



Nanotechnology Effects on Space Charge Relaxation Measurements for Polyvinyl Chloride Thin Films

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Abstract: Space charge accumulation in insulation materials indicates to conduction current through a dielectric material and it is important to know as well as possible the amount of charge stored in the dielectric. In this research, space charges tests are done to distort the local electric fields, high-field conduction and breakdown phenomena in thin films of Polyvinyl Chloride nanocomposite insulation materials. Therefore, space charge characteristics have been investigated by pulsed electro-acoustic (PEA) system for thin thickness of Polyvinyl Chloride nanocomposite materials, which filled with different separate nanoparticles like Clay, and Fumed Silica, from the experimental tests carried out it is noticed that adding Clay and Fumed Silica to Polyvinyl Chloride changes its breakdown phenomena. This research aims to study the effects of types and concentrations of nanoparticles on space charge accumulation in Polyvinyl Chloride nanocomposites and illustrates which fillers that enhance Polyvinyl Chloride industrial applications.

Keywords: Space charge, Nano-composite, pulsed electro-acoustic (PEA) system, Polymers, Polyvinyl Chloride, Nanoparticles

1. Introduction

Polyvinyl Chloride PVC is the most widely used of any of the thermoplasts, polymerized vinyl chloride, and this is produced from ethylene and anhydrous hydrochloric acid. PVC is stronger and more rigid than other general-purpose thermoplastic materials like ac and dc cable insulations, etc. It has a high tensile strength and modulus of elasticity. Additives are used to further specific end uses, such as thermal stabilizers, lubricity, impact modifiers, and pigmentation. In recent years, there has been a constant increase of interest in possible applications of nanocomposite materials in the field of polymeric insulation technology. The adoption of inorganic additives (fillers) in a polymeric matrix, in order to create a composite material is a common technique. By reducing the filler's particle dimensions to the nanometric scale, it is possible to dramatically increase the number of interactions between the organic (matrix) and the inorganic (filler) phase; although the link between interface-size effect and macroscopic performances is not plainly understood, this fact can originate smart properties in the material. In particular it has been demonstrated that the employment of organically modified layered silicate (clays such as montmorillonite, etc) as filler may increase the thermal resistance, the mechanical strength, the flame retardancy and the gas impermeability [1-5], by using a filler rate equal to 5% -10 typical of "conventional" nanofillers. With rapid development of the world's major cities, the electric energy consumption is increasing annually. Due to this demand, direct current transmission technology which can reduce the costs and energy losses has been a hot topic in the electrical engineering domain. The high voltage DC plastic insulated cable has gradually replaced oil-paper insulated DC cables for the advantage of relatively small volume, great transmission capacity and no maintenance. Polyvinyl Chloride PVC is widely used as an insulating material for power cables due to its excellent mechanical, thermal and dielectric properties. However, the non-homogenous

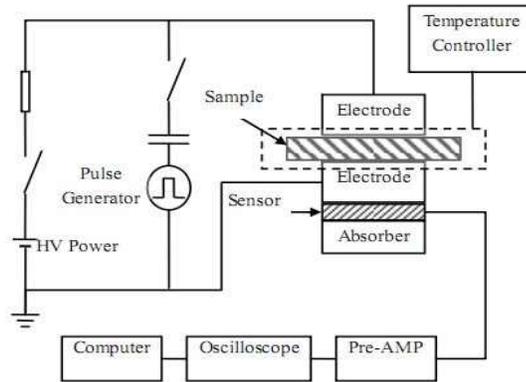
distribution of space charge in the cable insulation may distort the distribution of electric field which will reduce the dielectric strength and accelerate the deterioration of the insulation. Especially when the voltage is switched off or the polarity is reversed, this phenomenon becomes more apparent [6-11]. Up to now there are many papers reporting dielectric properties of polymeric nanocomposite, of which space charge distribution is investigated in details, for example, space charge at various electric stresses, its inception field and etc. Since most of engineering dielectric concerning to various electrode materials, it is inevitable to considering whether space charge distribution in polymer nanocomposite is sensitive to electrode materials. It stimulates us to fall in step with space charge characterization in the convention dielectric materials. With the pulsed electro-acoustic method (PEA), space charge in a nanocomposite was investigated with different metal electrode pairs, as well as space charge. However, the suppression mechanism of space charge accumulation by adding nano-fillers to polymers under high electric field at high temperature has not been clear yet. Therefore, it has been proposed a charge trapping effect of induced potential well at interface between polymer and nano-fillers based on difference between their permittivities [12-16]. Recently, the research goes towards for concerning about the effect of nanotechnology on space charge distribution in polymeric insulations. With a continual progress in polymer nanocomposites, the current research depicts the effects of types and concentration of nanoparticles in new nanocomposite industrial polymer material. Space Charge Dynamics in Polyvinyl Chloride nano-composite materials which use clay, or fumed silica, or ZnO nanoparticles separately under DC Stress have been investigated and discussed experimentally.

