

PARTIAL DISCHARGE BEHAVIOUR OF CROSS-LINKED POLYETHYLENE -
NATURAL RUBBER BLENDS NANOCOMPOSITES AS ELECTRICAL
INSULATING MATERIAL

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To

My beloved husband Muhammad Nor Harith Bin Ismail,

My precious daughter Nur Amani Sofea,

My beloved father and mother

Wan Mohd Zawawi Bin Wan Abd Rahman and Sarah Binti Ramli,

And last but not least my siblings and also my in-laws family.

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ABSTRACT

Polymeric materials are widely used in power apparatus as electrical insulation, especially for high voltage cable insulation. However, partial discharge (PD) has always been a predecessor to major faults and problems in this field. By adding a weight percentage (wt%) of a nanofiller to the electrical insulation, the physical and electrical properties can be enhanced. In this research, natural rubber (NR) blends polymeric material of cross-linked polyethylene (XLPE) as insulation was combined with nanofillers, namely nanosilica (SiO_2) or organo-montmorillonite (O-MMT). Seven samples comprising six compositions of a blend of 20 wt% NR and 80 wt% of XLPE with 2, 4, and 8 pph from SiO_2 and O-MMT, and one without nanofiller were used in the experiments. Two PD tests were carried out based on CIGRE Method II technique, where 7 kV_{rms} high voltage was applied for 1 hour and 3 hours. LabVIEW™ program was used to analyse the PD data captured from the on-line and off-line PD measuring system where PD pulse magnitudes and number of PD occurrences were measured. Results showed that samples of NR-XLPE blended with SiO_2 have lower PD number than the O-MMT samples. Scanning Electron Microscopy images showed that smoother surfaces were observed as the wt% of the nanofiller increased, indicating that the samples were less degraded. Energy Dispersive X-ray measurement of samples containing SiO_2 emitted more stable amounts of oxygen and carbon contents when exposed to high voltage. Analysis on Fourier Transform Infrared spectroscopy showed a reduction of OH groups in the samples. Using QuickField™, the electric field distribution of the samples confirmed that in series of 2, 4, and 8 pph nanofiller loading, there is a correlation between the amount of nanofiller and discharge activities. The findings have shown that SiO_2 and O-MMT and the different loadings do enhance the insulation properties when mixed with NR-XLPE.

ABSTRAK

Bahan polimer digunakan dengan meluas dalam alat kuasa sebagai penebat elektrik, terutamanya sebagai penebat kabel voltan tinggi. Walau bagaimanapun, nyahcas separa (PD) sentiasa menjadi pendahulu kepada kerosakan dan masalah utama dalam bidang ini. Dengan menambah peratusan berat (wt%) pengisi nano kepada penebat elektrik ciri-ciri fizikal dan elektrik polimer boleh dipertingkatkan. Dalam kajian ini getah asli (NR) yang menggabungkan bahan polimer polietilena silang-hubung (XLPE) sebagai penebat disatukan dengan pengisi nano, iaitu nanosilika (SiO_2) atau organo-montmorilonit (O-MMT). Tujuh sampel yang terdiri daripada enam komposisi campuran 20 wt% NR dan 80 wt% XLPE dengan 2, 4 dan 8 pph daripada SiO_2 dan O-MMT serta dengan satu tanpa pengisi nano telah digunakan dalam eksperimen ini. Dua ujian PD telah dijalankan mengikut teknik CIGRE Kaedah II dengan voltan tinggi $7 \text{ kV}_{\text{rms}}$ digunakan untuk ujian PD selama 1 dan 3 jam. Program LabVIEW™ telah digunakan untuk menganalisis data PD yang diperolehi daripada sistem pengukuran PD dalam talian dan luar talian. Magnitud pulsa PD dan bilangan kejadian PD diukur. Keputusan ujian menunjukkan sampel NR-XLPE yang dicampur dengan SiO_2 mempunyai bilangan PD lebih rendah berbanding dengan sampel O-MMT. Imej imbasan elektron mikroskopi (SEM) sampel menunjukkan bahawa permukaan lebih licin dapat diperhatikan apabila wt% pengisi ditambah yang menunjukkan bahawa sampel kurang terosot. Pengukuran tenaga serakan x-ray (EDX) sampel yang mengandungi SiO_2 mengeluarkan jumlah kandungan oksigen dan karbon yang lebih stabil apabila terdedah kepada voltan tinggi. Analisis spektroskopi inframerah transformasi Fourier (FTIR) menunjukkan pengurangan kumpulan OH dalam sampel. Dengan QuickField™ taburan medan elektrik sampel mengesahkan bahawa terdapat korelasi antara jumlah pengisi nano dengan aktiviti nyahcas dalam siri muatan 2, 4 dan 8 pph. Penemuan ini menunjukkan bahawa SiO_2 dan O-MMT dan muatan yang berbeza dapat meningkatkan ciri-ciri penebat apabila dicampur dengan NR-XLPE.

