Carbohydrate Polymers 90 (2012) 147–151

Contents lists available at SciVerse ScienceDirect

Carbohydrate Polymers

journal homepage: www.elsevier.com/locate/carbpol

Electrical insulated paper from cotton linter

Houssni El-Saied[a], Magda G. El-Meligy[a], Samar H. Mohamed[a,*], S. Abd El-Mongy[b]

[a] *Cellulose and Paper Department, National Research Center, Dokki, Cairo, Egypt*
[b] *Physics Department, Faculty of Women, Ain Shams University, Cairo, Egypt*

ARTICLE INFO

Article history:
Received 23 February 2012
Received in revised form 20 April 2012
Accepted 3 May 2012
Available online 22 May 2012

Keywords:
Insulated paper
Cotton linter
Linseed oil
Dielectric constant ($\acute{\varepsilon}$)
AC electrical conductivity
Strength properties

ABSTRACT

Insulated paper had been prepared from cotton linter containing certain additives. Strength properties had been studied for all paper prepared from cotton linter, before and after impregnating in the linseed oil. Also, the dielectric constant ($\acute{\varepsilon}$) and AC electrical conductivity with frequencies over the range (100 kHz to 3 MHz) and at different temperatures were studied. Blended cotton linter with glass fiber or polyester fiber increased the dielectric constant. Since the glass fibers lowered the power factor from 0.63 to 0.28% and enhanced dielectric constant. The addition of hydrophilic fibers such as rayon or polyester fiber can be made paper of low porosity, low density and high dielectric resistance. Also, the addition of lead sulphate improved dielectric constant of paper since it has dielectric coefficient >20. The dielectric constant in sample which dipped in oil is higher than the sample without oil.

1. Introduction

An insulator is a material that resists the flow of electric current. It is an object intended to support or separate electrical conductors without passing current through itself. Paper is among the cheapest and best electrical insulating known. Although the amount of paper consumed in the electrical field is not large compared with other fields, paper is a very important insulating material in radio and telephonic fields and is used in many electrical applications as part of the insulation of wiring, cables, and as layer insulators or as dielectric paper for various types of capacitor (Arjan, Jos, & Paat, 2007; Willis & Raju, 2003).

Electrical properties are in general; depend on the physical and chemical properties of the paper. The important electrical properties for a good electrical insulation paper are high dielectric constant, high dielectric strength (electrical resistance) and low power factor (dielectric loss). Electrically insulating papers or capacitor papers are made from cotton, linen and kraft pulp or mixture of these pulps. The commercial capacitor paper is made without the addition of sizing and filling material. It should be free from electrolytes as these led to electrolysis, high power factor and shorter life. Also, the paper should be free from pin-holes, conducting particles and chlorides (Fahmy, El-Meligy, & Mobark, 2008).

The properties of electrically insulating paper can be improved by addition of suitable fiber other than cellulosic and by mean of chemical modification. Addition of polyacrylic fibers or some synthetic fiber decreased the tangent of the dielectric loss angle and improved mechanical properties. These papers were used as electric insulators for cable having reduced air permeability (Johnston & Bradley, 1989; Kaplan, Chekunaev, Bezhikina, & Nikolskii, 1994; Samm, 1987).

Glass fibers are insulation, heat resistant fabric, corrosion resistant fabric, regular fiber and high strength fabric. A glass fiber in the paper forming composition exhibits a remarkably high dielectric constant and improved dielectric strength as well as superior chemical resistance (Jouw, Chen, Chaod, & Linc, 2001).

Solid substance of high dielectric coefficient (>20), e.g. lead sulphate, lead carbonate and titanium dioxide can be applied on paper by mechanical means to impart high capacitance (Kaplan et al., 1994). Paper has low dielectric constant compared to pure cellulose. This due to large percentage of air voids, the presence of which leads to ionization and dielectric breakdown even at relatively low voltage and electrical gradient. To overcome the low dielectric strength, paper used for insulation in power transmission cables, or as dielectric in capacitors, is impregnated with oil, wax or certain resins because these materials have greater specific inductive capacity than air and of high dielectric property. The dielectric constant of impregnated paper is a complex function of the electrical properties of individual cellulose fibers, paper and impregnating material (Fahmy, Mobarak, & El-Meligy, 2008; Pahlavanpour & Martins, 2003; Seok & Lae, 2004).

