INFLUENCE OF COST-LESS NANOPARTICLES ON ELECTRIC AND DIELECTRIC CHARACTERISTICS OF POLYETHYLENE INDUSTRIAL MATERIALS

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ABSTRACT

Nanoparticles have attracted wide interest for enhancing electrical properties of polymer industrial materials as form nanocomposites, therefore, preparation new Polyethylene nanocomposites will be helpful both the manufacturers and users for enhancing electrical performance of Polyethylene applications. This paper has been enhanced electric and dielectric characterizations of polyethylene with adding costless nanoparticlelow density polyethylene (LDPE), and high density polyethylene (HDPE) as a base matrix. Polyethylene trapping properties are highly modified by the presence of costless nanofillers(clay, and fumed silica) nanoparticles. Also, it has been studied experimentally the influence of costless nanofillers(clay, and fumed silica) and their concentrations on electric and dielectric properties of polyethylene materials. Experimental comparative study has been discussed about Polyethylene nanocomposites with respect to commercial polyethylene materials to explain the effect of types and concentrations of nano-fillers for enhancing electric and dielectric Polyethylene characteristics.

Keywords: Dielectric properties, Low density polyethylene, High density polyethylene, Nano-composite, Nanoparticles, Polymers

1. INTRODUCTION

Nanotechnologies are present in a lot of domain since they are a great source of innovation. They may have a powerful impact on development of advanced electrical and electronic device. In the case of nanocomposite, it has been reported that a few percent of functional nanofiller can improve mechanical characteristic permeability characteristic and
electrical properties. The way to disperse nanofillers layer in polymer matrix at a nanometric level is still under optimization, but good results in terms of orientation, control of interaction between host material and nanograin (intercalation, exfoliation) have been achieved already. The use of nanoadditives in dielectric materials has made great progress in the last few years. Many papers discussing the general overview, theory and the functionality of nanocomposite dielectrics have been published [1-6]. Polymeric nanocomposites have gained importance in the manufacture of products of high performance properties like light weight, material transparency, enhanced stiffness and toughness, increased barrier properties, decreased thermal expansion, decreased flammability and enhancement in dielectric properties for different industries such as automobiles, electrical and electronics, packaging, coatings etc [7-14].

The addition of inorganic nanoparticles into polymer (polymer nanocomposite) has been studied and applied to engineering materials for industrial products to improve various properties of material. It has been reported that the polymer nanocomposite has abilities to improve the dielectric properties of base material. The characteristics of polymer nanocomposite for electrical and dielectric properties were also studied to ensure the high reliability of the insulating system. The effective properties of dielectric mixtures have been investigated mathematically and experimentally for prediction of effective dielectric properties [15-18]. The use of polymers as electrical insulating materials has been growing rapidly in recent decades. The base polymer properties have been developed by adding small amounts of different fillers but they are expensive to the polymer material. Recently, great expectations have focused on costless nanofillers. However, there are few papers concerning the effect of types of costless nanofillers on electrical properties of polymeric nanocomposite. With a continual progress in polymer nanocomposites, this research depicts the effects of types and concentration of costless nanoparticles in electrical properties of industrial polymer material. This research has been investigated experimentally the results that detect the effects of nanoparticles (clay and fumed silica) on electric and dielectric properties of polyethylene nanocomposites; low density polyethylene (LDPE), high density polyethylene (HDPE).

2. EXPERIMENTAL SETUP AND MATERIAL PREPARATION CHARACTERIZATION

**Nanoparticles:** Nano-clay is spherical particle shape and it is the most important characteristic of nanoclay for polymer applications. Cost less of clay catalyst to be the best filler among nano-fillers industrial materials. Nano-fumed silica is widely used as a rheology modifier, imparting highly thixotropic properties at relatively low percentages. Fumed silica powders used in paints and coatings, silicone rubber and silicone sealants, adhesives, cable compounds and gels, printing inks and toner, and plant protection.

