Effects of Sample's Dielectric Property on the Performance of Microwave Heating

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Abstract

The performance of microwave heating depends on its operating frequency, applied power, sample's dielectric property, geometry, thickness, position of the sample placed in the multimode applicator and the size of applicator. This paper presents the effects of dielectric properties of the clay sample placed inside the multimode applicator on the performance of microwave heating. COMSOL Multiphysics software was used to simulate and estimate the electric field distribution over the surface of the sample for two different dielectric properties of clay sample. The simulated and experimentally obtained results are almost matched.

1. Introduction

High heating efficiency is one of the most desired characteristics for both industrial and domestic microwave ovens; since electric energy is expensive and also low efficiencies high power reflections, which might damage the magnetron [1]. Also the quality of the processed material is determined by its heating efficiency.

Many researches indicate that load matching improves the heating efficiency of microwave system by reducing the reflected power that goes to the waveguide. So far load matching has been done by using external devices, such as tuners, stubs or irises [1,2], feeding the applicator from more than one position [3,4], surrounding the sample material with dielectric multilayer [5-7] or by changing the position of the sample material inside multimode applicator[8]. However, the above mentioned techniques have thier own limitation and difficulties in the overall cost of the system.

It has been recently shown in several works that efficiency of multimode applicator dependes on the operating frequency, samples location, shapes of the sample and so on. Many reaserchers invstigate the effects of different sample's dielectric property, geometry, size, applied power, and positions of the sample inside the waveguid on the heating efficiency of microwave oven and for each different samples they found different efficiency [9-12].

In this study we investigated the effects of dielectric properties of the clay sample placed inside the multimode applicator on microwave heating efficiency of the system. The simulation work was done by COMSOL Multiphysics software. The parameter chosen for this study is two different dielectric properties of the clay sample.

2. Theoretıcal Part

The schematic and modelling diagram of microwave oven prepared for this study is illustrated in figure 1. The microwave multimode applicator is represented by a metallic box of rectangular shape and it's fed by standard rectangular waveguide, which operates at 2.45 GHz frequency. The location of the sample is fixed near to the bottom of the applicator for this study. For this particular study rectangular shape clay sample was chosen. The clay sample has been chosen in order to study real industrial dielectric materials that represent high dielectric and loss-factor values which are difficult to heat. The results obtained in this work can be applied in industrial processes where pieces of clay must be dried. In this study, the electromagnetic problem has been solved in the frequency domain with the aid of the following vector-wave equation;

$$\nabla^2\vec{E} + \omega^2\mu\varepsilon\vec{E} = 0 \qquad (1)$$

where is the vector's electric field, ω is the angular frequency, μ is the magnetic permeability, and ε is the dielectric comple permittivity of the medium, given by;

$$\varepsilon = \varepsilon_0(\varepsilon' - j\varepsilon'') = \varepsilon_0(\varepsilon' - j\frac{\sigma}{\omega}) \qquad (2)$$

where ε_0 is the vacuum permittivity, ε' is the dielectric constant, ε'' is the loss factor, and σ is the conductivity of the medium. The ability of a dielectric material to absorb microwaves and store energy is given by the complex permittivity of the medium.

The ratio of the dielectric loss to the dielectric constant is known as the loss tangent (tan δ) which is given as;

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \qquad (3)$$

Hence with values of less dielectric constant and large values of loss tangent or dielectric loss, materials couple with microwave with great efficiency. In addition, the dielectric properties of a material depend upon the temperature, frequency, and so on.