2. Experimental Setup

Acoustic wave propagation in the thick samples is significantly attenuated and dispersed due to the loss and dispersive properties of the polymer and principle of space charge measurement using the PEA technique. The specifications of each module in PEA system is being as follows: The oscilloscope (LECROY, LC334AM, 500MHz), impulse generator (TECHMP, 10nsec), VHF fixed attenuator (30W, 50Hz, 40dB) and stabilized voltage supply (Type L30). Measurements are performed in silicon oil to avoid partial discharges, and to keep the temperature constant. The applied voltage was monitored simultaneously by using a resistance voltage divider. In order to observe the effect of pre-stressing on impulse breakdown, it existed that an impulse generator, and a coupling capacitor (2000 pF). Figure (1) shows Life photo and Schematic diagram respectively of the PEA system which used in measurement.



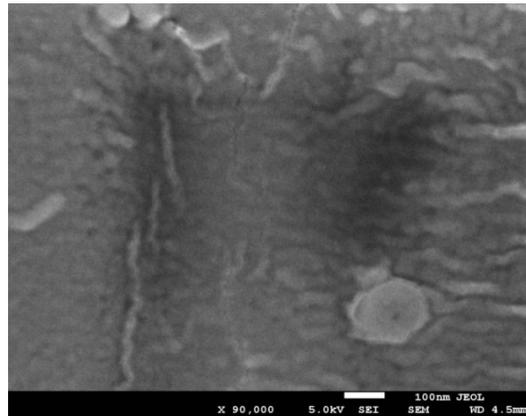
(a) Life photo for experimental PEA system



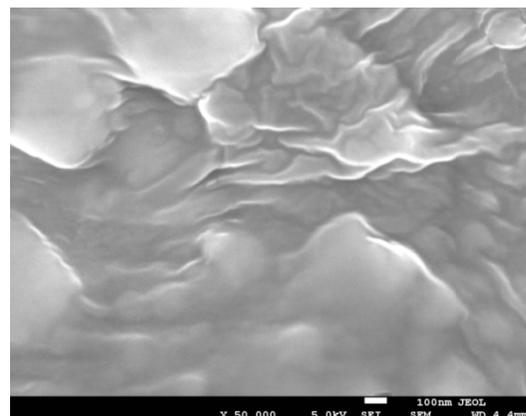
(b) Schematic diagram of PEA system
Figure 1. PEA system testing equipments

3. Material Preparation and Characterization

Nanoparticles: Nanoclay is nanomer 1.30E, clay surface modified with 25-30wt. % octadecylamine. Spherical particle shape 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. Fumed Silica (SiO_2) are powders used in paints and coatings, silicone rubber and silicone sealants, adhesives, cable compounds and gels, printing inks and toner, and plant protection.



