

DOI: 10.2478/v10129-011-0054-6

Mohd. Shafi Khan<sup>1</sup>, Vishal Singh Chandel<sup>2\*</sup>, Rajiv Manohar<sup>3</sup>, Jagdeesh Prasad Shukla<sup>3</sup>

<sup>1</sup>Department of Physics, A.I.E.T. Lucknow, (U.P.), India-226002; <sup>2</sup>Department of Physics, Integral University, Lucknow, (U.P.), India-226026; <sup>3</sup>Department of Physics, Lucknow University, Lucknow, (U.P.), India-226007,  
\*e-mail: chandel.integral@gmail.com

STUDY OF DIELECTRIC PROPERTIES OF FENUGREEK SEEDS  
(*TRIGONELLA FOENUM GRAECUM*)

ABSTRACT

The present paper studied the dielectric constant, dielectric loss, and ac conductivity of fenugreek seed, a medicinal seed (*Trigonella foenum graecum*), within the frequency range of 10 kHz and 10 MHz and the temperature range of 30°C and 50°C. Impedance gain/phase analyser (HP 4194 A) was used to measure the dielectric constant and the dielectric loss and Julabo (temperature controller, F-25, Germany) was used for keeping the temperature of fenugreek seeds constant. It was found that the dielectric constant and the dielectric loss decrease with the increase in the frequency while the same increase with the increase in temperature and moisture content. The ac conductivity increased with the increase in frequency, moisture and temperature.

*Key words:* ac conductivity, dielectric constant, dielectric loss, fenugreek, moisture.

INTRODUCTION

Fenugreek (*Trigonella foenum graecum*), a leguminous medicinal plant, is cultivated in North Africa, China, India, Pakistan, Egypt and the Mediterranean countries (Duke 1986). Its leaves are consumed as green vegetable throughout India and are also used as a supplement to wheat and maize flours for bread.

Fenugreek seeds contain many nutrients such as carbohydrates, protein, fiber, fats, saponins, choline and trigonellin, vitamins, minerals and enzymes, among which Fiber and saponin show bioactivity. Moreover, the presence of steroidal saponin, especially diosgenin (25 R-spirost-5-en-3β-ol), has also been re-

ported in fenugreek seeds (Brenac and Sauvaire 1996, Petit *et al.* 1995), which is a basic component in the hemi synthesis of steroid drugs. This makes fenugreek seeds a significant base material in pharmaceutical industry. These seeds contain almost 26.8% fenugreek galactomann gum, a chemical with blood glucose reducing property (Amin-Ryiad *et al.* 1988), and this gum, in fact, has a greater hypoglycemic effect compared to that of the seed itself. The fenugreek galactomann has extensive application in many industries, like food, pharmaceuticals, cosmetics, paper products, paint, plasters, etc (Amin-Ryiad *et al.* 1988, Scherbukhin and Anulov 1999).

The chemical constituents of fenugreek seeds contain 6.2% moisture, 23.2% protein, 8% fat, 9.8% fiber, 26.3% mucilaginous materials and 4.3% ash. According to Duke, whole grain contains (per 100g of edible portion), 369 calories, 7.8% moisture, 28.2g protein, 5g fat, 54.5g total carbohydrate, 8g fiber, 3.6g ash. Its flour contains 375 calories, 9.9% moisture, 25.5g protein, 8.4g fat, 53.1g total carbohydrate, 7.1g fiber, 3.1g ash. Raw leaves contain 35 calories, 87.6% moisture 4.6g protein, 0.2g fat, 6.2g total carbohydrate, 14g fiber, 1.4g ash (Duke 1986, Petropoulos 2002).

