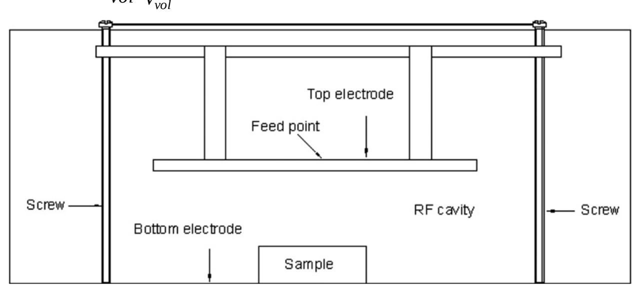

Fig. 3.1. Schematic diagram of RF applicator

3.1.4 Simulation workflow:

The flowchart for simulation set up of the RF heating model is shown in Fig. 3.2

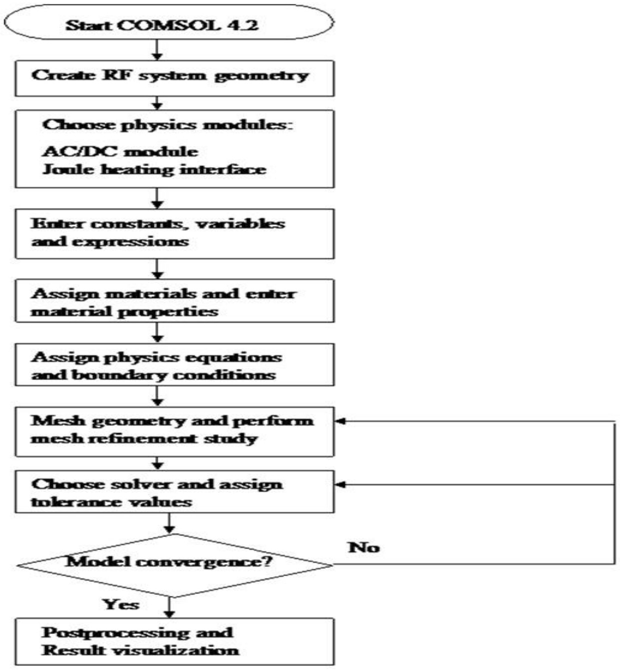

Fig. 3.2. Flowchart of numerical modelling process

3.1.5 Geometry*:*

In order to reduce the simulation time as well as computational memory, only one half of the RF cavity size was considered for numerical modelling. Cavity dimension of 900 mm X 680mm X 1000 mm was used as shown in Fig. 3.3

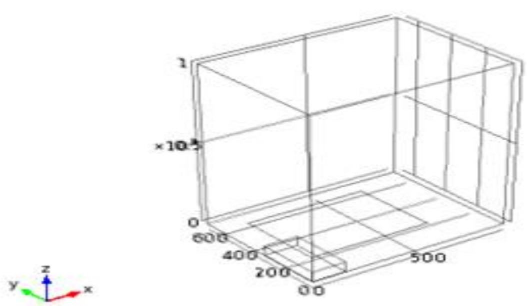

Fig. 3.3. Geometry of the RF system used for FEM analysis

3.1.6 Material assignment:

The dielectric food sample was assigned to the part of the geometry shown in the inset of Fig. 3.4

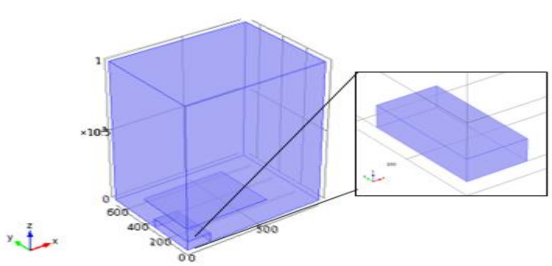

Fig. 3.4. Material assignment to domains of the geometry (zoomed sample shown in inset)

Air was assigned to the remaining part of the geometry. Properties of air were used from the COMSOL's inbuilt material library as shown in Table 3.1

