EXPERIMENTAL STUDY FOR DIELECTRIC STRENGTH OF NEW NANOCOMPOSITE POLYETHYLENE INDUSTRIAL MATERIALS

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ABSTRACT

The base polymer properties have been developed experimentally by adding small amounts of different fillers but they are expensive to the polymer material. Thus, it has been investigated that the incorporation of cost-less nanoparticles like clay and fumed silica nanoparticles into low density polyethylene LDPE and high density polyethylene HDPE which controlled the breakdown strength and voltage endurance significantly of new nanocomposite materials which compared with unfilled industrial materials. This paper simplified the breakdown test model which has been used as a basis for experimental treatment for several new nano-composite specimens of industrial polymer materials. So that, it has been experiment the dielectric strength of new nano-composite industrial materials for ac applications which have been improved significantly with respect to the basis, unfilled materials. Finally, according to the experiment test model, it has been presented measurements of electric field strength of new nanocomposite materials that exceeds unfilled industrial materials.

Keywords: Dielectric properties, Nanocomposite, Nanoparticles, Polymers, Insulation

1. INTRODUCTION

Polymer nanocomposites have attracted wide interests in various industries. This new class of material is capable of providing significant improvements in combined electrical, thermal and mechanical properties. Although the potential use of polymer nanocomposites in electrical insulating industry has only recently begun to be explored, a great number of researches have been conducted with regards to high voltage electrical insulation performance. However, it is found that the fundamental physics and chemistry concerning the property enhancement due
to the incorporation of nanocomposites is still poorly understood, and there is still room for improvement in this research area. 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 increase in dielectric properties for different industries such as automobiles, electrical and electronics, packaging, coatings etc [1-3]. Polyolefin based nanocomposites are very important because of the formation of intercalated structure with layered silicate using conventional processing technology [4]. Generally layered silicate is modified with quaternary ammonium or phosphonium compounds to make them organophilic from hydrophilic by cation exchange reaction between quaternary compound and cations between the clay galleries. The molecules of quaternary ammonium compound between the clay galleries act as pillars to increase the layer spacing of the clay. Quaternary compound lower the surface energy of the clay surface so the wetting between the organic and inorganic phase improves and it facilitates the polymer molecules to penetrate between the clay galleries [5].

The earliest experimental work on polymer nanocomposites in electrical insulation perspective was credited to Henk et al. [6] and Nelson et al. [7] when they documented some potential benefits of polymer nanocomposites. In their research works, the authors highlighted the unusual properties of polymer nanocomposites, which were very different as compared the base polymer and the so called polymer microcomposites (polymer composites added with microfillers). One of the most important property changes of nanocomposites is the enhancement in dielectric breakdown strength which is found when the filler particles attain nanometric dimensions. This property has in fact been widely documented in many literatures [8-13]. Not only this, other electrical properties, such as permittivity, dissipation factor, space charge formation, partial discharge and tracking resistance were also found to be favorable when polymer nanocomposites were introduced.

The insulation strength of discharge gaps is one of the main factors determining the reliability of High Voltage HV devices. Also, increasing demand for high performance of polymers requires that the dielectric strength of the polymers be measured accurately of their intended use. Lack of accurate data on dielectric strength leads to design short comings, either use of excessive insulation resulting in more expensive equipments or on the other hand, use of inadequate insulation with increased risk of premature failure. The safe operation of high voltage electrical energy transmission grids depends on the reliability of its components, as switchgears, power transformers and gas insulating lines. Their reliability depends primarily on the performance of the insulating structures they contain nanoparticle filled polymers provide advantages over micron filled polymers because they provide resistance to degradation, and improvement in thermo mechanical properties without causing a reduction in dielectric strength [14-18].
In most papers devoted to the research of polymeric dielectric behavior of polymeric nanocomposites which 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 increase in dielectric properties for different industries such as automobiles, electrical and electronics, packaging, coatings etc. Polymer nanocomposites are composite materials having several wt% of inorganic particles of nanometer dimensions homogeneously dispersed into their polymer matrix. This new type of polymer composite has recently drawn considerable attention because nanocomposites or nanostructured polymers have the potential of improving the electrical, mechanical, and thermal properties as compared to the neat polymers [19-21].

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 [20]. With a continual progress in polymer nanocomposites, this research depicts the effects of types and concentration of costless nanoparticles on electrical properties of industrial polymer material. All experimental results of dielectric characterization have been investigated and discussed to detect all effects of nanofillers on electrical properties of nanocomposite industrial material which fabricated; like PVC with various nanofillers of clay and fumed silica [22-25]. The present work addresses the analysis of dielectric and thermal properties of standard enamel and Zirconia mixed enamel [26-29]. The current research has been concentrated on the electric breakdown failure of LDPE, and HDPE matrixes with various added costless nanoparticles (clay, and fumed silica). It has been demonstrated the effective of cost-less nanoparticles like clay and fumed silica nanoparticles for controlling in breakdown strength and voltage endurance significantly of low density polyethylene LDPE and high density polyethylene HDPE which compared with unfilled industrial materials.