The medicinal properties of fenugreek seeds have been extensively explored. The following are some the well known studies of fenugreek seeds' medicinal properties: G.M.S El-Bahy reported FTIR and Raman Spectroscopic study of fenugreek (El-Bahy 2005), while J. X. Jiang *et al.* reported characterization of galactomann gum of seeds and rheological properties (Jiang *et al.* 2007), Ebubekir Altuntas *et al.* reported some physical properties of fenugreek seeds (Altuntas *et al.* 2004). Preethi B Gopalpura *et al.* reported its effect on the glycemic index of food, (Gopalpura *et al.* 2007), Amira Kassem *et al.* (Kassem *et al.* 2005) reported its effect on antifertility in male and female rabbits. R. D. Sharma *et al.* reported hypoglycemic effect of it in non-insulin dependent diabetic subjects (Sharma and Raghuram, 1990), while Valette *et al.* have shown the hypocholesterolaemic effect of the same seeds (Valette *et al.* 1984). M. Prasanna, Moosa *et al.* and Vijaya Kumar *et al.* reported the hypolipidemic effect of fenugreek seeds (Prasanna 2000, Moosa *et al.* 2006, Vijaya Kumar *et al.* 2010).

Even though a lot of literature is available describing the medicinal behavior of the fenugreek seed and the dielectric and conductive studies on variety of seeds have also been done by many researchers (Berbert *et al.* 2001, 2002, 2004, 2007, Khan and Chandel 2011, Kumar *et al.* 2006, Sacilik and Colak 2005, 2010, Sacilik *et al.* 2006, 2007, Singh *et al.* 2006, Sirikulrat and Srikulrat 2008), the dielectric properties of the fenugreek seed remain inadequately explored. The study of moisture-dependent dielectric properties of these seeds will yield valuable information on the storage and germination of fenugreek seeds and will also describe the behavior of these seeds under high frequency electric fields or dielectric heating (Nelson 1991).

## MATERIAL AND METHODS

The dust and other foreign materials were removed from the fenugreek seeds used in the present study. The seeds were kept in an air-tight container to avoid any moisture gain or loss. The seeds were then kept in a hot-air oven for 24 hours at 60°C to make the moisture content of all seeds the same. Then, the different moisture contents 2, 4, 6, 8 and 10% were made on weight basis. The samples were subjected to frequent agitation to aid uniform distribution of moisture. These samples were further kept in an air-tight container to avoid moisture loss.

The capacitances ( $C_M$ ) and dissipation factor ( $D_M$ ) measurements were taken with the help of impedance/gain phase analyzer (Model No. HP-4194A) frequency range (100Hz to 40 MHz) using a coaxial cylindrical capacitor. The sample holder was gold plated to reduce the dissipation loss. It was calibrated using standard liquids (Benzene and Methanol), and the error in measurement for dielectric constant ( $\epsilon'$ ) was found to be less than 1% and for dielectric loss ( $\epsilon''$ ) it was found to be 1.5%. The dielectric parameters and conductivity were calculated with the help of the following relations:

(1)

$$\epsilon' = \frac{C_M - C_0}{C_G} + 1$$

(2)

$$\tan\delta = \frac{C_M \times D_M - C_0 \times D_0}{C_M - C_0}$$

(3)

$$\tan\delta = \frac{\epsilon''}{\epsilon'}$$

(4)

$$\epsilon'' = \epsilon''_d + \frac{\sigma_i}{\omega \times \epsilon_0} = \epsilon''_d + \frac{\sigma_i}{2 \times \pi \times f \times \epsilon_0}$$

(5)

$$dp = \frac{\lambda_0 \times \sqrt{\epsilon'}}{2 \times \pi \times \epsilon''}$$

(6)

$$\sigma = \omega \times \epsilon_0 \times \epsilon''$$

Here  $C_M$  is the capacitance of sample holder with sample,  $C_0$  is the capacitance of empty sample holder,  $C_G$  is the geometrical capacitance:

$$C_G = \frac{q}{v} = \frac{2 \times \pi \times \epsilon_0 \times h}{\log_e(b/a)}$$

where  $a$  and  $b$  are the internal and external radii,

$h$  is the height of capacitor,

$\epsilon_0$  is the permittivity of free space, and

$\omega$  is angular frequency.

The temperature of the seeds was varied by placing the sample holder in a specially-designed glass jacket through which heated oil was circulated using refrigerated circulator of Julabo (model number F-25, Germany). The accuracy of temperature measurement was up to  $\pm 0.01$ . The experiments were performed in the Physics Department, Lucknow University, Lucknow, India.