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LIST OF ABBREVIATIONS

+ve	-	Positive
μm	-	Micrometre
AC	-	Alternating current
AD	-	After degradation
AFM	-	Atomic Force Microscopy
Al_2O_3	-	Aluminium trioxide/ alumina
ATH	-	Alumina Trihydrate
ATR	-	Attenuated Total Reflectance
BD	-	Before degradation
BS	-	British Standard
cm	-	Centimetre
DC	-	Direct current
div	-	Division
EDX	-	Energy Dispersive X-ray
EPDM	-	Ethylene-Propylene-Diene Monomer
EPR	-	Ethylene Propylene Rubber
FESEM	-	Field Emission Scanning Electron Microscope
FTIR	-	Fourier Transform Infrared
g	-	Gram
GHz	-	Giga hertz
h	-	Hour
H_2O	-	Moisture/ water
HDPE	-	High Density Polyethylene
HV	-	High voltage
IEC	-	International of Electrotechnical Commission

IEEE	-	Institute of Electrical & Electronic Engineers
IMC	-	Impedance Matching Circuit
km	-	Kilometre
kV	-	Kilovolt
LDPE	-	Low Density Polyethylene
LLDPE	-	Linear Low Density Polyethylene
LVSEM	-	Low Vacuum Scanning Electron Microscope
MC	-	Microcomposite
MDPE	-	Medium Density Polyethylene
MgO	-	Magnesium Oxide
MHz	-	Mega hertz
min	-	Minute
mm	-	Millimetre
MMT	-	Monmorillonite
ms	-	Milisecond
Ms/S	-	Megasecond per sample
mV	-	Milivolt
nA	-	Nano ampere
NDI	-	Normalized Degradation Index
NF	-	No filler
nm	-	Nanometer
NR	-	Natural rubber
°C	-	Degree celcius
OH	-	Hydroxyl
O-MMT	-	Organo-Montmorillonite
PA	-	Polyamide
PD	-	Partial discharge
PE	-	Polyethylene
PI	-	Polyimide
PP	-	Polypropylene
PUR	-	Polyurethane rubber
PVC	-	Polyvinyl Chloride
R&D	-	Research and development

rms	-	Root mean square
SEM	-	Scanning Electron Microscopy
SF ₆	-	Sulphur Hexafluoride
SiO ₂	-	Silicon Dioxide/ silica
SiR	-	Silicone Rubber
SMR	-	Standard Malaysian Rubber
TiO ₂	-	Titanium dioxide/ titania
-ve	-	Negative
vol. %	-	Volume percentage
wt%	-	Weight percentage
XLPE	-	Crosslinked Polyethylene
XRD	-	X-ray Diffractometer

LIST OF SYMBOLS

Z_L	-	Load impedance
Z_S	-	Source impedance
R_a	-	Average Roughness
ε	-	Permittivity
U_0	-	Voltage assigned on ground electrode
U_{HV}	-	Voltage assigned on high voltage electrode

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Nanotechnology includes techniques for controlling, modifying, and fabricating materials and devices with nanometric dimensions. It has a very broad definition in fields of surface science, physics, engineering materials, molecular biology, organic chemistry, etc. Through this technology, it will be able to create or fabricate many new materials and devices in a wide range of application including polymer nanocomposites. Polymer nanocomposites will possess promising high performances as engineering materials if they are prepared and fabricated properly [1, 2].

Polymer molecular composites and polymer nanocomposites have been a target for R&D since the 1970's. In fact, polymer composite research has begun in the early 1900 [3]. Since 1990, much effort has been made to develop and apply polymer nanocomposites in transportation, electrical and electronics engineering, food packaging, and building industries. Good mechanical and chemical properties such as tensile strength, impact strength, elastic modulus, and heat deflection temperature have become an added value to the nanocomposite polymer as a material in these fields [2].

In recent years, there have been a lot of research activities in electrical insulating material involving nanotechnology by utilizing renewable source added with nanocomposite as the electrical insulating material [1-7] due to its promising properties enhancement which leads to researches on nanocomposite polymer. Polymer nanocomposites are the second generation of filled resin in the insulation engineering which consists of polymers filled with small amount of nano-sized fillers that slowly overrule the first generation of filled resin micro-sized fillers. The polymer nanocomposites provide better electrical characteristics as dielectrics materials such as discharge characteristic and dielectric strength.

1.1.1 Research Trends on Polymer Nanocomposite Dielectrics

The research trends on polymer nanocomposites dielectrics has started in early 1990's as the paper entitled "Nanometric Dielectrics" by T. J. Lewis was published in IEEE Transactions on Dielectrics and Electrical Insulation [8]. It has become a trigger bullet to a vast research in dielectrics that after the becoming years, a lot of experimental data on nanometric dielectric were published. More detailed concept on nanometric dielectric was studied with yearly increasing rate, including the structure of nanocomposites, the interactions between the polymer matrix and nanocomposites, and the effects of nanostructuration on dielectrics [5].

1.1.2 Application of Nanocomposite Insulating Material in Electrical Apparatuses

Development in nanostructuration has opened a wide opportunity in the application of nanocomposite materials as electrical insulation, especially cable

insulation. Studies [9-12] have shown that XLPE filled with a small amount of filler can hold great performance as power cable insulation. The problems that occur in the dielectrics are partial discharge, water tree, thermal failure in the insulation, and space charge accumulation. Adding a small amount of nanofiller seems to enhancing the ability of the dielectrics, thus overcoming these problems.