Impregnation, of deinked recycled old newsprint paper, by linseed oil enhanced the breaking length of paper and remarkably improved its dielectric properties, i.e. the dielectric constant increased greatly and the alternatively current conductivity

* Corresponding author. Tel.: +20 506964849; fax: +20 233370931.
E-mail address: hanafysamar@yahoo.com (S.H. Mohamed).

0144-8617/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.carbpol.2012.05.007

Table 1
Strength properties of the prepared paper before and after impregnation in the linseed oil.

Sample	Properties					
	Breaking length (m)		Percent of increasing %	Tearing resistance (g)		Percent of increasing %
	Before impregnation	After impregnation		Before impregnation	After impregnation	
Cotton linter	517.6	800.1	54.5	108	142.8	32.2
Blend cotton linter (I)	675	950	40.7	124	160.2	29.1
Blend cotton linter (II)	650.2	901	27.8	112	153	36.6
Cotton linter containing 10% lead sulphate	444.3	660.1	48.5	108	137.5	27.3
Blend cotton linter (I) containing 10% lead sulphate	518.9	830.6	60.0	124	158.4	21.7
Blend cotton linter (II) containing 10% lead sulphate	506.6	780.5	54.0	110	148.1	25.7

Blend cotton linter I: cotton linter containing 20% glass fiber.
Blend cotton linter II: cotton linter containing 20% polyester fiber.

decreased significantly due to impregnation. Even at elevated temperature, the improvement in dielectric properties of paper, due to impregnation, was sustained (Fahmy, Mobarak, et al., 2008).

Dielectric constant measurement is a well-established tool in the investigation of synthetic polymer materials. Many review articles (Burchard, 1983; Havriliak, 1999) deal with this subject, presenting theoretical and experimental aspects and summaries of many experimental data of this substance class. On other hand, the dielectric and dynamic properties of polysaccharides have also been discussed (Gilbert, 1993) although in general, the dielectric constant of polysaccharides has been considered controversial by many scientists up to now. Polysaccharides consist of anhydroglucose units, carrying two hydroxyl groups (—OH) and one methylol group (—CH_2—OH). Dielectric relaxation separates different molecular groups of a repeating unit of a polymer with respect to the rate of its orientational dynamics (Einfeldt, Meiner, & Kwasniewski, 2003). In this present work, we studied strength properties, dielectric constant ($\acute{\varepsilon}$) and AC electrical conductivity of electrical insulated paper prepared from cotton linter containing additives before and after impregnating in linseed oil.

2. Experimental

2.1. Materials

Cotton linter (96% α-cellulose and D.P. 740), as a raw material, glass fiber, polyester fiber, lead sulphate are additives and linseed oil as impregnated oil.

2.2. Treatment of the cotton linter

Cotton linter with or without the addition of 20% glass fiber or 20% polyester fiber had been beaten in a Jokro beater at 5% consistency until they reached 45 SR. The beaten pulps were extracted by 1% HCl, for 1 h, and then the pulp washed properly till neutrality. Lead sulphate (10% $PbSO_4$ based on oven dry pulp) added during hand sheet formation. After paper sheet formation, the papers were conditioned for 24 h, at 50 RH and 20 °C.

Sheets had been impregnated in linseed oil for 1 h, at room temperature and left till dry at room temperature. The sheets before and after impregnation had been subjected to the following tests.

2.3. Mechanical properties

Mechanical properties of the paper, namely tensile strength, breaking length and tearing resistance hade been measured (Casey, 1981).

2.4. Electrical properties of the prepared paper sheets

Dielectric constant measurements on cotton linter and blending cotton linter had been made over the frequency range of 100 kHz to 3 MHz in the temperature range of (303–373 K). The dependence of AC electrical conductivity on the frequencies at different temperatures (303–373 K) of cotton linter and cotton linter containing certain additives had been discussed. An empirical relation can express the frequency dependence of AC conductivity (Parker, 1997; Saleh, Gould, & Hassan, 1993) as follows:

$$\sigma_{AC} \propto (2\pi f)^n$$

where f is the frequency and n is not a constant for all substances, but it is a function of temperature, approaching unity at low temperatures and 0.5 or less at high temperature.

The dielectric constant ($\acute{\varepsilon}$) can be calculated as follows:

$$\acute{\varepsilon} = \frac{Cd}{\varepsilon_0 A}$$

where C is the capacitance of the measured sample in farad, d is the sample thickness in meter, A is the cross section area of sample, ε_0 is the permittivity of vacuum = 8.85×10^{-12} F m^{-1}.