Moisture contents in fenugreek seeds were determined on the wet-basis method. The moisture contents were adjusted by adding distilled water and conditioning of the sample at  $20^\circ\text{C}$ . These were stored in sealed jars at  $20^\circ\text{C}$  and permitted to reach room temperature ( $30^\circ\text{C}$ ) in sealed jars before the jars were opened and the dielectric constant and the dielectric loss for the fenugreek seeds were measured. The samples were kept in this condition for about 26 hours before the measurements were taken. The moisture content of the samples was determined by approved oven method (USDA 1971). Thus, the prepared samples were measured for the dielectric constant and the dielectric loss.

## RESULT AND DISCUSSION

As Figures 1 and 2 indicate, the dielectric constant and dielectric loss decrease with increase in frequency for all moisture content at a give temperature. Because of dispersion mechanism, in the lower frequency region the rate of decrease of dielectric constant is higher than that of it in the higher frequency region. The high values of dielectric constant in the lower frequency region for higher moisture content may be because of the high mobility of water dipole due to free water state and electrode polarization, whereas for dielectric loss, it may be due to high mobility of water dipole, electrode polarisation and increase in ionic and surface conductivity. The higher values of dielectric loss due to ionic conductivity have already been reported by Magario and Yamaura (Magario and Yamaura 1988)

$$\epsilon'' = \epsilon_d + \frac{\sigma_i}{2 \times \pi \times f \times \epsilon_0}$$

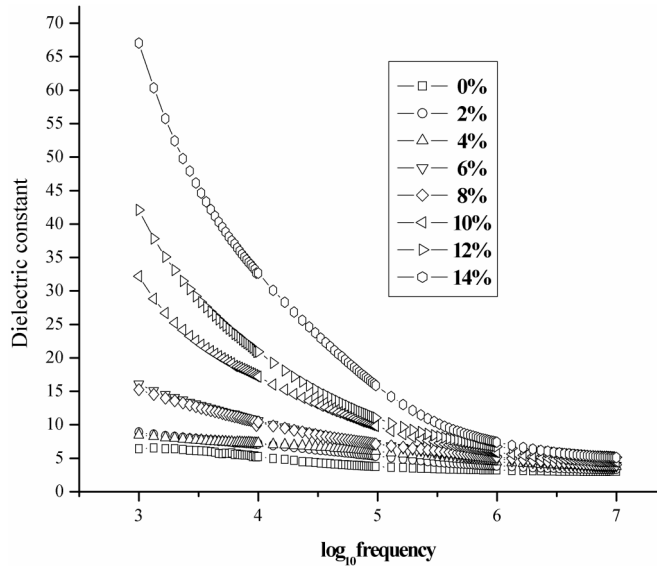


Fig. 1. Variation of dielectric constant of fenugreek seeds with frequency at 30°C

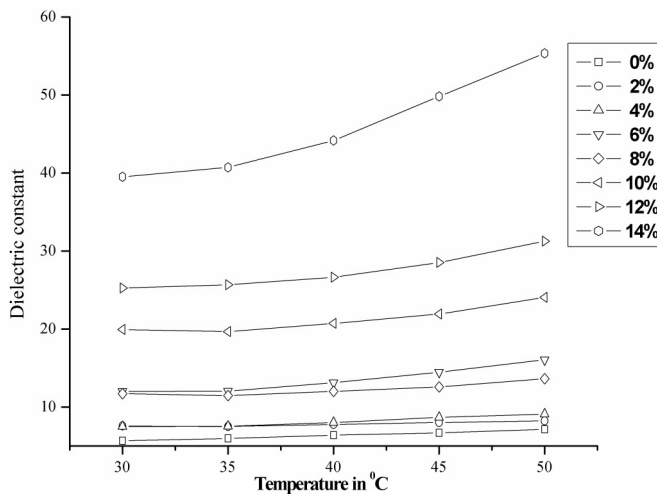


Fig. 2. Variation of dielectric loss of fenugreek seeds with frequency at 30°C

Thus, the ionic loss is higher in lower frequency region than in the higher frequency region. In the higher frequency region, dipolar energy loss is the predominant loss, and ionic loss is negligible. The combined effects of these losses make the expression of dielectric properties of seeds (heterogeneous system) more complex. The nature of decrease is almost the same for all the seeds of all moisture content. This type of behaviour has been reported by many groups including our own group (Berbert *et al.* 2001, 2002, 2004, 2007, Khan and Chan-

del 2011, Kumar *et al.* 2006, Sacilik and Colak 2005, 2010, Sacilik *et al.* 2006, 2007, Singh *et al.* 2006, Sirikulrat and Srikulrat 2008).