**Polyethylene Materials:** Low-density polyethylene (LDPE) is a thermoplastic made from petroleum and it is defined by a density range of (0.910 - 0.940) g/cm³. LDPE contains the chemical elements carbon and hydrogen. High-Density Polyethylene (HDPE) is a polyethylene thermoplastic made from petroleum. HDPE has little branching, giving it stronger intermolecular forces and tensile strength than lower-density polyethylene.

Additives of nanoparticles to the base industrial polymers have been fabricated by using mixing, ultrasonic, and heating processes. HIOKI 3522-50 LCR Hi-tester device is measuring device for characterization of nanocomposite insulation industrial materials. HIOKI 3522-50 LCR Hi-tester device as shown in Figure (1) has been measured electrical parameters of nano-metric solid dielectric insulation specimens at various frequencies. Specification of LCR is Power supply: 100, 120, 220 or 240 V(±10%) AC (selectable), 50/60 Hz, Frequency: DC, 1 mHz to 100 kHz, Display Screen: LCD with backlight / 99999 (full 5 digits), Basic Accuracy: Z : ± 0.08% rdg. θ : ± 0.05˚, and External DC bias ± 40 V max.(option) (3522-50 used alone ± 10 V max./ using 9268 ± 40 V max.).
Finally, it can be measured all dielectric properties for pure and nanocomposite industrial materials by using HIOKI 3522-50 LCR Hi-tester device and have been detected. The studied industrial materials in this research have been formulated utilizing nano particulates. Electric and dielectric properties of the studied materials are detailed in table (1).

<table>
<thead>
<tr>
<th>Materials</th>
<th>Dielectric Constant at 1kHz</th>
<th>Resistivity (Ω.m)</th>
<th>Materials</th>
<th>Dielectric Constant at 1kHz</th>
<th>Resistivity (Ω.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pure LDPE</td>
<td>2.3</td>
<td>$10^{14}$</td>
<td>Pure HDPE</td>
<td>2.3</td>
<td>$10^{15}$</td>
</tr>
<tr>
<td>LDPE + 1%wt Clay</td>
<td>2.23</td>
<td>$10^{15}$</td>
<td>HDPE + 1%wt Clay</td>
<td>2.23</td>
<td>$10^{16}$</td>
</tr>
<tr>
<td>LDPE + 5%wt Clay</td>
<td>1.99</td>
<td>$10^{15}$-$10^{18}$</td>
<td>HDPE + 5%wt Clay</td>
<td>1.99</td>
<td>$10^{16}$-$10^{19}$</td>
</tr>
<tr>
<td>LDPE + 10%wt Clay</td>
<td>1.76</td>
<td>$10^{18}$-$10^{20}$</td>
<td>HDPE + 10%wt Clay</td>
<td>1.76</td>
<td>$10^{19}$-$10^{21}$</td>
</tr>
<tr>
<td>LDPE + 1%wt Fumed Silica</td>
<td>2.32</td>
<td>$10^{13}$</td>
<td>HDPE + 1%wt Fumed Silica</td>
<td>2.32</td>
<td>$10^{14}$</td>
</tr>
<tr>
<td>LDPE + 5%wt Fumed Silica</td>
<td>2.39</td>
<td>$10^{13}$-$10^{11}$</td>
<td>HDPE + 5%wt Fumed Silica</td>
<td>2.39</td>
<td>$10^{14}$-$10^{12}$</td>
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<tr>
<td>LDPE + 10%wt Fumed Silica</td>
<td>2.49</td>
<td>$10^{11}$-$10^{9}$</td>
<td>HDPE + 10%wt Fumed Silica</td>
<td>2.49</td>
<td>$10^{12}$-$10^{10}$</td>
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3. RESULTS AND DISCUSSION

Dielectric Spectroscopy is a powerful experimental method to investigate the dynamical behavior of a sample through the analysis of its frequency dependent dielectric response. The measurements were made using high resolution dielectric spectroscopy and this technique is based on the measurement of the capacitance as a function of frequency of a sample sandwiched between two electrodes. Dielectric loss (\(\tan \delta\)), and capacitance (C) were measured as a function of frequency up to 100 kHz at 25 °C for all test samples.