3. Results and discussions

3.1. Effect of blending cotton linter, lead sulphate and impregnation in linseed oil on the strength properties of the prepared paper

Treated cotton linter or blended cotton linter extracted with 1% HCl for one hour in a reflux had been used to get rid of metal ions which reduce aging time of the paper and ultimately causes the mechanical and dielectric degradation. It was clear from Table 1 that the tensile strength and tearing resistance of the paper made from cotton linter blended with 20% glass fiber or polyester fiber had higher properties than paper made from cotton linter. This is due to the fact that blending of cotton linters improved the inter fiber bonding of pulp and gave papers more strength properties (Khristova, Kordsachia, Patt, & Karar, 2006). But the addition of 10% lead sulphate decreased the breaking length as shown in Table 1 since it forms a weaker filler–fiber bond (El-Meligy, Abdel-Kader, & Mohamed, 2010), but its addition is necessary to improve the dielectric properties because of its dielectric coefficient is >20 (Kaplan et al., 1994). The last prepared papers were impregnated with linseed oil using dipping technique, then the impregnate paper sheets had been hang to dry in air at room temperature. Table 1 showed that the strength properties of the prepared paper enhanced after impregnating the paper in linseed oil. This is due to the fact that the oil filling the air voids in the paper and a

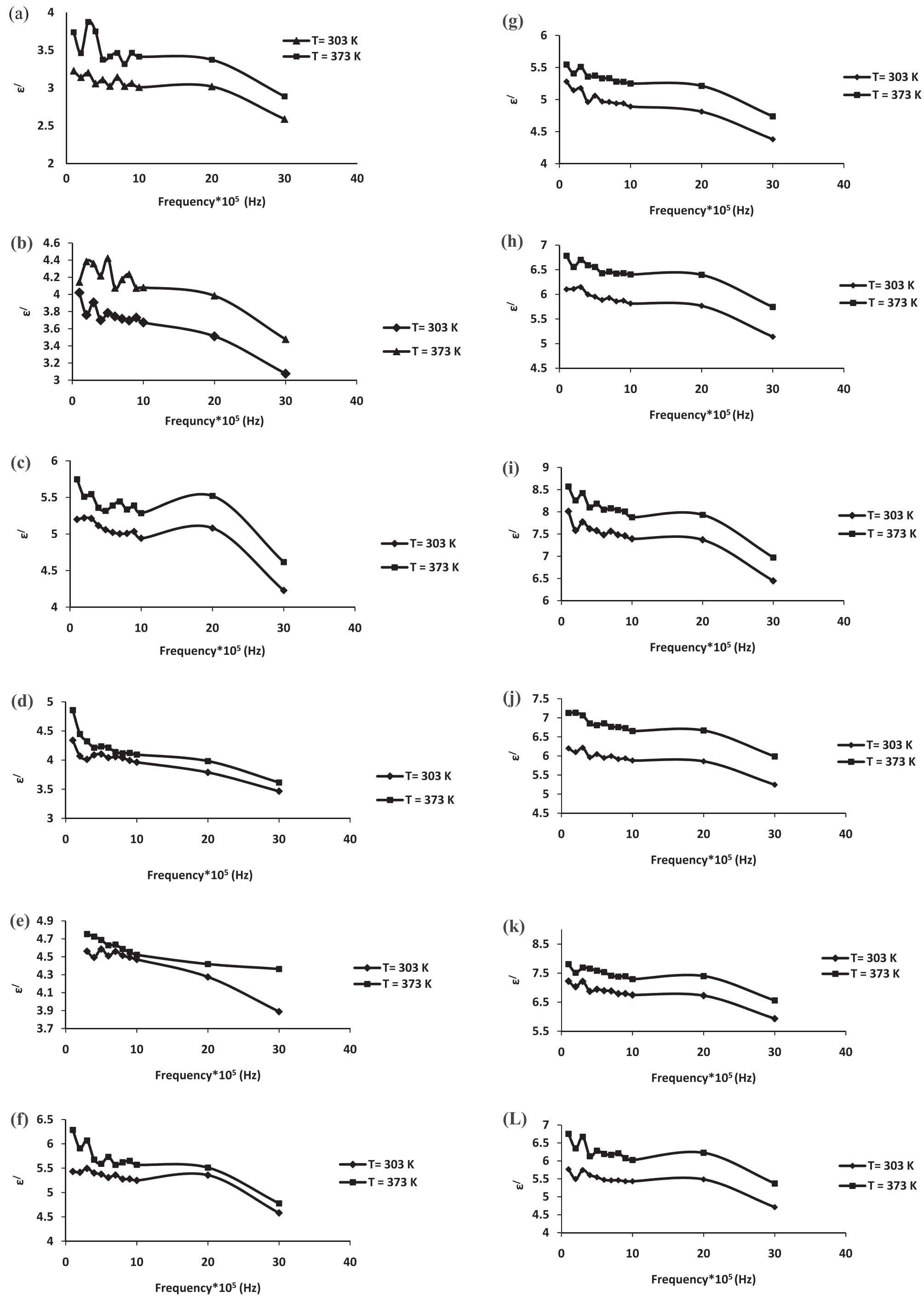