Table 3.1. Material parameters of air

Description	**Value**
Relative permeability	{{1, 0, 0}, {0, 1, 0}, {0, 0, 1}}
Relative permittivity	{{1, 0, 0}, {0, 1, 0}, {0, 0, 1}}
Ratio of specific heats	1.4
Electrical conductivity	{{0[S/m], 0, 0}, {0, 0[S/m], 0}, {0, 0, 0[S/m]}}
Heat capacity at constant pressure	Cp(T[1/K])[J/(kg*K)]
Density	rho(pA[1/Pa],T[1/K])[kg/m^3]
Thermal conductivity	{{k(T[1/K])[W/(m*K)], 0, 0}, {0, k(T[1/K])[W/(m*K)], 0}, {0, 0, k(T[1/K])[W/(m*K)]}}

3.2 RF heating system:

In a radio-frequency heating framework, the RF generator makes a substituting electric field between two electrodes. The substance to be heated is put between the electrodes where the exchanging energy causes polarization, where the molecules in the material persistently reorient themselves to look inverse poles. At the point when the electric field is rotating at radio frequencies, for example 27.12 MHz, the electric field interchanges 27,120,000 cycles for each second. The friction coming about because of the rotational development of the molecules and the space charge movement makes the material quickly heat throughout its mass. The amount of heat created in the item is controlled by the frequency, the square of the app1ied voltage, measurements of the material and the dielectric misfortune factor of the material, which is basically a measure of the ease with which the material can be heated by radio waves. Specifications of RFG2K5 – 2500-Watt Water-Cooled RF Generator are given in the Table 3.2 and Specifications of automatic matching network which was used for experimental purpose are given in Table 3.3

Table 3.2. Specification of RFG2k5-2500 Watt Water Cooled RF Generator

Sr.No	RF generator	Specification
1	Frequency	27.12 MHz
2	Frequency stability	27.12 MHz +/- 2.7KHz
3	Maximum Output Power	2500 Watts CW
4	Power control range	Between Zero-Max output power
5	Harmonic output	Better than 40 db below fundamental
6	Output impedance	50 Ohms
7	RF Connector	7/16 Type
8	Protections	Over temperature, Reflected power
9	AC Power line	380/415V AC-3 Phase,50/60 Hz
10	Operating temperature	0-35°C
11	Standards compliance	EN6100-6-4, EN 61000-6-1

Table 3.3. Specifications of Automatic matching network

Sr. No	Automatic matching network	Specification
1	Configuration	L network
2	Input impedance	50 Ohms
3	Input connector	7/16 Type
4	Output connector	7/16 Type
5	Output impedance range	0.5-20 Ohms
6	AC power line	85-265V AC,50/60Hz
7	Case material	Chromated aluminum

4. Results and Discussions:

In this chapter the results of the variation of the dielectric properties; dielectric constant and dielectric loss factor with respect to % moisture content at different temperature ranges, the result of variation of Dielectric properties of the wafer, Inter-electrode gaps, Electrode spacing, Electrode height, Material of conveyor belt and Electrode structure/configuration on RF power uniformity are reported

and discussed. The design of RF applicator and testing of RF heating scheme for post baking of biscuit are reported and discussed.

4.1 Dielectric Properties Measurement:

Variations of dielectric properties of biscuit dough samples were measured using parallel plate capacitor at different moisture content ranges from 0-40 % db at different temperature ranges were reported and discussed.

4.1.1 Dielectric constant:

Dielectric constants of biscuit dough samples were measured using parallel plate capacitor at different moisture content ranges from 0-40 % db at temperature ranges i.e. temperature range 20-40^0 C, 40-60^0 C, 60-80^0 C , 80-100^0 C , 100-125^0 C are shown in Fig. 4.1

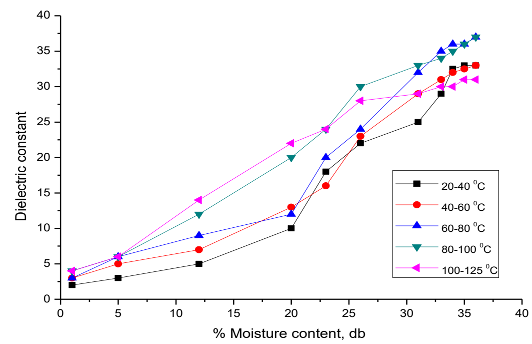

Fig. 4.1. Dielectric constant vs. % moisture content and temperature

The dielectric constant of biscuit dough samples was improved somewhat regularly as moisture content improved and also illustrated a gradual increase with the increasing temperature in the range of 0.1-40. A similar trend was obtained by Y.R.Kim et.al (1998) for wheat flour and baked samples.