3.1 Effect of Nanoparticles on Low Density Polyethylene LDPE Characterization:

Figure 2.a shows loss tangent as a function of frequency for Clay/ Low-density polyethylenenanocomposites at room temperature (25°C). The measured loss tangent contrasts on loss tangent with increasing frequency. The loss tangent increases with increases the percentage of clay nanoparticles percentage up to 5%wt, specially, at low frequencies but decreases with increasing clay nanoparticles percentage up to 10%wt, specially, at high frequencies. Figure 2.bcontrasts on loss tangent as a function of frequency for fumed silica/ Low-density polyethylenenanocomposites at room temperature (25°C). The measured loss tangent decreases with rising percentage of fumed silica nanofillers in the nanocomposite up to 5wt% specially, at low frequencies but increases with increasing fumed silica nanoparticles percentage up to 10%wt, specially, at high frequencies.

Figure 3.a contrasts on capacitance of Clay/ Low-density polyethylenenanocomposites as a function of frequency at room temperature (25°C). The measured capacitance decreases with rising percentage of clay nanofillers in the nanocomposite up to 5%wt but it increases with increasing clay percentage nanofillers up to percentage10%wt. Figure 3.b shows capacitance
as a function of frequency for fumed silica/ Low-density polyethylenenanocomposites at room temperature (25°C). The measured capacitance shows that decreasing in capacitance with rising percentage of fumed silica nanofillers in fumed silica/ Low-density polyethylene nanocomposite up to 1wt% but it increases with increasing fumed silica percentage nanofillers at 5-10wt%.

Fig 3 Measured capacitance of Low Density Polyethylene nanocomposites at room temperature (25°C)

(a) Clay/LDPE nanocomposites  (b) Fumed Silica/LDPE nanocomposites

3.2 Effect of Nanoparticles on High Density Polyethylene HDPE Characterization:

Figure 4.a shows loss tangent as a function of frequency for Clay/HDPE nanocomposites at room temperature (25°C). The loss tangent of Clay/High Density Polyethylenenanocomposite decreases with increasing clay percentage nanofillers up to 1%wt Clay but, it increases with increasing clay percentage nanofillers from 5%wt up to 10%wt. Figure 4.b shows loss tangent as a function of frequency for Fumed Silica/ HDPE nanocomposites at room temperature (25°C). The measured loss tangent of Fumed Silica/High Density Polyethylene decreases with increasing fumed silica percentage nanofillers up to 1%wt fumed silica but, it increases with increasing fumed silica percentage nanofillers up to 10%wt fumed silica nanoparticles.
Fig. 4 Measured loss tangent of High Density Polyethylene nanocomposites at room temperature (25°C)

Fig. 5 Measured capacitance of High Density Polyethylene nanocomposites at room temperature (25°C)
Figure 5.a shows capacitance as a function of frequency for Clay/HDPE nanocomposites at room temperature (25°C). The measured capacitance of Clay/High Density Polyethylene increases with increasing clay percentage nanofillers up to 10%wt. Figure 5.b shows capacitance as a function of frequency for Fumed silica/HDPE nanocomposites at room temperature (25°C). Also, this figure illustrates that the capacitance of Fumed silica/High Density Polyethylene increases with increasing fumed silica percentage nanofillers up to 10%wt. Noting that, Clay nanofillers increases capacitance of High Density Polyethylene more than increasing fumed silica nanofillers in High Density Polyethylene at the same percentages.

4. COMPARATIVE CHARACTERIZATIONS OF COMMERCIAL AND NANOCOMPOSITE POLYETHYLENE INDUSTRIAL MATERIALS

In the beginning, adding fumed silica has increased permittivity of the new nanocomposite materials whatever, adding clay has decreased permittivity of the new nanocomposite materials as shown in table (1).