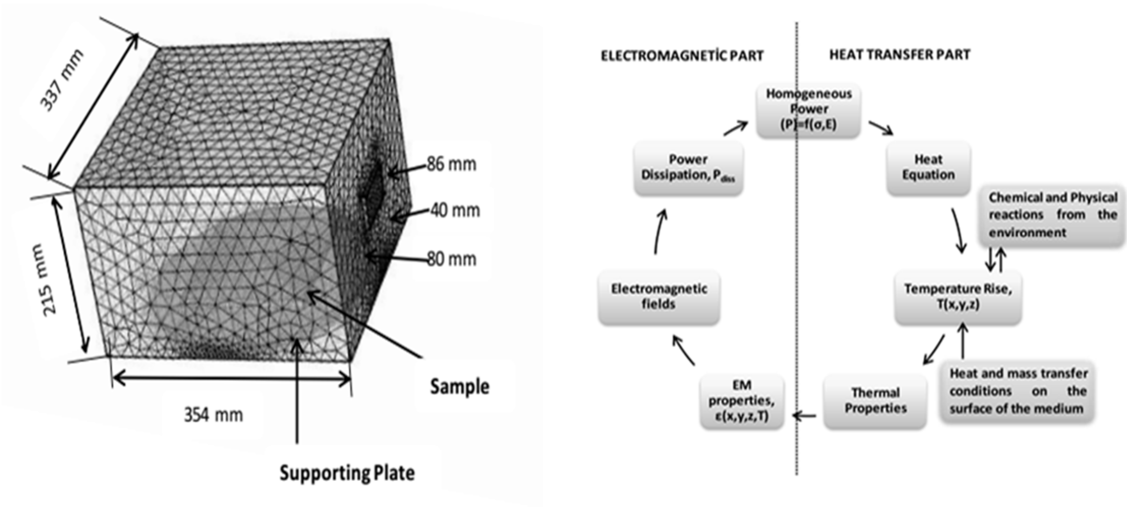


Fig. 1. Microwave oven schematic and modelling diagram

The reflection coefficient in the waveguide has been computed by relating the incident electric field and the reflected electric field within the waveguide as follows;

$$\rho = \frac{E_r}{E_i} \quad (4)$$

where E_i and E_r are the incident and reflected electric field, respectively. The heating efficiency, the ratio between the reflected power towards the source and the incident power, has been defined as a function of the reflection coefficient;

$$\eta = 1 - |\rho|^2 \quad (5)$$

The above mentioned equations with the proper boundary conditions of the metallic walls and the waveguide excitation are used during the microwave heating of clay sample.

Table 1. dielectric characteristics of the clay samples

	ε'	ε''	tan(δ)
Sample 1	59.99	11.63	193.87
Sample 2	77.10	9.19	119.2

3. Results and Discussion

The above mentioned equations have been applied to study the effects of different dielectric properties of clay samples placed inside multimode microwave applicator as shown in figure 1 for efficient microwave heating. Microwave heating efficiency is affected by geometry of the sample, its dielectric properties, the placement inside the applicator and so on. However, in this study we will observe and discuss only the effects of sample's dielectric values while keeping the other factors constant for the entire simulation and experimental work. The initial heating temperature is not the same for both samples but both of them are heated for 5 minutes at 2.45 GHz operating frequency inside the multimode microwave applicator. The sample is placed over a cylindrical shaped glass plate, which is located near to the bottom of the applicator. The applicator is fed 900W for the entire simulation process through the rectangular waveguide. The numerical and simulation results relating the microwave heating are presented and discussed as follows.

The dielectric properties of the samples located inside the applicator influences the amount of the microwave power absorbed in the sample during its heating process. The dielectric values used for simulation and experimental test is measured by network analyzer (Agilent, E506 1B) insturument with two parallel 200mm probe at 2.45 GHz frequency.

Fig. 2 shows the electric field distribution over the clay sample during microwave heating process for rectangular shaped sample. The result shows that the electric field distribution over the sample for different clay sample is different due to the sample's dielectric loss factor. The maximum value was obtained at the top and bottom right of the sample as shown in the figure.. It is found that the electric field intensity is stronger near to the right and left walls of the microwave applicator, and the weakest is located in the middle of the microwave applicator. This variation in electric field distribution also leads to different microwave efficiency.

Fig. 2a shows the electric field distribution over sample 1. The power absorbed by the sample is 430.83 W, from this we calculated the efficiency of the system, 47.87%. Fig. 2b shows electric field distribution for clay sample 2. From the simulation for sample 2b, the power absorbed by the sample during microwave processing is 380.83 W, from this we calculated the efficiency of the system as 42.31%.

Finally, from the analysis of the influence of the clay sample employed in the microwave heating process, it can be concluded that different sample's dielectric permittivity produce different levels of efficiency. This indicates that sample's dielectric value is one of the utmost importance when trying to design an efficient microwave oven.

