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The effect of silica content to partial discharge characteristic of low-density polyethene and natural rubber blend as the electrical insulator

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ABSTRACT

The dielectric properties of low-density polyethylene natural rubber (LDPE-NR) biopolymeric insulating materials can be improved by adding the silica nanoparticles in a certain percentage of weight (w%). In the present study, four types of bio-nano polymeric samples were prepared. To each sample, the nanosilica particles with wt% 1.5%, 3%, 4.5% and 6%. As one characteristic of dielectric, the partial discharge (PD) characteristics, each sample has been tested for 1 hour under AC high voltage field, and the pulses were counted for each sample and grouped into positive and negative pulses. The PD pattern was also plotted based on X-Y axes, namely Φ-q-n pattern. It was found that the number of positive and negative partial discharge (PD) pulses for each silica sample after 60 minutes of testing varied for all samples. It is also found that samples with a higher percentage of nanosilica had fewer PD pulses. The PD pattern in lower w% of silica was identified in the 90 degrees mostly in containing This indicates that w% of nanosilica particles can improve the PD resistance or the insulation quality of LDPE-NR insulation materials.

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1. INTRODUCTION

The polymeric-based is widely used today as an electrical insulating material. This insulating material has some advantages compared to other materials such as having water repellent properties, thermal properties, and excellent dielectric properties [1-4], which are characterized by high penetrating stress levels [5-7]. Also, polymer materials are lightweight and straightforward in the manufacturing process [8, 9]. One of the inorganic polymer materials that have excellent electrical insulating properties is low-density polyethylene natural rubber (LDPE) with a density of 0.91-0.925 gr/cm^3, which can have short or long branches. LDPE has several advantages including strong mechanical properties, a bit translucent, high strength at low temperatures, resistant to chemical changes, can be made in the form of transparent thin films and has excellent electrical properties. LDPE can be mixed with natural rubber (NR) to form a called bio-polymer or bio-composite.

Natural rubber is a hydrocarbon compound containing carbon atoms (C) and hydrogen atoms (H). The general characteristics of natural rubber are dark brown in color, with a specific gravity of 0.91-0.93. The maximum operating temperature of the highest NR is 90 °C. If the temperature is increased consistently, then at a temperature of 130 °C it will begin to soften and will decompose at around 200 °C.

The insulating material is affected by environmental conditions such as gases that fill cavities, pressure, humidity, and temperature the nanocomposite-based insulation and reduce the electrical and mechanical resistances [10]. Theses properties of the necessary polymeric materials can be improved by adding a certain amount of nano-sized particles to form called a bio-nano composite material [11-13]. For this reason, insulation resistance analysis, such as partial discharge testing is necessary to diagnose the degradation rate of nanocomposite material [14-16]. Besides, several congenital defects can affect the performance of the polymer material is in the form void defects, impurities (impurities), and protrusions (protrusion) on the surface of a semiconductor or a conductor and insulating polymer in the production process. These defects can result in a high electric field strength on the part of the defect and cause accelerated ageing in polymer isolation polymer [17, 18].

The nonsilicate ceramic material related to its high electrical resistance and resistance to thermal shock and corrosion such as nanosilica can be used to improve the LDPE-NR composite as the high voltage insulation. Silica has an excellent heat and electrical insulators [19, 20]. The evaporating point of silica is 2230 °C and melts in 1600-1725 °C with a molar mass of 60.08 g mol^{-1}. With theses excellent properties, the nanosilica particles can increase the dielectric performance like the resistance of insulating materials to partial discharge and thermal properties [12, 21-23]. To develope the nanocomposite insulation materials, the related study should be done extensively in order to understand the phenomena possessed by the content fully [24, 25]. In the current report, the investigation of the effect percentage weight of nanosilica to partial discharge (PD) characteristics of low-density polyethylene (LDPE) and natural rubber (NR) biopolymer [26] were examined.