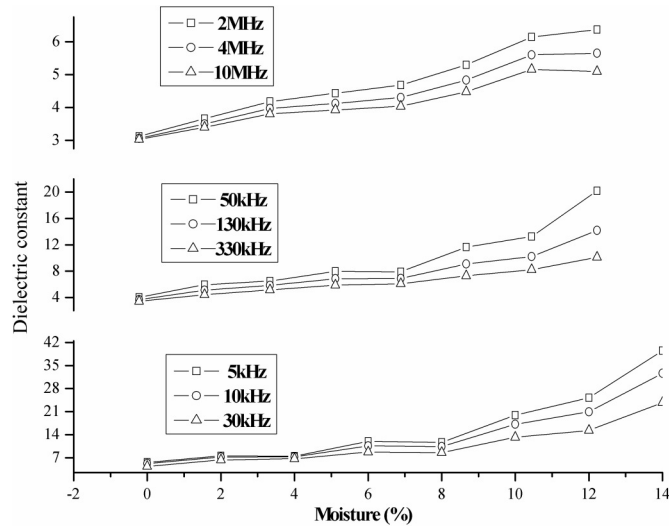


Fig. 3. Variation of dielectric constant of fenugreek seeds with moisture at 30°C

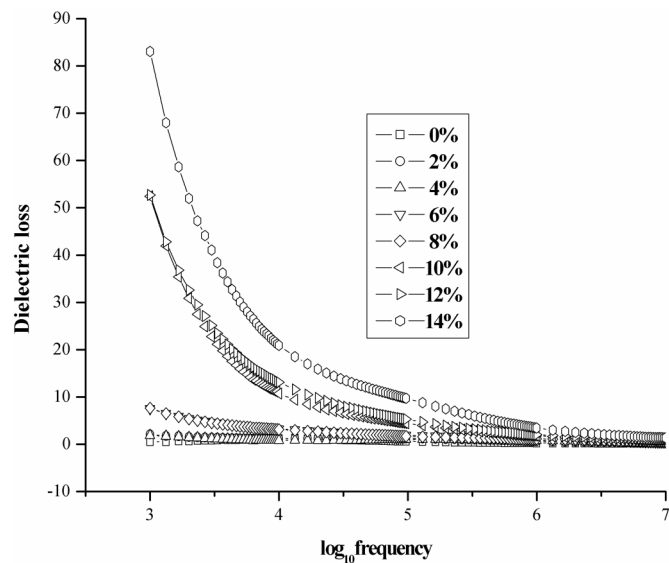


Fig. 4. Variation of dielectric loss of fenugreek seeds with moisture at 30°C

In Figures 3 and 4, the variation of dielectric constant and dielectric loss with moisture at a fixed temperature is shown. It is well established that the water content of a seed affects its physiological activities (Ruply *et al.* 1983, Vertucci *et al.* 1985). In seeds, water binds with varying strengths at different water con-

centrations and therefore has different thermodynamic properties (Ruply *et al.* 1983). There are 3 different types of water in a seed (Vertucci and Leopold 1984, Vertucci *et al.* 1985). The main components of seeds are carbohydrates, lipids and proteins. Carbohydrates (mainly starch) and proteins are the most important for water retention, and proteins contain more polar sites for attraction of water molecule than carbohydrates. Hence they can adsorb a large amount of water. In fenugreek seed, protein is about 23%, and hence its dielectric properties are highly affected by moisture content. For low moisture content, dielectric constant is low while for high moisture content it is high. It may be because at high moisture content more water dipoles contribute to polarisation, as water molecules easily follow up the applied field variation (free water). It can also be seen that both  $\epsilon'$  and  $\epsilon''$  are low below 6% moisture content. This is because of strong bound water state (monolayer) where distance between the water molecule and the cell wall is very small, and attraction force is very large. This strong force prevents water molecules from aligning in the varying electric field. Therefore, the dielectric constant and loss are small. Beyond 6% moisture content the values of dielectric constant and loss increase which may be because of the change in bound water state from the first (monolayer) to the second (multilayer) type (free water). At high moisture content and low frequency, the ionic conductivity is high, therefore at high moisture content and low frequency the dielectric loss is quite high.