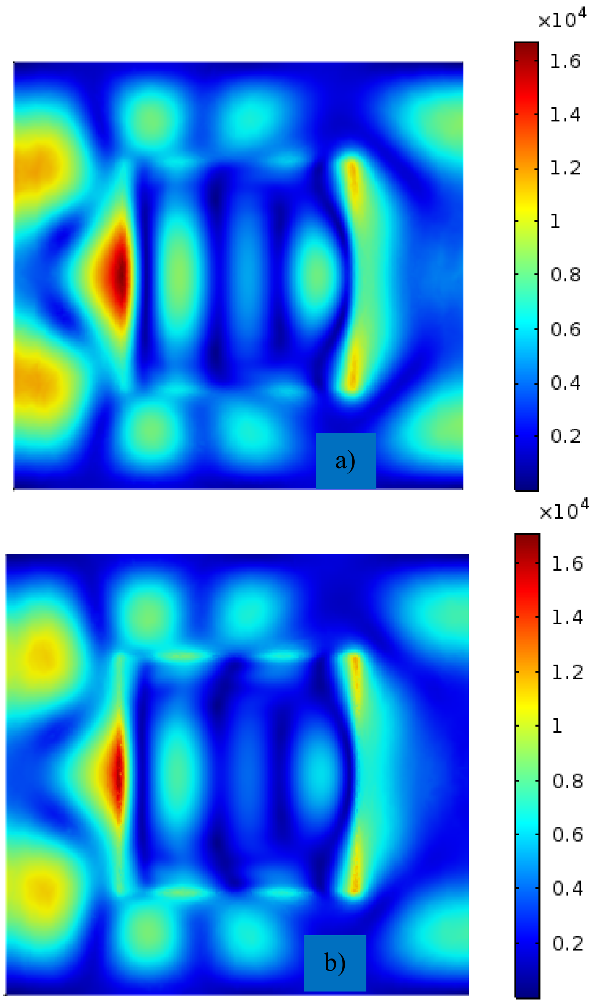


Fig.2. Electric field distribution inside the applicator: a) sample 1 b) sample 2

Table 2. Summary of the obtained results for different dielectric permittivity values of clay sample at 900W input power

	Dielectric permittivity	tanδ (10^{-3})	Absorbed power (W)	η (%)
Sample 1	59.99-j*11.23	193.87	430.83	47.87
Sample 2	77.10-j*9.19	119.2	380.34	42.31

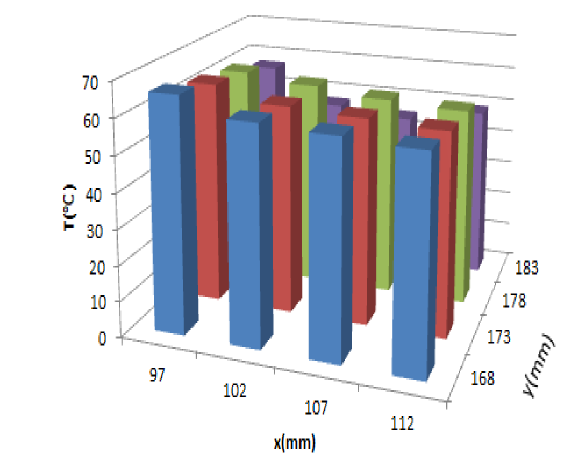
4. Experimental Validation

The simulations was done using COMSOL Multiphysics commercial software. This 3D electromagnetic solver uses the finite-difference time-domain method to compute the electric-field distribution in several situations [13]. In order to validate the simulation result for different dielectric values of the clay sample, experimental works were done.

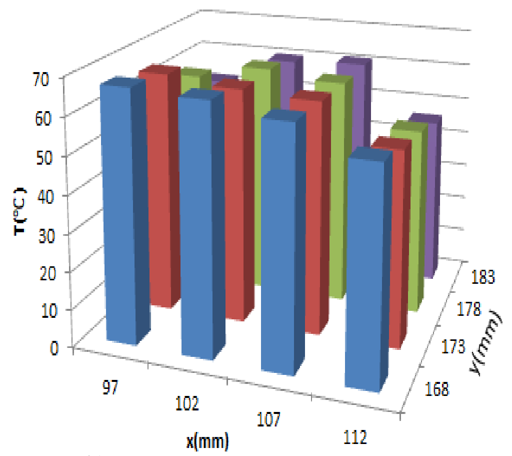
A thermal fax paper was placed on the top of the sample before microwave drying and placed inside the applicator. Fig. 3 shows the stain made by the sample during microwave heating. The stains obtained on the fax paper agree with the hot and cold spots generated during microwave heating. The temperature pattern over the samples was measured by the laser thermometer.

Fig. 4 represents temperature distribution pattern for both samples, generally coincides with the simulated electric field distribution. For example, at the region of maximum electric field intensity on sample 1, V= 23.193 kV/m and 28.521 kV/m, the temperature that rises over sample 1 is also at the maximum; i.e., 61^{0}C and 67^{0}C, respectively. Also for sample 2 it shows that, at maximum electric field intensity region, the temprature rise is also maximum and at lower electric field region, the tempreture rise is low. From the above experimental result, we can see clearly the direct relationship between the electric field intensitty and temperature pattern, the temperature rise is affected by the sample's dielectric properties, which also affected the system's overall efficieny, and this validates our work.