2. RESEARCH METHOD

In the present study, biopolymer composite materials were used are LDPE and NR (bio-composite) with a fixed ratio of 80:20 of the total sample weight. The total sample weight in one samples is 60 grams. Addition of nanosilica is 1.5%, 3%, 4.5% and 6% by weight of LDPE-NR. The LDPE, NR and silica were put into the mixing chamber simultaneously, namely the rheomix machine at 150 °C with a rotor rotation speed of 60 rpm for 12 minutes. Before the insulation sample is moulded using Hotpress Collin 300 p in 4 phases is stored in an oven for 24 hours at 70 °C for cooling down process.

Figure 1 shows the partial discharge (PD) experimental setup. The measurements were carried out using a PD measurement system produced by Haefely instrument type 9332 [27]. This testing equipment used the 9230 coupling capacitor series which was carried out on a test sample via a Z impedance. The sample is placed between a high-voltage ball-plate electrode. The high voltage source is increased slowly and maintain the value of 6.5 kV during one hour test.

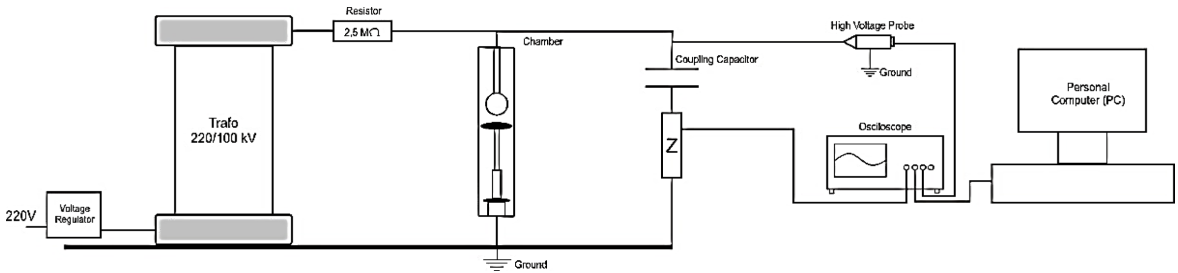


Figure 1. Partial discharge experimental setup

3. RESULTS AND ANALYSIS

3.1. Positive and negative PD pulses characteristic of bionanosilica composite

PD pulses are represented in the form of pulses sequence in each cycle or the form of n-t patterns. Where n is the number of PD pulses that occur, and t is the time when PD occurs. Each time the PD occurs, the counter starts to count until the last pulse is detected. Figure 2 shows the PD pulses of bio-nano composites with various compositions. It can be seen while the w% silica contains is increasing from w% of 1.5 to 6%, in contradiction, the number of PD pulses decreases after 60 minutes the testing period both in the positive cycle and the negative cycle. In the positive cycle, the bio-nano composites with w% of 1.5 have the most number of PD pulses, and silica w% of 6 has the least amount of PD pulses. The same trend is also notified in the negative cycle. In the positive cycle, the number of pulses decreases from 174 to 70 pulses, or about 148% decrease refers to the last value, 70 pulses.

In the same way, in the negative cycle, the number of PD pulses decreased from 196 to 91 or about 115% decrease. In total, the PD pulses decrease from 370 to 161 pulses or 130% decrease. The result shows that the addition of silica in the LDPE-NR composite can reduce the PD pulses significantly. In other words, the PD resistance of bio-nano composite improves more than twice with nanosilica contain increase from 1.5 wt% to 6 wt%.