Figures 5 and 6 demonstrate variation in the dielectric constant and dielectric loss of the seeds with respect to temperature at a fixed frequency (50 kHz). It is clear from the figures that the dielectric constant and dielectric loss increase with increase in temperature. For lower moisture content the variation of  $\epsilon'$  and  $\epsilon''$  with temperature is almost linear, however, a slight nonlinearity is observed at high moisture content. As temperature changes, the energetic status of the molecule and their aptitude to rotate with electric field also change, thus, a change in contribution of water molecule for polarisation ultimately changes into effective complex permittivity. As temperature increases, the molecular mobility increases and relaxation frequency which is strongly related to the molecular mobility decreases (Barrow 1988). Hence the peaks of  $\epsilon'$  and  $\epsilon''$  shift to higher frequency. Increase in temperature also increases the ionic conduction, leading to an increase in dielectric loss factor. Thus, both  $\epsilon'$  and  $\epsilon''$  increase as temperature increases. At lower frequency and high moisture content, ionic conduction as well as molecular mobility are more affected by the increase of temperature because of decrease of viscosity in osmotic or free water state. Therefore, under these conditions, the rate of increase in  $\epsilon'$  and  $\epsilon''$  with temperature is high and might be nonlinear. The dielectric constant is less affected by temperature than that of the dielectric loss factor because the increase of ionic conduction gives additional effect on dielectric loss factor, whereas dielectric constant is least or not at all affected by the ionic conduction.

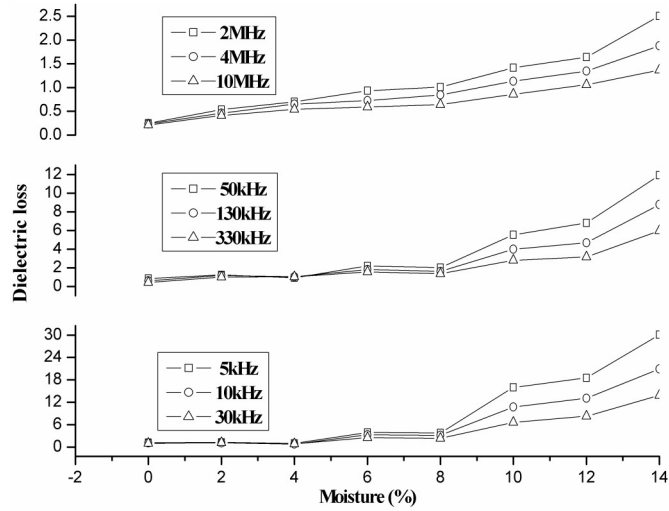


Fig. 5. Variation of dielectric constant of fenugreek seeds with temperature at 50 kHz

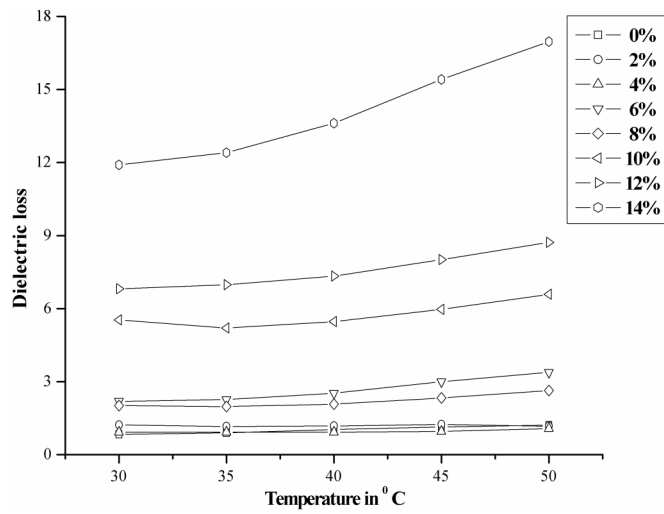


Fig. 6. Variation of dielectric loss of fenugreek seeds with temperature at 50 kHz