2. MATERIAL PREPARATION AND CHARACTERIZATION

The industrial materials studied here is LDPE, and HDPE which have been formulated utilizing nano particulates of clay. The base of all these polymer materials is a commercially available material already in use in the manufacturing of HV industrial products and their properties detailed in Table (1). Preparation of studied polymers has been used SOL–GEL method. The sol-gel processing of the nanoparticles inside the polymer dissolved in non-aqueous or aqueous solution is the ideal procedure for the formation of interpenetrating networks between inorganic and organic moieties at the milder temperature in improving good compatibility and building strong interfacial interaction between two phases. This process has been used successfully to prepare nanocomposites with nanoparticles in a range of polymer matrices. Several strategies for the sol-gel process are applied for formation of the hybrid materials. One method involves the polymerization of organic functional groups from a preformed sol–gel network.
The sol-gel process is a rich chemistry which has been reviewed elsewhere on the processing of materials from glass to polymers. The organic–inorganic hybrid nanocomposites comprising of polymer, and nanoparticles were synthesized through sol–gel technique at ambient temperature. The inorganic phase was generated in situ by hydrolysis–condensation of tetraethoxysilane TEOS in different concentrations, under acid catalysis, in presence of the organic phase, polymer, dissolved in formic acid [30].

Additives of clay nanoparticles to the base industrial polymers has been fabricated by using mixing, ultrasonic, and heating processes in Nano-technology Research Centre, Aswan - Egypt. The base of all these polymer materials is a commercially available material already in use in the manufacturing of HV industrial products and their properties, 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 as shown in Table (1).

<table>
<thead>
<tr>
<th>Materials</th>
<th>Dielectric Constant at 1kHz</th>
<th>Resistivity (Ω.m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDPE + 0%wt Clay</td>
<td>2.3</td>
<td>10^{14}</td>
</tr>
<tr>
<td>LDPE + 1%wt Clay</td>
<td>2.23</td>
<td>10^{15}</td>
</tr>
<tr>
<td>LDPE +5%wt Clay</td>
<td>1.99</td>
<td>10^{15}-10^{18}</td>
</tr>
<tr>
<td>LDPE +10%wt Clay</td>
<td>1.76</td>
<td>10^{18}-10^{20}</td>
</tr>
<tr>
<td>LDPE +1%wt Fumed Silica</td>
<td>2.32</td>
<td>10^{13}</td>
</tr>
<tr>
<td>LDPE +5%wt Fumed Silica</td>
<td>2.39</td>
<td>10^{13}-10^{11}</td>
</tr>
<tr>
<td>LDPE +10%wt Fumed Silica</td>
<td>2.49</td>
<td>10^{11}-10^{9}</td>
</tr>
<tr>
<td>HDPE + 0%wt Clay</td>
<td>2.3</td>
<td>10^{15}</td>
</tr>
<tr>
<td>HDPE + 1%wt Clay</td>
<td>2.23</td>
<td>10^{16}</td>
</tr>
<tr>
<td>HDPE + 5%wt Clay</td>
<td>1.99</td>
<td>10^{16}-10^{19}</td>
</tr>
<tr>
<td>HDPE + 10%wt Clay</td>
<td>1.76</td>
<td>10^{19}-10^{21}</td>
</tr>
<tr>
<td>HDPE + 1%wt Fumed Silica</td>
<td>2.32</td>
<td>10^{14}</td>
</tr>
<tr>
<td>HDPE + 5%wt Fumed Silica</td>
<td>2.39</td>
<td>10^{14}-10^{12}</td>
</tr>
<tr>
<td>HDPE + 10%wt Fumed Silica</td>
<td>2.49</td>
<td>10^{12}-10^{10}</td>
</tr>
</tbody>
</table>

3. EXPERIMENTAL SETUP

HIPOT Tester Model ZC2674 device has been specified as 1kVA, 20kV, AC and DC voltages, 10mA, AC and DC currents. Figure (1.a) illustrates Hi-pot Tester Model ZC2674 device for experiment uniform and non-uniform electric field distribution through the thickness of insulation layer with different nanocomposite materials. Experimental results are focused on Polypropylene PP, Polyvinyl Chloride PVC, LDPE, and HDPE insulation materials with various percentage weight of clay nanoparticles. Configuration of both two electrodes of uniform electric field has been made from copper and has 30mm diameter but
configuration of tip electrode of non-uniform electric field has 0.5mm diameter. HIOKI 3522-50 LCR Hi-tester device as shown in Figure (1.b) has been measured electrical parameters of nano-metric solid dielectric insulation specimens at various frequencies: |Zl|, |Yl|, \( \theta \), Rp (DCR), Rs (ESR, DCR), G, X, B, Cp, Cs, Lp, Ls, D (\( \tan \delta \)), and Q.