(a) PVC with Clay



(b) PVC with Fumed Silica

Figure 2. Polyvinyl Chloride PVC with Nanoparticles

Polyvinyl Chloride (PVC): It is the most widely used of any of cables, thermoplastics, polymerized vinyl chloride, and which is produced from ethylene and anhydrous hydrochloric acid. PVC is stronger and more rigid than other general purpose thermoplastic materials. PVC's are basically tough and strong, resist water and abrasion, and are excellent electrical insulators. SEM photos for Polyvinyl Chloride PVC with Clay and fumed silica has been illustrated as shown in figure (2).

Also, the studied industrial material here, Polyvinyl Chloride, has been formulated utilizing nano particulates of clay, fumed silica, and zinc oxide. The base of all these polymer materials is a commercially available material already in use in the manufacturing of high-voltage (HV) industrial products and their electric and dielectric properties detailed in table 1.

Table 1. Dielectric Properties of Pure and Nano-composite Materials

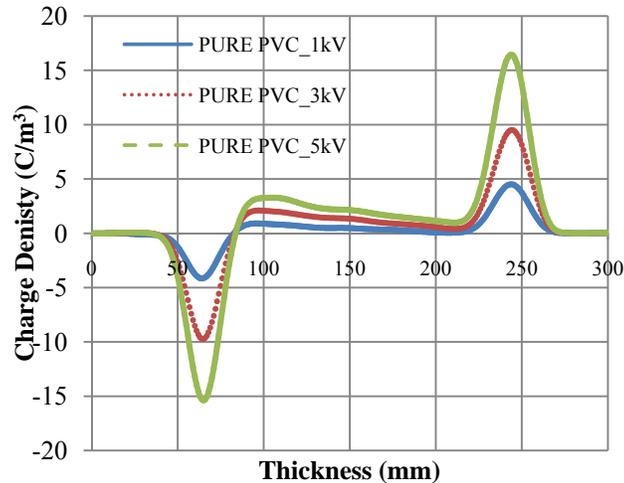
Materials	Dielectric Constant at 1kHz	Resistivity ($\Omega.m$)
PURE PVC	3.3	10^{13}
PVC + 5%wt Clay	3.04	$10^{13}-10^{14}$
PVC + 10%wt Clay	2.85	$10^{14}-10^{15}$
PVC + 5%wt Fumed Silica	3.29	$10^{13}-10^{12}$
PVC + 10%wt Fumed Silica	3.29	$10^{12}-10^{11}$
PVC + 10%wt ZnO	3.04	$10^{15}-10^{16}$

4. Results and Discussion

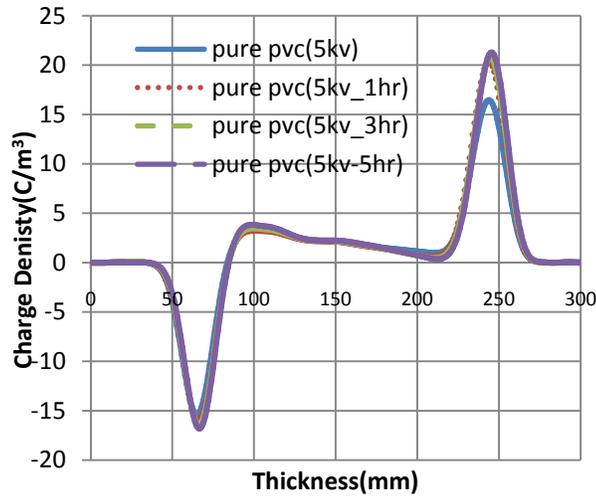
PEA system measurements were carried out using two semiconductors cylindrical stainless steel electrodes with diameter 50 mm, and placing specimens in a mineral oil vessel kept at 20°C. Tests were realized applying an increasing dc breakdown voltage up to 7.5 kV. The following figures show space charge distribution at various dc voltage stressed and at variant period times. It can be seen the positive and negative space charge peaks related to the cathode and anode electrodes that found subsequently using variant applied voltages and times.