The regression of moisture (M) on permittivity ( $\epsilon'$ ,  $\epsilon''$ ), yielded the following equations:

$$\epsilon'_{10 \text{ kHz}} = 0.000M^4 - 0.009M^3 + 0.038M^2 + 0.605M + 5.353$$

$$\epsilon'_{50 \text{ kHz}} = 0.000M^4 - 0.001M^3 - 0.061M^2 + 0.907M + 4.108$$

$$\epsilon'_{10 \text{ MHz}} = 0.000M^4 + 0.012M^3 + 0.111M^2 + 0.450M + 2.989$$

$$\epsilon'_{2 \text{ MHz}} = 0.000M^4 + 0.012M^3 + 0.113M^2 + 0.526M + 3.089$$

$$\epsilon''_{10 \text{ kHz}} = 0.000M^4 + 0.017M^3 + 0.035M^2 + 0.101M + 1.167$$

$$\epsilon''_{50 \text{ kHz}} = 0.000M^4 + 3E - 06M^3 + 0.015M^2 + 0.013M + 0.900$$

$$\epsilon''_{10 \text{ MHz}} = 0.000M^4 - 0.005M^3 + 0.059M^2 + 0.257M + 0.191$$

$$\epsilon''_{2 \text{ MHz}} = 0.000M^4 - 0.002M^3 + 0.005M^2 + 0.119M + 0.259$$

with coefficients of determination  $R^2$  of 0.987, 0.985, 0.981, 0.993, 0.976, 0.978, 0.951, 0.992 respectively and all very close to unity.

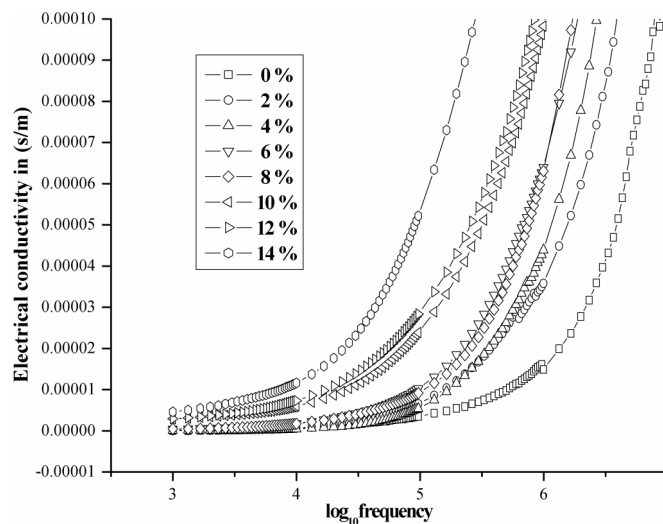


Fig. 7. Variation of electrical conductivity of fenugreek seeds with frequency at 30°C

Figures 7, 8 and 9 show that the electrical conductivity for the fenugreek seeds increases with the increase in the frequency, moisture content and temperature. As temperature increases, the contribution to dielectric loss from dielectric polarisation

decreases whereas contribution from ionic conduction increases with temperature. At a given moisture content, it has been found that conductivity shows increasing trend with increase in frequency. The conductivity of fenugreek seeds also increases with increase in moisture content at a given temperature.

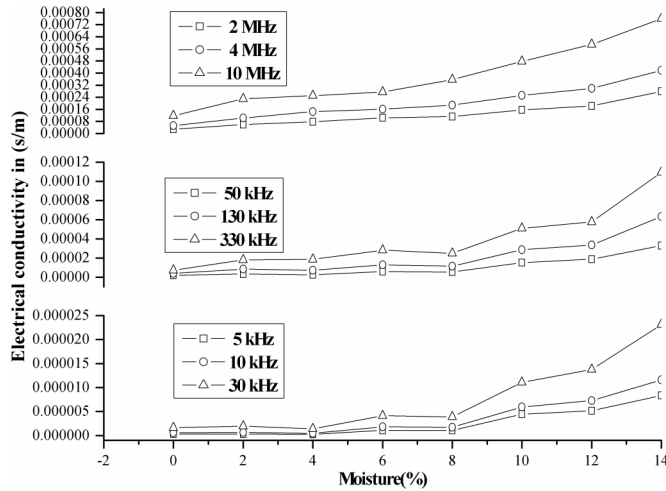


Fig. 8. Variation of electrical conductivity of fenugreek seeds with moisture at 30°C