With comparing results for depicting the effect of raising concentration of clay and fumed silica nanofillers which are pointed out in Figures (2,3) where loss tangent and capacitance of new Low-density polyethylene nanocomposite materials are reported for different weight concentrations of modified nanofillers concentration at room temperature (T=25°C) i.e. the loss tangent increases with increases the percentage of clay nanoparticles percentage up to 5%wt, specially, at low frequencies but decreases with increasing clay nanoparticles percentage up to 10%wt, specially, at high frequencies. Whatever, the measured loss tangent decreases with rising percentage of fumed silica nanofillers in the nanocomposite up to 5wt% specially, at low frequencies but increases with increasing fumed silica nanoparticles percentage up to 10%wt, specially, at high frequencies. With respect to the measured capacitance of new Low-density polyethylene nanocomposites, it is cleared that, the measured capacitance decreases with rising percentage of clay nanofillers in the nanocomposite up to 5%wt but the measured the capacitance of Low-density polyethylene nanocomposites increases with increasing clay percentage of nanofillers up to 10%wt. Whatever, The measured capacitance decreases with rising percentage of fumed silica nanofillers in the Low-density polyethylene nanocomposite up to 1wt% but it increases with increasing fumed silica percentage nanofillers at 5%wt - 10%wt.

Also, the effect of raising concentration of clay nanofillers is pointed out in Figures (4,5) where loss tangent and capacitance of new High Density Polyethylene nanocomposite materials are reported for different weight concentrations of modified nanofillers concentration. i.e. the loss tangent of Clay/High Density Polyethylene nanocomposite decreases with increasing clay percentage nanofillers up to 1%wt Clay but, it increases with increasing clay nanofillers from 5%wt up to 10%wt. Also, The measured loss tangent of Fumed Silica/High Density Polyethylene nanocomposites decreases with increasing fumed silica percentage nanofillers up to 1%wt fumed silica but, it increases with increasing fumed silica percentage nanofillers up to 10%wt fumed silica nanoparticles. Whatever, the measured capacitance of High Density Polyethylene nanocomposites increases with increasing Clay and Fumed silica nanoparticles percentage up to 10%wt.
5. CONCLUSIONS

- Adding clay is decreasing the permittivity of new nanocomposite materials and the effects of adding small amount of clay nanoparticles percentage to Low density polyethylene decreases capacitance and loss tangent. Whatever, adding small amount of clay nanoparticles percentage to High density polyethylene increases capacitance and loss tangent, specially, at low frequencies.

- Adding clay nanofillers increases capacitance of High Density Polyethylene more than increasing fumed silica nanofillers in High Density Polyethylene at the same percentages.

- Adding fumed silica is increasing the permittivity of new nanocomposite materials, small amount of fumed silica nanoparticles on Low density polyethylene increases capacitance and loss tangent, specially, at low frequencies. Whatever, small amount of fumed silica nanoparticles on High density polyethylene increases capacitance but decreases loss tangent, specially, at low frequencies.

- Adding large amounts of clay or fumed silica nanoparticles to polyethylene will be reverse dielectric behavior characteristics gradually which depends on nature of nanoparticles structure in polymer matrix.

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REFERENCES


AUTHORS’ INFORMATION

Ahmed Thabet was born in Aswan, Egypt in 1974. He received the BSc (FEE) Electrical Engineering degree in 1997 and MSc (FEE) Electrical Engineering degree in 2002 both from Faculty of Energy Engineering, Aswan, Egypt. PhD degree had been received in Electrical Engineering in 2006 from El-Minia University, Minia, Egypt. He joined with Electrical Power Engineering Group of Faculty of Energy Engineering in Aswan University as a Demonstrator at July 1999, until; he held Associate Professor Position at October 2011 up to date. His research interests lie in the areas of analysis and developing electrical engineering models and applications, investigating novel nano-technology materials via addition nano-scale particles and additives for usage in industrial branch, electromagnetic materials, electroluminescence and the relationship with electrical and thermal ageing of industrial polymers. Many of mobility's have investigated for supporting his research experience in UK, Finland, Italy, and USA …etc. On 2009, he had been a Principle Investigator of a funded project from Science and Technology development Fund “STDF” for developing industrial materials of ac and dc applications by nano-technology techniques. He has been established first Nano-Technology Research Centre in the Upper Egypt (http://www.aswan.svu.edu.eg/nano/index.htm). He has many of publications which have been published and under published in national, international journals and conferences and held in Nano-Technology Research Centre website.