Fig. 3. Thermal fax paper stain of sample 1 during microwave drying



a)



b)

Fig. 4. Temperature distribution over the samples:
a) sample 1 b) sample 2

5. Conclusion

In this paper, the effects of dielectric properties of clay sample on the performance of microwave heating have been investigated and discussed. The sample is heated for 5 minutes at 2.45 GHz frequency while the applicator is fed 900 W by the rectangular waveguide. Microwave heating is affected by different parameters like placement of sample inside the applicator, dimension and shapes of the sample, operating frequency, dielectric properties of the sample particularly by samples dielectric loss factor. However, in this paper only the dielectric properties of the sample had been studied by fixing the other factors constant throughout the work to see only the effect of the dielectric properties changes. We used rectangular clay sample with different dielectric values. The simulation and experimental result shows that the performance of the microwave system is greatly affected by the properties of the sample to be heated. For this study we used only rectangular geometry clay sample for different sample's dielectric properties.

6. References

[1] A. C. Metaxas and R. J. Meredith, "Industrial Microwave Heating". London, U.K, Peter Peregrinus, 1983.

[2] Mehrdad Mehdizadeh, "Microwave/RF Applicators and Probes for Material Heating, Sensing and Plasma Generation: A Guide", Wilmington, Delaware, February 18, 2009

[3] Dharmendra Singh Rajpurohit and Rahul Chhibber, "Design of Multimode Microwave Cavity for Materials Processing", 5th International & 26th All India Manufacturing Technology, Design and Research Conference (AIMTDR 2014) December 12th–14th, 2014, IIT Guwahati, Assam, India

[4] Dharmendra Singh Rajpurohit and Rahul Chhibber, "Design Optimization of Two Input Multimode Applicator for Efficient Microwave Heating", International Journal of Advances in Microwave Technology (IJAMT) Vol.1, No.3,68-73, Nov. 2016

[5] J. Monzo´-Cabrera, J. Escalante, A. Dı´azMorcillo, A. Martı´nez-Gonza´lez, and D. Sa´nchez-Herna´ndez, "Load matching in multimode microwave-heating applicators based on the use of dielectric layer moulding with comercial materials", Microwave Opt TechnolLett 41 (2004), 414–417.

[6] J. Monzo´-Cabrera, A. Dı´az-Morcillo, J.L. Pedren˜o-Molina, and D. Sa´nchez-Herna´ndez, "A new method for load matching in multimodemicrowave heating applicators based on the use of dielectric-layer superposition", Microwave Opt Technol Lett 40 (2004)

[7] E. Domínguez-Tortajada, J. Monzó Cabrera, and A. Díaz-Morcillo, "Load matching in microwave-heating applicators by means of genetic algorithms optimization of dielectric multilayer structures", Microw.Opt. Technol. Lett., vol. 47, no. 5, pp. 426–430, Dec. 2005.

[8] M. E. Requena-PCrez, J.L. Pedreiio-Molina, M. Pinzolas-Prado,J. Monzo-Cabrera,A. Diaz-Morcillo and D. Sinchez-Hernandez, "Load matching in multimode microwave-heating applicators by load location optimization", 34" European Microwave Conference - Amsterdam, 2004

[9] J.L. Pedreño-Molina, J. Monzó-Cabrera and M. Pinzolas, "A new procedure for power efficiency optimization in microwave ovens based on thermographic measurements and load location search", international Communications in Heat and Mass Transfer 34 (2007) 564–569

[10] Idris Ahmed Ali, "Effect of load on the heatıng efficıency and temperature uniformity in multimode cavity applicators", journal of microwave power and electromagnetic energy, 2016, vol.50, no.2,123-137

[11] G. Brodie, "The influence of load geometry on temperature distribution during microwave heating", Vol. 51(4): 1401-1413, 2008 American Society of Agricultural and Biological Engineers ISSN 0001-2351

[12] Waraporn Cha-um, "Phadungsak Rattanadecho and WatitPakdee, Experimental analysis of microwave heating of dielectric materials using a rectangular wave guide (MODE: TE10) (Case study: Water layer and saturated porous medium)", Experimental Thermal and Fluid Science 33,2009, 472–481