5. Space Charge Characterization of Pure Polyvinyl Chloride Industrial Polymers

Figure 3(a) shows space charge distribution that relevant to pure Polyvinyl Chloride (PVC) under various DC electric field 70 kV/mm. The measurements imply the injection of impulse high voltages on the charge density of Pure PVC dielectric materials; the cathode is at the left and the anode is at the right that the charge density increases by increasing impulse voltages and hetero-charge accumulated near the cathode.



(a)Space charge profiles with varying DC fields



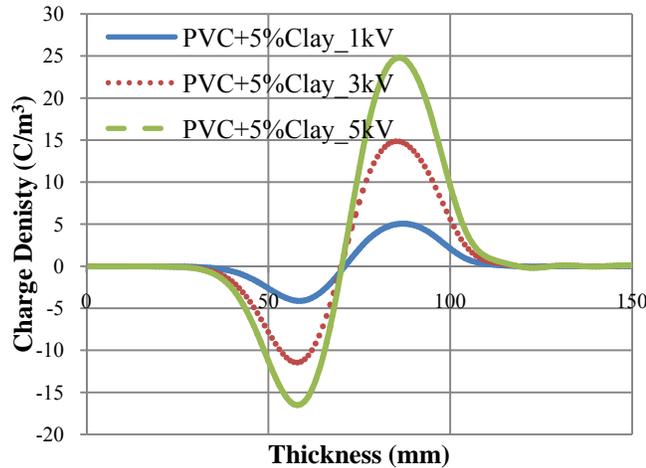
(b) Space charge profiles under constant DC fields

Figure 3. Space charge profiles for Pure Polyvinyl Chloride PVC

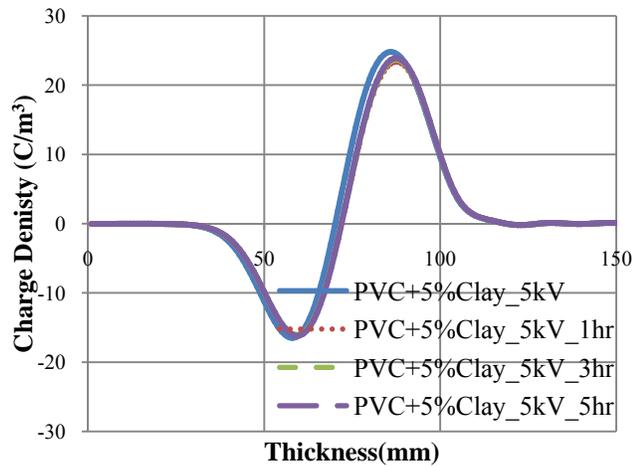
Whatever, Figure 3.b contrasts on the space charge distribution, and its decay happened in remaining 5kV, observed in the samples after three hour space charge electrodes. Charge density increases with remaining impulse voltages at 5kV only at the Anode and the hetero-charge accumulated near the cathode is not increased. The measurements therefore imply the injection of negative charge from the cathode, which remains trapped close to the injecting electrode when the duration is three hours.

6. Space Charge Characterization of Clay /Polyvinyl Chloride Nanocomposites

Figure 4(a) shows space charge profiles relevant to Polyvinyl Chloride (PVC) with 5% clay nanoparticles up to 70kV/mm DC electric fields. This figure contrasts on the space charge distribution with rising voltage up to 5kV. The measurements imply the injection of impulse high voltages on the charge density of Polyvinyl Chloride PVC with 5% Clay nanocomposite materials; charging density at the anode is more than charging density at the cathode with increasing impulse applied voltages up to 5kV and there is no hetero-charge accumulated near the cathode. Figure 4(b) contrasts the space charge distribution, and its decay which is