Specification of LCR is power supply: 100, 120, 220 or 240 V(±10%) AC (selectable), 50/60 Hz, Frequency: DC, 1.0mHz to 100kHz, Display Screen: LCD with backlight / 99999 (full 5 digits), Basic Accuracy: Z: ±0.08% rdg. \( \theta \): ±0.05˚, and External DC bias ±40V max. (option) (3522-50 used alone ±10V max./ using 9268 ±40V max.).

![Experimental testing equipment's](image)

(a) HIPOT Tester Model ZC2674 device  (b) HIOKI 3522-50 LCR Hi-tester device

Fig. 1. Experimental testing equipment’s

4. RESULTS AND DISCUSSION

The breakdown voltage of new nanocomposites industrial materials has been measured with a 35mm diameter for both two copper electrodes in uniform electric field, and 0.5mm tip diameter in non-uniform electric field. The applied AC voltage on the specimen was varied from 0.1kV until breakdown occurs. AC leakage current has been measured through testing the specimen from 0A up to 1mA per unit length (m). The following subsections detailed the results and analysis for the effects of adding clay and fumed silica nanoparticles into Low density polyethylene (LDPE) and High density polyethylene (HDPE) industrial materials.

4.1. Effect of Uniform Electric Field on Nanocomposite Industrial Polymers

Figures (2.a and 2.b) illustrate the effect of adding clay and fumed silica nanoparticles on dielectric strength and leakage pass current in LDPE specimens in uniform electric field respectively. It is noticed that, increasing percentage of clay up to 10%wt nanoparticles in the nanocomposite increases dielectric strength of the industrial materials with respect to unfilled specimens but increasing percentage of fumed silica up to 10%wt nanoparticles in the nanocomposite
decreases dielectric strength of the industrial materials with respect to unfilled specimens. Although, figures (3.a and 3.b) show the effect of adding clay and fumed silica nanoparticles on dielectric strength and leakage pass current in HDPE specimens in uniform electric field respectively. It is noticed that, increasing percentage of clay up to 10%wt nanoparticles in the nanocomposite increases dielectric strength of the industrial materials specimens with respect to unfilled specimens but increasing percentage of fumed silica up to 10%wt nanoparticles in the nanocomposite specimens that decreases dielectric strength of the industrial materials with respect to unfilled specimens. Thus, leakage pass current effect of both clay nanoparticles in LDPE and HDPE in the new nanocomposite materials increases by increasing dielectric strength smoothly with adding nanofillers percentage from 1%wt. up to 10%wt. nanoparticles. But, leakage pass current effect of both fumed silica nanoparticles in LDPE and HDPE in the new nanocomposite materials decreases by increasing dielectric strength smoothly with adding nanofillers percentage from 1%wt. up to 10%wt. nanoparticles.
4.2. Effect of Non-Uniform Electric Field on Nanocomposite Industrial Polymers

Figures (4.a and 4.b) show effect of adding clay and fumed silica nanoparticles on dielectric strength and leakage pass current in LDPE materials in non-uniform electric field. It is noticed that increasing percentage of clay up to 10%wt. nanoparticles in the nanocomposite increases dielectric strength of the industrial materials gradually with respect to unfilled specimens. Although, increasing percentage of fumed silica up to 1%wt. fumed silica nanoparticles in the nanocomposite increases dielectric strength of the industrial materials but increasing percentage of fumed silica (1%wt.:10%wt) fumed silica nanoparticles in the nanocomposite decreases dielectric strength of the industrial materials with respect to unfilled specimens. And so, it is noticed that, leakage pass current through the new nanocomposite increases with increasing percentage clay nanoparticles up to 10%wt. but the leakage pass current decreases smoothly with increasing fumed silica nanofillers percentage from up to 5%wt. except for percentage range (5%wt: 10%wt).

Figures (5.a and 5.b) illustrate effect of adding clay nanoparticles on dielectric strength and leakage pass current in HDPE materials in non-uniform electric field. It is noticed that increasing percentage of clay up to 5%wt. nanoparticles in the nanocomposite increases dielectric strength of the industrial materials gradually but, increasing percentage of clay (5%wt.:10%wt) nanoparticles in the nanocomposite decreases dielectric strength of the industrial materials with respect to unfilled specimens. Although, it has been cleared that, increasing percentage of fumed silica up to 10%wt fumed silica nanoparticles in the nanocomposite decreases dielectric strength of the industrial materials with respect to unfilled specimens.