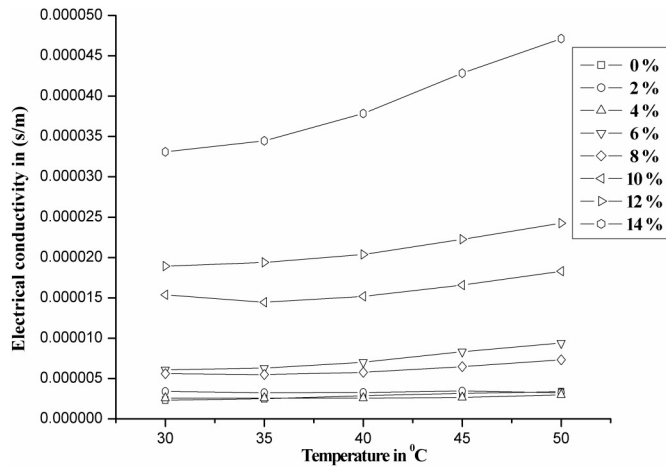


Fig. 9. Variation of electrical conductivity of fenugreek seeds with temperature at 50 kHz

### CONCLUSION

In the present study, it is found that the complex permittivity of fenugreek seeds shows dependence on the moisture, temperature and frequency. Moisture

content of the seeds largely affects the permittivity of fenugreek seeds. Both the dielectric constant and dielectric loss increase with the increase in the moisture content. On the other hand dielectric constant and dielectric loss decrease with frequency and increase or decrease with increase in temperature.

## REFERENCES

- Altuntas E., Özgöz E., Taser Ö. F. 2004. Some physical properties of fenugreek (*Trigonella foenum-graecum* L.) seeds. *Journal of Food Engineering* 71: 37-43.
- Amin-Riyad M., Abdul-Ghani S., Soleiman-Mohammad S. 1988. Effect of Fenugreek and Lupine Seeds on the Development of Experimental Diabetes in Rats. *Planta Med.* 54(4): 286 -290.
- Barrow G.M., 1988. *Physical chemistry.* (5th Ed.) Japanese edition. McGraw-Hill. New York, NY. 861 p.
- Berbert P.A., Molina M.B., Oliveiracarlesso V., Oliveira M.T.R. 2007. Moisture determination in coffee seeds by the capacitance method at radio frequencies. *Revista Brasileira de Sementes* 29(2): 159-170.
- Berbert P. A., Viana A. P., Dionello R.G., Carlesso V.O. 2004. Three dielectric models for estimating common bean moisture content. *Proc. of the 14<sup>th</sup> International Drying Symposium.* Sao Paulo, Brazil, B, 1502-1509, 22-25.
- Berbert P.A., Queiroz D.M., Melo E.C. 2002. Dielectric properties of common bean. *Biosystem Engineering* 83(4): 449-462.
- Berbert, P.A., Queiroz, D.M., Sousa E.F., Molina M.B., Melo E. C., Faroni L.R.D. 2001. Dielectric properties of parchment coffee. *J. Agric. Engng. Res.* 80(1): 65-80.
- Brenac P., Sauvaire Y. 1996. Accumulation of sterols and steroidal saponin in developing fenugreek pods: Possible biosynthesis in situ. *Phytochemistry* 41(2): 415-422.
- Duke A.J. 1986, *Handbook of Legumes of World Economic importance.* Plenum Press, New York and London. 345p.
- El-Bahy G.M.S. 2005. FTIR and Raman Spectroscopic Study of Fenugreek Seeds. *J. Applied Spectroscopy* 72 (1): 111-116.
- Gopalpura P.B., Jayanthi C., Dubey S. 2007. Effect of trigonella foenum seeds on the glycemic index of food. *International Journal Diabetes* 27(2): 41-45.
- Jiang J.X., Zhu L.W., Zhang W.M., Sun R.C. 2007. Characterization of Galactomannan Gum from Fenugreek (*Trigonella foenum-graecum*) Seeds and Its Rheological Properties. *International Journal of Polymeric Materials* 56(12): 1145 – 1154.
- Kassem A., Al-Aghbari A., Al-Habori M., Al-Mamary M. 2006. Evaluation of the potential antifertility effect of fenugreek seeds in male and female rabbits. *Contraception* 73: 301-306.
- Khan M.S., Chandel V.S., (2011). Study of conductivity and penetration depth in argemone seeds at different concentrations of moisture. *J. Pure Appl. and Ind. Phys.* 1(2):153-161.
- Kumar P., Singh S.P., Manohar R., Shukla J.P., 2006. Moisture dependent parameters as an indicator of germinations of seeds. *International Journal of Agricultural Research* 1(6): 534-544.
- Magario K., Yamaura I. 1988. Temperature dependence of microwave dielectric properties in saline solution. *Denki-Joho-Tsushin Gakkai Gihou. EMCJ* 88 (11): 21-26.
- Moosa A.S.M., Rashid M.U., Asadi A.Z.S., Mojib Uddin N.A.M., Ferdous A. 2006. Hypolipidemic effect of fenugreek seed powder. *Bangladesh J Pharmacol.* 1: 64-67.
- Petit P.R., Sauvaire Y.D., Hillaire-Buys D.M., Leconte O.M., Baissac Y.G., Ponsin G.R., Ribes G.R. 1995. Steroid saponins from fenugreek seeds: extraction, purification, and pharmacological investigation on feeding behavior and plasma cholesterol. *Steroid* 60(10):674-680.
- Petropoulos G.A. 2002. *Fenugreek The genus Trigonella.* Taylor and Francis Inc, New York, NY. 195 p.
- Prasanna M. 2000. Hypolipidemic effect of fenugreek: A clinical study. *Indian Journal of Pharmacology* 32: 34-36.
- Ruply J.A., Gratton E., Careri G. 1983. Water and globular proteins. *Trends Biochem. Sci.* 8: 18-22.
- Sacilik K., Colak A. 2010. Determination of dielectric properties of corn seeds. *Powder Technology* 203(2): 365-370.
- Sacilik K., Tarimci C., Colak A. 2007. Moisture content and bulk density dependence of dielectric properties of safflower seed in the radio frequency range. *Journal of Food Engineering* 78(4): 1111 -1116.
- Sacilik K., Tarimci C., Colak A. 2006. Dielectric properties of flaxseeds as affected by moisture content and bulk density in the radio frequency range. *Biosystem Engineering* 93 (2): 153-160.