4.1.2 Dielectric Loss Factor:

Dielectric loss factors of biscuit dough samples were measured using parallel plate capacitor at different moisture constant ranges from 0-40 % db at temperature ranges .i.e. temperature range 20-40^0 C, 40-60^0 C, 60-80^0 C, 80-100^0 C, 100-125^0 C are shown in Fig. 4.2

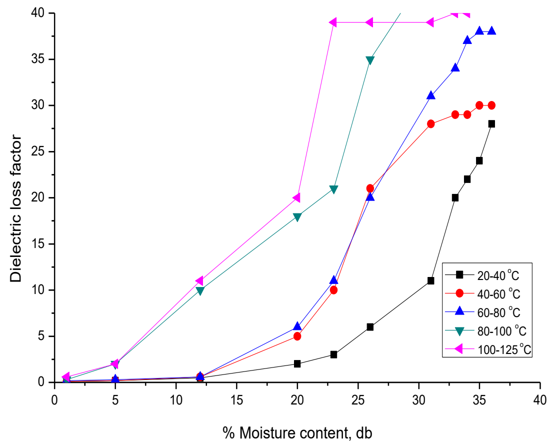

Fig. 4.2. Dielectric loss factor vs % moisture content and temperature

Dielectric loss factor was relatively same for the low moisture content range from 0-15 % db for the entire range of temperature and then exponentially improved from a particular point of moisture content i.e. from 15 % db; temperature apparently affected the dielectric loss factor starting here on. Additionally, temperature influenced this point of moisture content. A similar trend was obtained by Y. R. Kim et.al (1998) for wheat flour and baked samples.

4.2 Numerical Modelling of RF Heating:

The effects of disparity of dielectric properties of the biscuit, inter-electrode gaps, electrode height, electrode spacing, material of conveyor belt and electrode structure/configuration on RF power consistency were deliberate using COMSOL Multiphysics, Version 4.2 (COMSOL Multiphysics Pvt. Ltd, Bangalore, India) were reported and discussed.

4.2.1 Dielectric properties of the biscuit:

Dielectric properties of wafer samples obtained from experimental data were used for the arithmetical modelling of RF heating for biscuit post baking. Power consistency index differencse with dielectric constant and loss factor of biscuit for staggered electrode configuration are shown in Fig. 4.3.

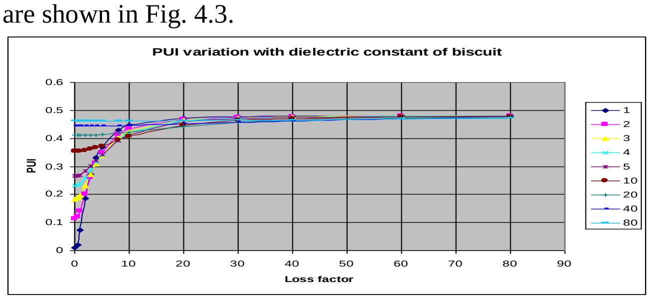

Fig. 4.3. Power uniformity index variations with dielectric constant and loss factor of biscuit for staggered electrode configuration

Power uniformity indices for loss factor in the range of 0-15 were increased with respect to dielectric constant while for loss factor above 20, power uniformity indices were relatively same.