Other than that, a university research team collaborated with an electrical apparatuses' manufacturer, Toshiba Corporation in Japan have developed a nanocomposite insulating material with high insulation performance obtained by homogeneous dispersion of nano fillers to epoxy resin. They focused on designing environmentally-friendly switchgear without sulphur hexafluoride (SF_6) that could gives environmental impact. One way is to use solid insulation systems using nano-clay and micro silica composites. Evaluations have verified that nanocomposites insulation are superior than SF_6 gas insulation in switchgear in terms of partial discharge degradation, thus longer time to breakdown [13, 14].

1.2 Problem Statement

The life expectancy of electrical insulation lies on its sensitivity towards partial discharge occurrence, dielectric stress, thermal stress, etc. Partial discharge has always been a predecessor faults and problem electrical insulation. A partial discharge (PD) is a short release of current caused by the build up of localized electric field intensity. According to BS 60270 "High Voltage Test Techniques-Partial Discharge Measurement", PD is defined as localized electrical discharge that only partially bridge the insulation between conductors and which can or can not occur adjacent to a conductor [15]. PD activities can initiate under normal working conditions in electrical insulation when the insulation is thermally aged or deteriorated due to surroundings or poor workmanship. The PD can propagate and develop into electrical trees, thus leads to problems such as current floating and

insulation breakdown, and affect a device or electrical system. The occurrence of PD can cause devastated problems that will consume high repairing cost and wastage if there is no early and accurate detection [16].

In order to enhance the electrical properties of electrical insulation, many researches utilizing improved technology has been done. Previously, addition of microsized filler or microfiller into a host polymer, for example crosslinked-polyethylene (XLPE) seems to make this happens. However, this conventional microcomposite requires a large amount of microfiller that it can reach up to 50 wt% of the total materials weight to be added into the composites, thus changing the characteristics of the base polymer considerably [17].

Recently, nanostructuring of filler material in electrical insulation has gained attention among researchers. By adding an amount of nanosized-filler, or nanofiller into electrical insulation, the partial discharge characteristics can be improved. Despite of these numerous research it has opens doors into many investigations and getting more exciting.

Other than that, a few researches have been done utilizing natural rubber blends in polymeric insulation. Natural rubber, an elastomer has been extensively studied because of its wide usage in human life. However, the utilization of natural rubber blends nanocomposite including discharge characteristics and interfacial phenomena of polymer-nanocomposites are not clearly understood. Malaysia is among the top 5 rubber producing country in the world. Hence, this could be an advantage of Malaysia to pursue utilization of natural rubber in electrical insulation. This proposed research work will utilize natural rubber-blends polymeric base material of polyethylene (PE) and nanoscale of silica (SiO_2), and organo-montmorillonite (O-MMT) as added materials. With proper preparation, these materials can offer great advantages as electrical insulation.

1.3 Objective of the Research

This study embarks on the following objectives:

1. To investigate partial discharge characteristics of natural rubber blends-nanocomposites as electrical insulating material.
2. To define morphological characteristics of natural rubber blends-nanocomposite after experiencing electrical stress.
3. To find optimum natural rubber blends-nanocomposite compound as electrical insulating material in terms of PD number, surface morphology, and element composition, as the measurement of the degradation level.

1.4 Scope of the Research

Laboratory investigations were carried out on sample of natural rubber blends XLPE and two types of nanofiller; i.e. silica and organo-montmorillonite. The process involved in sample preparation were mastication, extrusion, and compression moulding. Mastication process is a mechanical shearing process using two roll mill to soften the natural rubber as well as reducing its molecular weight and viscosity. Extrusion process is a high volume manufacturing process in which the mixed compounds are melted and formed into a long-tube shape composite. Compression moulding process prepares the sample into the desired thickness appropriate to the PD test.

The samples have undergone partial discharge test and several analyses. In order to study the partial discharge characteristic, the parameters observed are

voltage magnitude and number of partial discharge occurrences. The partial discharge test utilized CIGRE Method II as partial discharge measurement technique and Impedance Matching Circuit (IMC) in its transmission system. The data acquisition was done via LabVIEW™ program. The morphological structures of the samples were analyzed using Scanning Electron Microscopy (SEM), Energy Dispersive X-ray (EDX), and Fourier Transform Infrared Spectroscopy (FTIR) before and after being exposed to high voltage stress.

1.5 Significance of the Research

1. The partial discharge resistance test utilized CIGRE Method II as partial discharge measurement technique and Impedance Matching Circuit (IMC) in its transmission system. LabVIEW™ programs were used as the data acquisition in on-line monitoring and off-line analysis. In order to study the partial discharge characteristic, the parameters observed are voltage amplitude and number of occurrence of partial discharge.
2. Computational simulation studies using *Quickfield* was practical in showing the electric distribution in the test cell and sample in different voltage application, where it shows the surrounding the of the sample which most deteriorated from the PD stress.

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