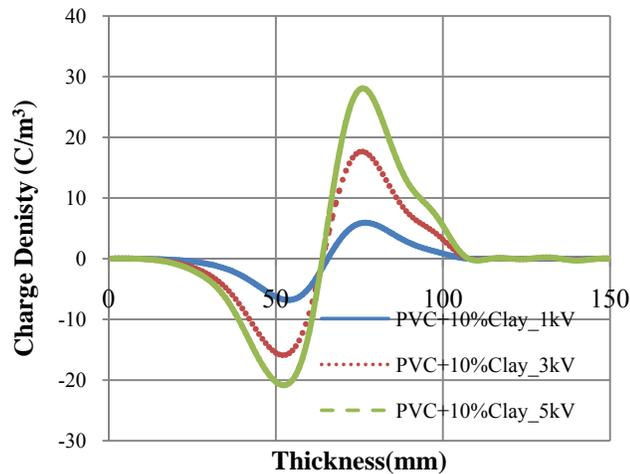
(a) Space charge profiles with varying DC electric fields



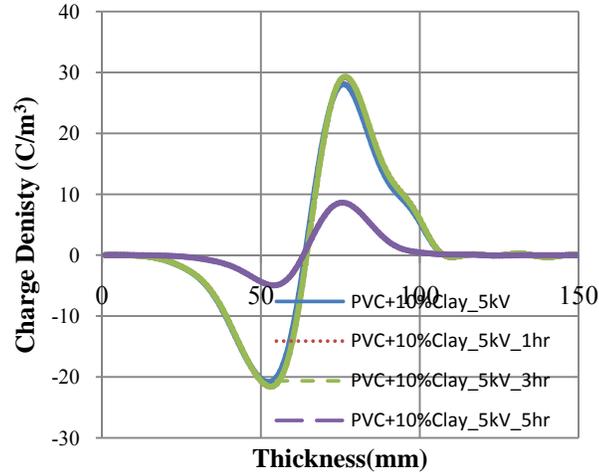
(b) Space charge profiles under constant DC electric fields

Figure 4. Space charge profile for nanocomposite of Polyvinyl Chloride PVC with 5%wt Clay

happened in remaining 5kV dc voltage, and is observed in the samples after half hour between space charge electrodes. There is no changing in Charge density with remaining impulse voltages but there is a very small reduction at the Anode. Figure 5.a contrasts the space charge distribution with rising DC applied voltage up to 5kV. The measurements imply the injection of impulse high voltages on the charge density of Polyvinyl Chloride PVC with 10% clay nanocomposite materials; charge density at the anode and cathode is increased in nanocomposite PVC with 10%clay and there are no hetero-charge accumulated charges between the anode and cathode electrodes. Figure 5(b) contrasts the space charge distribution, and its decay happened in remaining voltage, observed in the samples after half hour between space charge electrodes. Thus, Figure 8 contrasts on the effects of the space charge distribution, at remaining 5kV voltage on Polyvinyl Chloride PVC with 10% clay nanocomposite material. There is high reduction in charge density at anode and cathode with remaining impulse voltages at 5kV.