4.2.2 Inter-electrode spacing:

Inter-electrode gap range of 100 -600 mm with 100 mm increment were used for numerical modeling of RF heating for post baking of biscuit. Power uniformity index variations with respect to inter-electrode spacing are shown in the **Fig. 4.4**

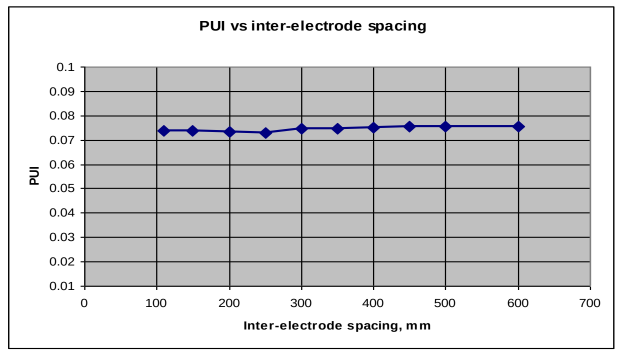

Fig. 4.4. Power uniformity index variations with respect to inter-electrode spacing

Power uniformity indices were relatively same and ranges from 0.072-0.078 for inter electrode spacing which ranges from the 100-600 mm. This indicated that inter electrode spacing has very less effect on the RF heating as shown in Fig. 4.4

4.2.3 Electrode height:

Electrode height range of 50-300 mm with 50 mm increment was used for numerical modeling of RF heating for post baking of biscuit. Power uniformity index variations with respect to inter-electrode spacing are shown in the Fig. 4.5

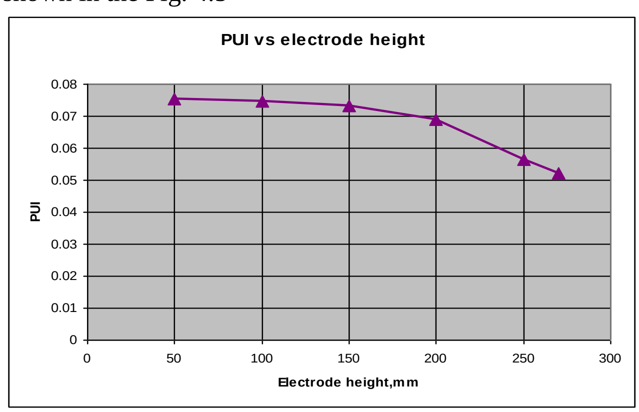

Fig. 4.5. Power uniformity index variations with electrode height

Power uniformity index values were decreased with the increasing electrode height. Therefore as electrode height increases uniformity of RF heating also increased. It indicated that for better uniformity in heating, spacing between top and bottom electrode should be decreased by increase in electrode height while designing the RF applicator.

4.2.4 Electrode spacing:

Electrode spacing between top and bottom electrode having range of 100 -350 mm with 50 mm increment were used for numerical modeling of RF heating for post baking of biscuit. Power uniformity index variations with respect to electrode spacing are shown in the Fig. 4.6

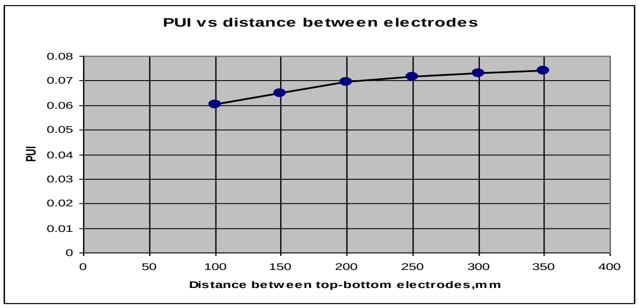

Fig. 4.6. Power uniformity index variations with distance between electrodes

Power uniformity index values were increased with increase in the distance between top and bottom electrode and ranges from 0.06-0.075 for spacing ranges from 100-350 mm with increment of 50 mm. Therefore for design of RF applicator, distance between top and bottom electrode was kept less for uniform heating of products.