- Sacilik, K., Colak, A. 2005. Dielectric properties of opium poppy seed. *TARIM BILIMILERI DERGISI* 11 (1): 104-109.
- Scherbukhin V.D., Anulov O.V. 1999. Legume seed galactomannans. *Applied Biochem. Microbiol.* 35: 257-274.
- Sharma R.D., Raghuram T.C. 1990. Hypoglycaemic effect of fenugreek seeds in non-insulin dependent diabetic subjects. *Nutrition Research* 10(7): 731-739.
- Singh S.P., Kumar P., Manohar R., Shukla J.P., 2006. Dielectric properties of some oil seeds at different concentration of moisture content and micro-fertilizer. *International Journal of Agricultural Research* 1 (3): 293-304.
- Sirikulrat, K., Sirikulrat, N. 2008. Dielectric properties of soybean. 34<sup>th</sup> Congress on Science and Technology of Thailand.
- Valette G., Sauvaire Y., Baccou J.C., Ribes G. 1984. Hypocholesterolaemic effect of fenugreek seeds in dogs. *Atherosclerosis* 50(1): 105-111.
- Vertucci C.W., Ellenson, J.L., Leopold A.C. 1985. Chlorophyll fluorescence characteristics associated with hydration level in pea cotyledons. *Plant Physiol.* 79: 248-252.
- Vertucci C.W., Leopold A.C. 1984. Bound water in soybean seed and its relation to respiration and imbibitional damage. *Plant Physiol.* 75: 114-117.
- Vijayakumar M.V., Pandey V., Mishra G.C., Bhat M.K., 2010. Hypolipidemic effect of fenugreek seeds is mediated through inhibition of fat accumulation and upregulation of LDL receptor. *Obesity* 18(4): 667-674.