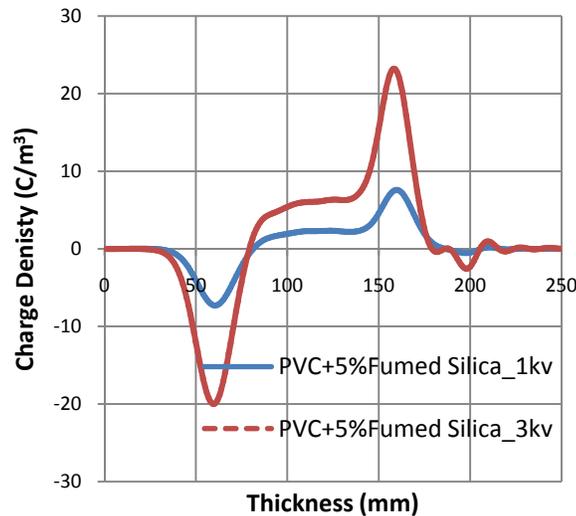
(a) Space charge profiles with var



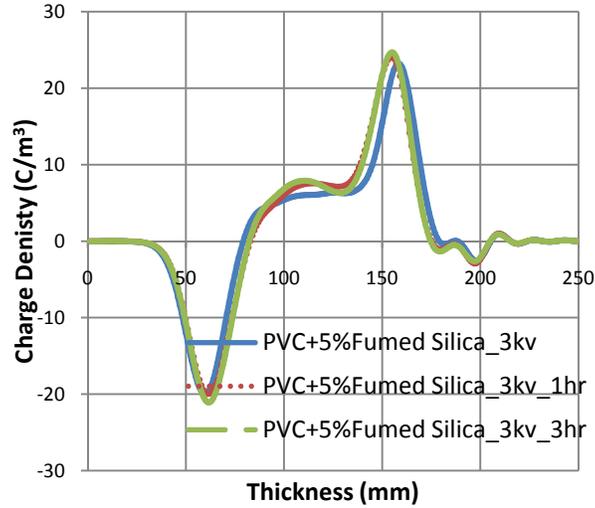
(b) Space charge profile under constant DC electric fields
 Figure 5. Space charge profiles for nanocomposite of Polyvinyl Chloride PVC with 10%wt Clay

6. Space Charge Characterization of Fumed Silica/Polyvinyl Chloride Nanocomposites

Figure 6(a) shows space charge distributions relevant to Fumed silica/Polyvinyl Chloride nanocomposites with 5%wt nanoparticles percentage under various DC electric field 70 kV/mm. The measurements imply the injection of impulse high voltages on the charge density of Fumed silica/Polyvinyl Chloride nanocomposites; charging density at the anode is more than charging density at the cathode with increasing impulse applied voltages up to 5kV and there is hetero-charge accumulated near the anode. Whatever, Figure 6.b contrasts on the space charge distribution, and its decay which applied 5kV dc voltage through three hour over Fumed silica/Polyvinyl Chloride nanocomposites with 5%wt nanoparticles percentage. So that, this figure illustrates that there is no changing in Charge density with remaining impulse voltages but there is a deviation and a very small rising at the Anode.

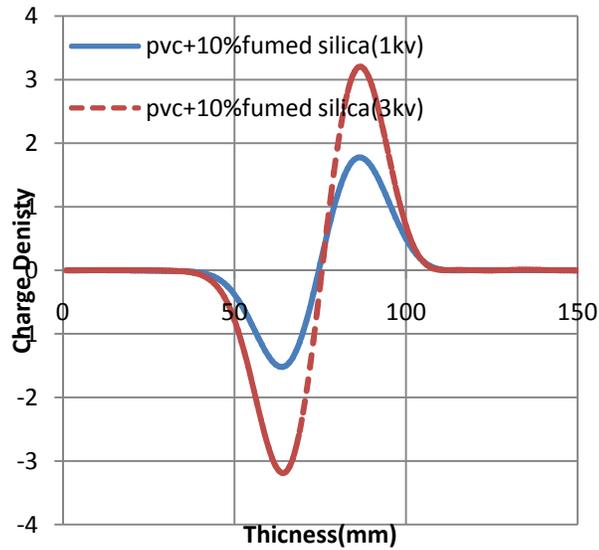


(a) Space charge profiles with varying DC electric fields

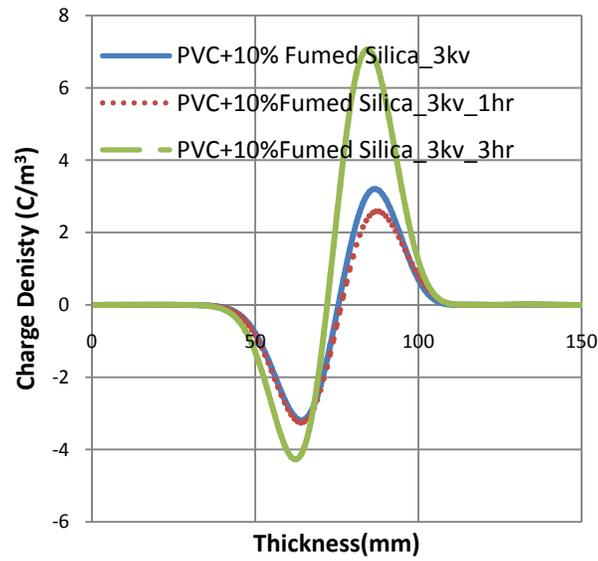


(b) Space charge profiles under constant DC electric fields
 Figure 6. Space charge profiles for nanocomposite of Polyvinyl Chloride PVC with 5%wt Fumed silica