Fig. 1. (a–c) Dielectric constant ($\acute{\varepsilon}$) as a function of frequencies at T = 303 and 373 K for (a) cotton linter, (b) cotton linter containing glass fiber, (c) cotton linter containing polyester. (d–f) Dielectric constant ($\acute{\varepsilon}$) as a function of frequencies at T = 303 and 373 K for (d) cotton linter containing lead sulphate, (e) cotton linter containing glass fiber and lead sulphate, (f) cotton linter containing polyester and lead sulphate. (g–i) Dielectric constant ($\acute{\varepsilon}$) as a function of frequencies at T = 303 and 373 K for (g) cotton linter, (h) cotton linter + glass fiber, (i) cotton linter + polyester. All samples in linseed oil. (j–L) Dielectric constant ($\acute{\varepsilon}$) as a function of frequencies at T = 303 and 373 K for (j) cotton linter containing lead sulphate, (k) cotton linter containing glass fiber and lead sulphate, (L) cotton linter containing polyester and lead sulphate. All samples in linseed oil.

hydrocarbon compound forms additional hydrogen bonds, which lead to stronger fiber to fiber bond (Parker, 1997). Also, linseed oil is a drying oil, when it exposes to air, the atmospheric oxygen attacks the double bonds of the polyunsaturated fatty acids present in linseed oil, which leads to cross-linking of the fatty acids chains and hence solidification of the oil which gives a strong film to the paper (Fahmy, Mobarak, et al., 2008; Parker, 1997), so, the strength properties of the paper increased.

3.2. Dielectric constant ($\acute{\varepsilon}$)

Dielectric constant measurements on cotton linter and blended cotton linter had been made over the frequency range of 100 kHz to 3 MHz in the temperature range of (303–373 K). The variation of dielectric constant cotton linter containing additives as a function of frequency at different temperatures had been shown in Fig. 1(a–L), the blended cotton linter by glass fiber or polyester fiber