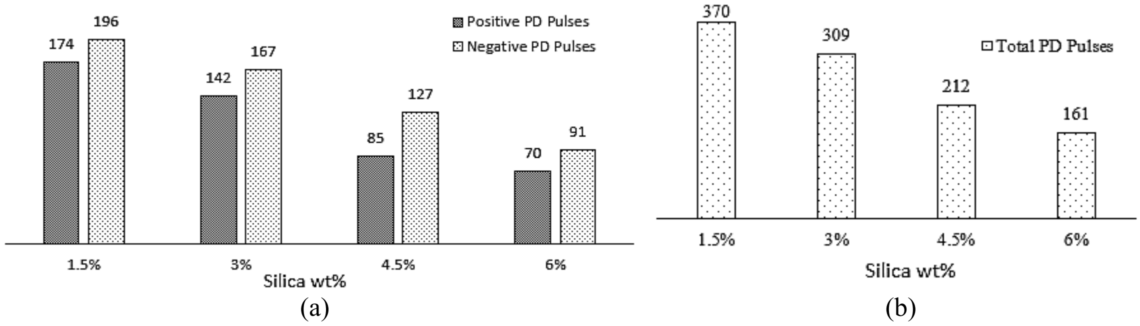


Figure 2. Partial characteristic of 4 types of silica bio-nano composites; (a) the positive and negative PD pulses, (b) the total PD pulses

3.2. Average PD charge

Figure 3 shows the average PD charge characteristics of bio-nano composite samples with various compositions. The average PD charge is seen in the positive cycle and the negative cycle of each silica variation. From the lower silica content w%, after 60 minutes test, the average PD charge of bio-nano composite samples tends to increase both for the positive and negative cycle. In the positive cycle, the average PD charge increases from 21 pC to 36 pC. In the negative cycle, the same trend is also identified where the charge is increasing from 24 pC to 41 pC.

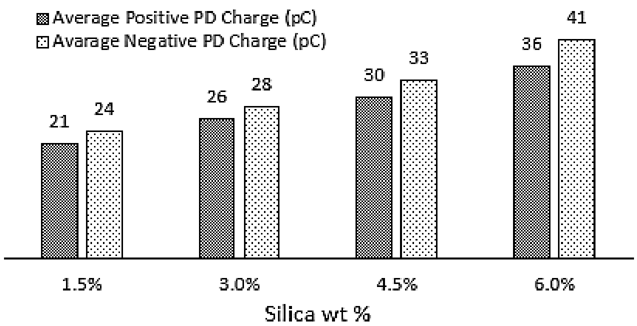
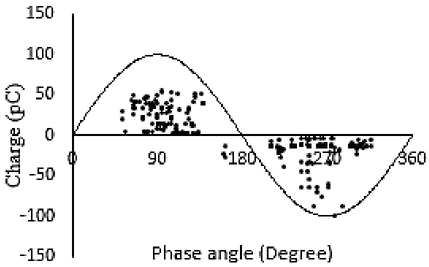


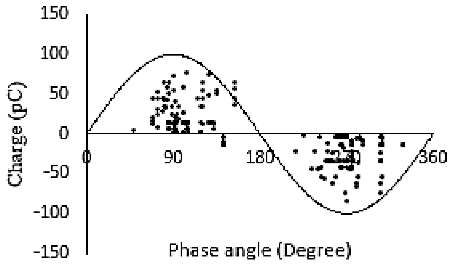
Figure 3. Characteristics of average positive and negative PD charges of four types of silica content bio-nano composite

3.3. Partial discharge pattern of bio-nano composite

The PD pattern is represented by (Φ-q-n) where Φ represents the phase angle, q is the average charge and n is the number of PD pulses. Figure 4 shows the PD pattern of four different compositions of bio-nano composites. It is identified that the PD mostly occur in the phases angle of 30° to 140° in a positive cycle and 200° and 270°. Ideally, the PD took place before 90° and 270°. This PD angle indicates that another form of PD, namely the corona discharge, was also recorded during the experiment and counted as PD pulses for bio-nano composites with the silica content is less than 4.5 wt%. See Figure 4 (a) and Figure 4 (b). For other samples, the PD occurs before 90° and 270°. In the higher wt% of silica, the PD pulse is more localized in phase angle before 90° dan before 270°, which is believed that the PD occur inside the insulating material. This result implies that the new biopolymeric insulating material has been improved by adding the silica content higher than wt% 4.5. Figure 5 shows the pictures of four types of bio-nano composites taken by using digital microscope Hirox KH-8700 with magnification 2500x. The Silica agglomeration is seen in the surface of the bio-nano composite at several places with a bright or white colour.