Figure 7(a) shows space charge distributions relevant to Fumed silica/Polyvinyl Chloride nanocomposites with 10%wt nanoparticles percentage under various DC electric field 70 kV/mm. The measurements imply the injection of impulse high voltages that depicts charge density at the anode and cathode is decreased to lowest values in Fumed silica/Polyvinyl Chloride nanocomposites and there are no hetero-charge accumulated charges between the anode or cathode electrodes. Also, increasing fumed silica nanoparticles from 5%wt up to 10%wt decreasing charge density in the nanocomposite molecules.



(a) Space charge profiles with varying DC electric fields



(b) Space charge profiles under constant DC electric fields
Figure 7. Space charge profiles for nanocomposite of Polyvinyl Chloride PVC with 10%wt Fumed silica

Whatever, Figure 7(b) contrasts on the space charge distribution in Fumed silica/Polyvinyl Chloride nanocomposites with 10%wt nanoparticles percentage, and its decay that happened in the samples through three hours remaining voltage. Charge density decreases in the beginning time with remaining impulse voltages at 3kV at first hour but it increases with increasing remaining time up to three hours, especially at the anode.

8. Effects of Nanoparticles on Space Charge Characterization Polyvinyl Chloride

Characterization of Polyvinyl Chloride which are shown in Figure 3 is pointed out the measurements imply the injection of impulse high voltages on the charge density of Pure PVC dielectric materials; the charge density increases with increasing impulse voltages and hetero-charge accumulated near the cathode. Also, charge density increases with remaining impulse voltages at 5kV only at the Anode and the hetero-charge accumulated near the cathode is not increased.

Whatever, the effect of raising concentration of clay nanofillers in Polyvinyl Chloride are pointed out in Figures (4, 5), these figures depicts clay nanoparticles effects, i.e. increasing percentages of clay nanoparticles up to 10%wt clay increases charge density about 20%. With aging under 5kV, charge density at the anode and cathode is decreased lightly in PVC with 5%wt clay but there is more reduction in charge density that happened in nanocomposite PVC with 10%wt clay and there are no hetero-charge accumulated charges between the anode and cathode electrodes.

The effect of raising concentration of fumed silica nanofillers in Polyvinyl Chloride are pointed out in Figures (6, 7), i.e.: it depicts that at 5%wt fumed silica, the measurements imply the injection of impulse high voltages on the charge density of Fumed silica/Polyvinyl Chloride nanocomposites; charging density at the anode is more than charging density at the cathode with increasing impulse applied voltages up to 5kV and there is hetero-charge accumulated near the anode. But, at 10%wt fumed silica, there are no hetero-charge accumulated charges between the anode or cathode electrodes. Also, increasing fumed silica nanoparticles from 5%wt up to 10%wt decreasing charge density in the nanocomposite molecules.

9. Conclusions

The charge density in Polyvinyl Chloride increases with increasing impulse voltages and hetero-charge accumulated near the one electrode. But, adding Clay nanoparticles in Polyvinyl Chloride increases the charge density at both electrodes with increasing impulse applied voltages also increases hetero-charge accumulated between both electrodes.

Adding fumed silica nanoparticles from up to 5% increases charge density with increasing impulse applied voltages and there is hetero-charge accumulated near the electrodes. But, adding fumed silica nanoparticles from up to 10% the measurements imply the injection of impulse high voltages that depicts charge density at the anode and cathode is decreased to lowest values in Fumed silica/Polyvinyl Chloride nanocomposites and there are no hetero-charge accumulated charges between the anode or cathode electrodes in nanocomposite molecules.

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