4.2.5 Material of conveyor belt:

Polysilicon, Nylon 60, Teflon, PVC and Polyethylene were used as conveyor belt material for numerical modeling of RF heating for post baking of biscuit. The effect of conveyor material on power uniformity index at room temperature (conveyor thickness = 1.5 mm) is shown in the Table 4.1

Table 4.1. Effect of conveyor material on power uniformity index at room temperature (conveyor thickness = 1.5 mm)

Sr. No.	Effect of conveyor material	PUI
1	Polysilicon	0.0731
2	Nylon 60	0.0838
3	Teflon	0.0894
4	PVC	0.0852
5	Polyethylene	0.0884

Polysilicon has lowest power uniformity index while Teflon has highest power uniformity index, so polysilicon was selected as material of conveyor of belt in design of RF applicator.

5. Summary and Conclusion:

A biscuit (pronounced “biskit”) in the United States, and widely used in popular American English, is a small bread made with baking powder or baking soda as a chemical leavening agent rather than yeast. Indian Biscuits Industry seems to be the largest among all the food industries and has a turnover of around ₹.3000 corers. Indian subcontinent is known to be the second largest manufacturer of biscuits, the first being USA. Biscuit making process have stages like mixing, forming, baking, cooling and packaging.

The baking process is the major energy consuming and quality deciding process. In conventional baking process, Checking arises due to the build-up of stresses in the product piece. These stresses are caused by differential moisture content between the outer surface and the centre bone of the biscuit and causes breakage. Radio Frequency Post Baking is a proven solution to this problem. RF heaters are similar to microwave ovens where products (food, biscuits, paper, textiles etc) passing through the oven (heater), are subjected to a direct or volumetric heating process in the form of a radio frequency (RF) energy source.

Keeping these in view, the following objectives are undertaken for study

1. Measurement of dielectric properties of biscuit dough at 27.12 MHz
2. Numerical modelling of Radio Frequency (RF) heating process for post baking of biscuit
3. Design of Radio Frequency applicator for post baking of biscuits
4. Testing of Radio frequency applicator for post baking of biscuits

Dielectric constant and loss factor of biscuit dough samples were measured using parallel plate capacitor at different moisture content ranges from 0-40 % db at temperature ranges i.e. temperature range 20-40^0 C, 40-60^0 C, 60-80^0 C , 80-100^0 C , 100-125^0 C.

The effects of variation of dielectric properties of the biscuit, inter-electrode gaps, electrode height, electrode spacing, material of conveyor belt and electrode structure/configuration on RF power uniformity were studied using COMSOL Multiphysics, Version 4.2 (COMSOL Multiphysics Pvt. Ltd, Bangalore, India).Design of RF applicator and testing of RF applicator for post baking of biscuits were carried.

Following conclusions were obtained from present study

1. The dielectric constant of biscuit dough samples was improved somewhat deliberately as moisture content expanded and also illustrated a progressive improvement with the increasing temperature having range from 0.1 to 40.

2. Dielectric loss factor of biscuit samples was relatively same for the low moisture content from 0 to 15 % db for the entire range of temperature and then exponentially upgraded from a convinced point of moisture content normally from 15 % db; temperature certainly affected the dielectric loss factor from this point on. Also, temperature influenced this point of moisture content.

3. Power uniformity indices for loss factor in the range of 0-15 were increased with respect to dielectric constant while for loss factor above 20, power uniformity indices were relatively same.

4. Power uniformity indices were relatively same and ranges from 0.072-0.078 for inter electrode spacing range from the 100-600 mm. This indicated that inter electrode spacing has very less effect on the RF heating.

5. Power uniformity index values were decreased with the increasing electrode height. Therefore, as electrode height increases uniformity of RF heating also increased. It indicated that for better uniformity in heating, spacing between top and bottom electrode was decreased by increasing electrode height while designing the RF applicator.

6. Power uniformity index values were increased with increase in the distance between top and bottom electrode and ranges from 0.06-0.075 for spacing ranges from 100-350 mm with increment of 50 mm. Therefore for design of RF applicator, distance between top and bottom electrode was kept less for uniform heating of products.

7. Polysilicon has lowest power uniformity index while Teflon has highest power uniformity index, so polysilicon was selected as material of conveyor of belt in design of RF applicator.

8. Designed RF applicator was successful for post baking of biscuits and moisture was successfully removed from 10 % to 1-2 % db.

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