(a)



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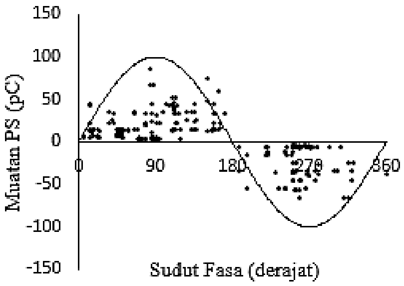
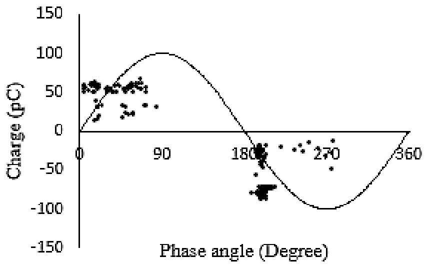
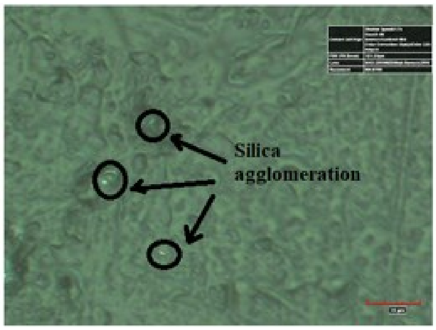


(c)

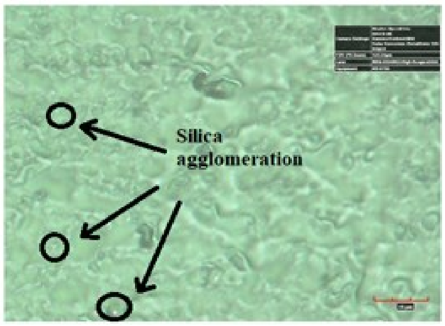


(d)

Figure 4. Partial discharge pattern of four types of silica content bio-nano composite: a) 1.5 wt %, (b) 3.0 wt %, (c) 4.5 wt %. and (d) 6 wt %



(a)



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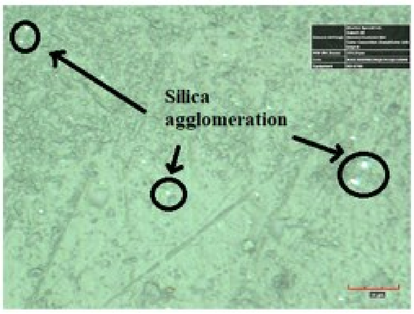

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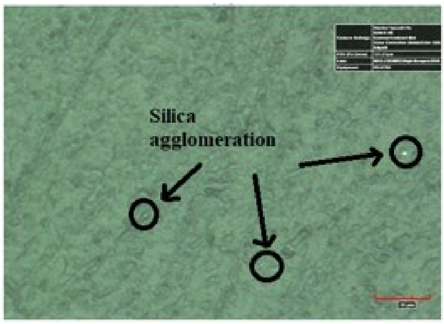

(d)

Figure 5. Surface pictures of four types of silica content of bio-nano composites, (a) 1.5 wt %, (b) 3.0 wt %, (c) 4.5 wt %. and (d) 6 wt %

4. CONCLUSION

The partial discharge testing of four bio-nano composites samples was successfully carried out. The result shows that samples with a higher percentage of nanosilica had fewer PD pulses. The PD pattern of a higher content of nanosilica clearly shows PD location is localized in phase angle before 90^{o} and before 270^{o}.

The results imply that silica improves the PD resistance as well as the surface of the insulating material. The four investigated samples have good potential to be used as the high voltage insulating material.

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