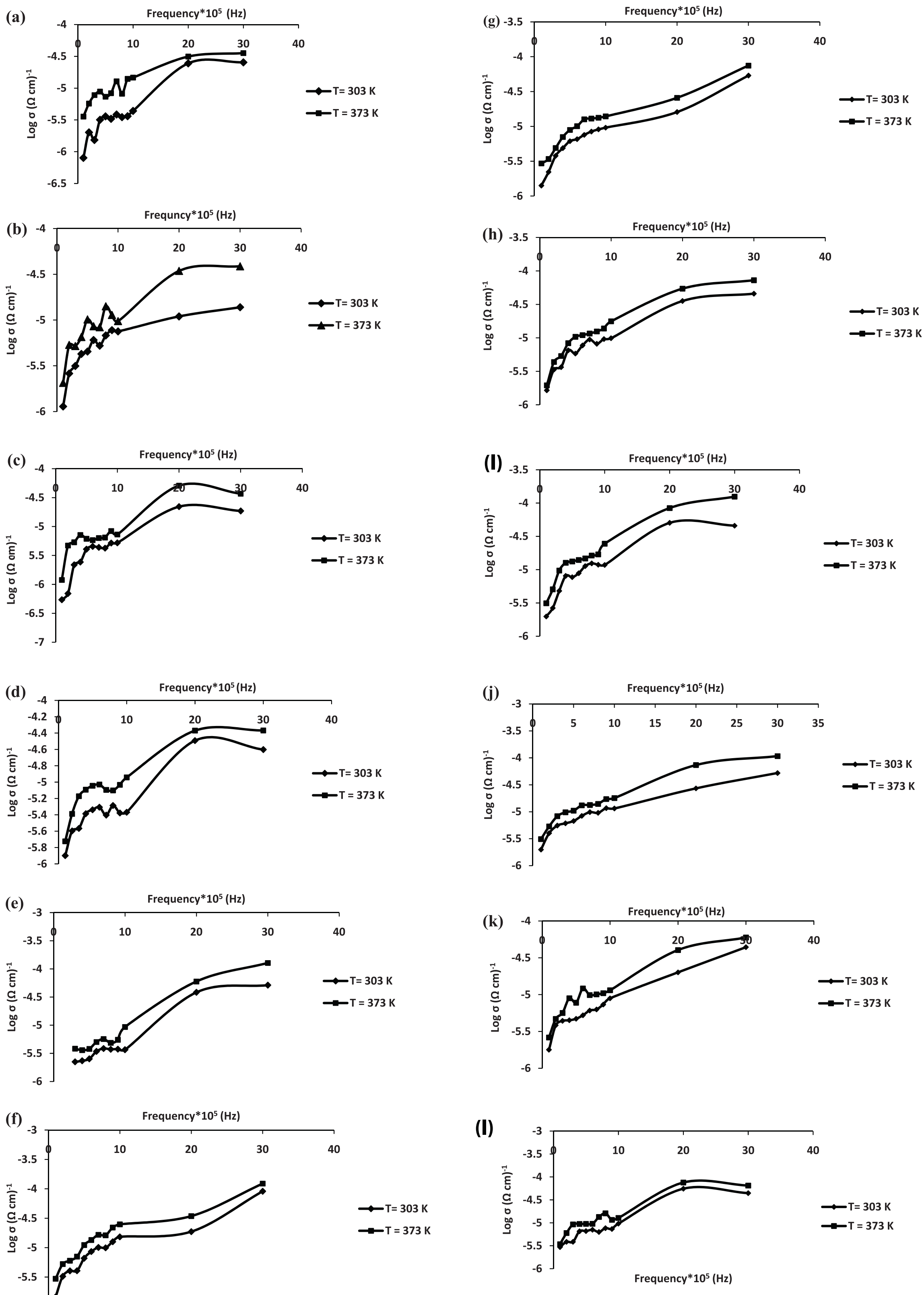

Fig. 2. (a–c) AC conductivity as a function of frequencies at T = 303 and 373 K for (a) cotton linter, (b) cotton linter containing glass fiber, (c) cotton linter containing polyester. (d–f) AC conductivity as a function of frequencies at T = 303 and 373 K for (d) cotton linter containing lead sulphate, (e) cotton linter containing glass fiber and lead sulphate, (f) cotton linter containing polyester and lead sulphate. (g–I) AC conductivity as a function of frequencies at T = 303 and 373 K for (g) cotton linter, (h) cotton linter containing glass fiber, (I) cotton linter containing polyester. All samples in linseed oil. (j–L) AC conductivity as a function of frequencies at T = 303 and 373 K for (j) cotton linter containing lead sulphate, (k) cotton linter containing glass fiber and lead sulphate, (L) cotton linter containing polyester and lead sulphate. All samples in linseed oil.

increased the dielectric constant. Since the glass fiber lowered the power factor from 0.63 to 0.28% and enhanced dielectric constant (Jouw et al., 2001; Kaplan et al., 1994), the addition of hydrophilic fibers such as rayon or polyester fiber can be made paper of low porosity, low density and high dielectric resistance (Johnston & Bradley, 1989; Kaplan et al., 1994). Also, the addition of lead sulphate improved dielectric constant of paper since it has dielectric coefficient >20 as mentioned before. From these Fig. 1(a–L), it is clear that, the dielectric constant almost decreases with increasing frequencies. This may be due to the fast variation of the field accompanied with the applied frequency and the electric dipoles are no longer able to rotate sufficiently fast to follow the field variation. This will lead to a decrease in the dielectric constant which increases the frequency. The dielectric constant in sample which dipped in oil is higher than the sample without oil. This may be due to that the oil has greater specific inductive capacity than air.

The dielectric constant almost increases with increasing temperature. This can be attributed to the orientation of the dipoles (which formed from the charge carriers) in the direction of the applied electric field. In general, temperature has a complicated influence on the dielectric constant, which in turn depends on electronic and ionic polarization, dipole orientation polarization, space charge polarization, etc. The variation of the dielectric constant with frequency could be used to elucidate which type of contributions is present. The space charge polarization contribution is mainly noticeable in the low frequency region. In contrast, dipole orientation polarization can be exhibited by materials even up to 10^{10} Hz, while electronic and ionic polarization always exists below 10^{13} Hz. Since higher values of the dielectric constant can be observed in lower frequency regions at which the space charge polarization contribution is predominant.