And so, it is noticed that, leakage pass current through the new nanocomposite increases with increasing percentage clay nanoparticles up to 10%wt. but the
leakage pass current decreases smoothly with increasing fumed silica nanofillers percentage from up to 10%wt..

**Fig. 5. Effect of nanoparticles on HDPE industrial polymers under non-uniform electric field**

### 4.3. Thermal Comparison of Dielectric Strength under Uniform and Uniform Electric Field

Table (2) depicts effect of clay nanoparticles on dielectric strength of pure and nano-composite materials in uniform electric field with varying cell test temperature from room temperature at 25 °C and 60 °C. It is cleared that there is increasing in dielectric strength with increasing clay nanoparticles percentage. And so, the dielectric strength has been decreased with increasing fumed silica nanoparticles percentage.

<table>
<thead>
<tr>
<th>Materials</th>
<th>Dielectric Strength (MV/m) at (25 °C)</th>
<th>Dielectric Strength (MV/m) at (60 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDPE + 0%wt Clay</td>
<td>30.8939</td>
<td>25.4653</td>
</tr>
<tr>
<td>LDPE + 10%wt Clay</td>
<td>69.0641</td>
<td>67.9765</td>
</tr>
<tr>
<td>LDPE + 10%wt Fumed Silica</td>
<td>22.2439</td>
<td>20.5733</td>
</tr>
<tr>
<td>HDPE + 0%wt Clay</td>
<td>22.2922</td>
<td>16.8776</td>
</tr>
<tr>
<td>HDPE + 10%wt Clay</td>
<td>50.9394</td>
<td>48.3462</td>
</tr>
<tr>
<td>HDPE + 10%wt Fumed Silica</td>
<td>7.0166</td>
<td>6.1736</td>
</tr>
</tbody>
</table>

Table (3) depicts effect of clay nanoparticles on dielectric strength of pure and nanocomposite materials in non-uniform electric field with varying cell test temperature from room temperature at 25°C and 60°C. It is cleared that clay and...
fumed silica nanoparticles changing electrical characteristics to withstand high applied electric strength rating with respect to uniform applied voltage.

Table (3) Dielectric strength of pure and nanocomposite materials in non-uniform electric field

<table>
<thead>
<tr>
<th>Materials</th>
<th>Dielectric Strength (MV/m) at (25 °C)</th>
<th>Dielectric Strength (MV/m) at (60 °C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LDPE + 0%wt Clay</td>
<td>34.4060</td>
<td>30.9643</td>
</tr>
<tr>
<td>LDPE + 10%wt Clay</td>
<td>44.0828</td>
<td>41.9435</td>
</tr>
<tr>
<td>LDPE + 10%wt Fumed Silica</td>
<td>28.5179</td>
<td>21.6743</td>
</tr>
<tr>
<td>HDPE + 0%wt Clay</td>
<td>26.6078</td>
<td>23.2776</td>
</tr>
<tr>
<td>HDPE + 10%wt Clay</td>
<td>38.4624</td>
<td>32.3462</td>
</tr>
<tr>
<td>HDPE + 10%wt Fumed Silica</td>
<td>11.5684</td>
<td>8.8756</td>
</tr>
</tbody>
</table>

5. CONCLUSIONS

Adding clay nanoparticles to Low density polyethylene and high density polyethylene industrial materials increases dielectric strength and leakage pass current smoothly with respect to unfilled industrial materials according to percentage of clay nanofillers and polymer molecular type. Although, adding fumed silica nanoparticles to Low density polyethylene and high density polyethylene industrial materials decreases dielectric strength and leakage pass current smoothly with respect to unfilled industrial materials according to percentage of fumed silica nanofillers and polymer molecular type. Dielectric strength of pure and nanocomposite materials in non-uniform electric field is higher than dielectric strength of pure and nanocomposite materials in uniform electric field and so, reduction percentage in dielectric strength of pure industrial materials is higher than that happened in nanocomposites with increasing cell test temperature.

ACKNOWLEDGEMENTS

The present work was supported by the Science and Technology Development Fund (STDF), Egypt, Grant No: Project ID 505.

REFERENCES


Transactions on Dielectrics and Electrical Insulation, Vol. 17, No. 6, pp. 1682-1686, 2010.


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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 South Valley 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. A lot of mobility’s has 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 more than 55 publications which have been published in international journals and conferences and held in his website (http://www.ghson.net/FOLDERS_INDEX/nano/dr_athabet.htm)

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