3.3. AC electrical conductivity

The dependence of AC electrical conductivity on the frequencies at different temperatures (303–373 K) of cotton linter and blended cotton linter had been shown in Fig. 2(a–L) the conductivity increased with increasing temperature and this behavior was acceptable because the thermal energy activates the charge carriers and increased their mobilities with the result of increasing conductivity.

Also the conductivity increases with increasing frequencies, due to the electrons in a molecular orbital excited to a higher energy level and tunneling through a potential barrier to a non-occupied state of a neighboring molecule. The available experimental results on the frequency dependence of AC conductivity have revealed a considerable similarity of behavior for the samples under investigation.

4. Conclusion

1. Tensile strength and tearing resistance of the paper made from cotton linter blended by 20% glass fiber or polyester fiber had higher properties than paper made from cotton linter.
2. The strength properties of the prepared paper enhanced after impregnating the paper in linseed oil.
3. The dielectric constant in sample which dipped in oil was higher than the sample without oil.
4. The conductivity increased with increasing temperature.

References

Arjan, V. S., Jos, W., & Paat, W. (2007). *Annual report conference on electric insulation and dielectric phenomena* Canada.

Burchard, W. (1983). Proceedings of workshop on dynamics of polymers. *Advances in Polymer Science*, 48.

Casey, J. P. (1981). *Paper testing and converting in pulp and paper* (3rd ed.). New Yourk Interscience Publisher., pp. 1714–1965.

Einfeldt, J., Meiner, D., & Kwasniewski, A. (2003). Fourier transform infrared spectroscopic and AC electrical conductivity studies of chitin and its derivatives. *Journal of Non-Crystalline Solids*, *320*, 40.

El-Meligy, M., Abdel-Kader, A., & Mohamed, S. (2010). Consolidation of paper by some binders and evaluating their efficiency. *Nature and Science*, *8*(2), 1–11.

Fahmy, T., El-Meligy, M., & Mobark, F. (2008). Introducing deinked old newsprint as a new resource of electrical purposes paper. *Carbohydrate Polymers*, *74*, 442–444.

Fahmy, T., Mobarak, F., & El-Meligy, M. (2008). Introducing undeinked old newsprint as a new resource of electrical purposes paper. *Wood Science and Technology*, *42*, 691–698.

Gilbert, R. D. (1993). Liquid crystalline solution of cellulose in phosphoric acid. *International Journal of Fiber Science and Technology*, *12*, 357.

Havriliak, S. (1999). Comparison of the Havriliak–Negami and stretched exponential functions. *Journal of Polymer*, *37*, 4107.

Johnston, D. R., & Bradley, C. R. (1989). Pros and cons of paper and polymeric insulated cables. *Power Engineering Journal*, *3*(4), 215–222.

Jouw, S., Chen, K., Chaod, Y., & Linc, Y. (2001). Flame retardant and dielectric properties of glass fiber reinforced nylon-66 filled with red phosphorous. *Polymer Degradation and Stability*, *74*(2), 239–245.

Kaplan, A. M., Chekunaev, N. L., Bezhikina, L. V., & Nikolskii, V. G. (1994). Composite papers with enhanced electrical strength. *Composites Science and Technology*, *513*, 325–329.

Khristova, P., Kordsachia, O., Patt, R., & Karar, T. (2006). Agricultural and biological science. *Industrial Crops and Products*, *23*, 131–139.

Pahlavanpour, E., & Martins, M. A. (2003). *Electrical insulation conference and electrical manufacturing and coil winding conference and exhibition no.3 (H3 748 0)* (pp. 283–288).

Parker, S. P. (1997). *Auto-oxidation, McGraw-Hill encyclopedia of science and technology* (8th ed.). New York: McGraw-Hill.

Saleh, A. M., Gould, R. D., & Hassan, A. K. (1993). Molecular structure, ion exchange and electrical properties of wood. *Physica Status Solidi*, *139*, 379.

Samm, R. W. (1987). How a paper polypropylene-paper laminate insulation will benefit the utility industry. *IEEE Electrical Insulating Magazine*, *3*(4), 41–42.

Seok, M. S., & Lae, H. (2004). *Annual meeting* Technical Section. Canadian Pulp and Paper Association B, (pp. 163–167).

Willis, H. L., & Raju, G. G. (2003). *Dielectrics in electric fields power engineering series*. New York/Basel: Marcel Dekker Inc.