I hereby declare that I have read through this report entitle "*Thermal Characteristics As Diagnostic Tools To Determine Surface Condition Of Polymeric Insulation Material*" and found that it has complied the partial fulfillment for awarding the degree of Bachelor of Electrical Engineering (Industrial Power)

Signature : ....

Supervisor's Name : Dr. Aminudin Bin Aman

Date : 29/05/2015

THERMAL CHARACTERISTICS AS DIAGNOSTIC TOOLS TO DETERMINE SURFACE CONDITION OF POLYMERIC INSULATION MATERIAL

AHMAD FAIZ BIN AHMAD MORLY

A report submitted in fulfillment of the requirement for the degree of Bachelor of Electrical Engineering (Industrial Power)

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2015

I declare that this report entitle "*Thermal Characteristics As Diagnostic Tools To Determine Surface Condition Of Polymeric Insulation Material*" is the result of my own research excepts as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ....

Name : AHMAD FAIZ BIN AHMAD MORLY

Date : 29/05/2015

DEDICATION

To my truly beloved parents, my late father Ayahanda Ahmad Morly Bin Sawidi and Bonda Faridah Binti Lebai Salleh, and my siblings for their encouragement, supports and understanding towards me. Also goes to everyone that involved indirectly in completing this project, thanks for your love and kindness.

May Allah bless all of us, Amin.

Wassalam.

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In the name of Allah, The Most Gracious and The Most Merciful. Praised be to Prophet Muhammad S.A.W, his companions and those who are on the path as what He preached upon. My everlasting thanks to Allah for granting me patience and hope to complete my final year project and thesis.

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Last but not least, thanks to my entire friends especially who works under same supervisor as me and anybody who involved directly or indirectly for their support, help and advice.

Thank you.

ABSTRACT

High voltage insulation technology has undertaken continuous development and improvement over time, from ceramics to synthetic polymer composite insulating material. Although synthetic polymer composite have several advantages compared to ceramics, but their ageing or long term performances is still lacking. A lot of studies have been conducted by the researchers in terms of their surface condition, ageing performance and leakage current signal as diagnostic tools. In this study, High Density Polyethylene thermoplastic polymer is choosing as material under study. In order to determine the surface condition of the composite insulation material, the test specimen are subjected to tracking and erosion conducted. The test under standard test is complied with International Standard Inclined Plane Tracking Test (IPT) BS EN 60587 : 2007. IPT is used to simulate leakage current on initial and continuous tracking voltage. Instead of LC parameters, this study focuses on identifying its thermal characteristics as analytical tools to determine surface condition of polymeric insulation material. In addition, the thermal profile of the sample during the tracking process is analyzed based on thermal images captured by an IRISYS IRI – 4010 infrared thermal imager. The correlation between visual observations of damage, the leakage current and thermal behaviours of test specimens under constant voltage stressed is investigated. From the results, it can be concluded that thermal characteristic of the tracking and erosion can be used as diagnostic tools to determine its surface condition.

ABSTRAK

Pembangunan teknologi penebat voltan tinggi telah melalui proses penambahbaikan dari semasa ke semasa daripada seramik kepada bahan penebat polimer sintetik. Walaupun polimer sintetik masih mempunyai banyak kelebihan berbanding seramik, namun kelemahan sintetik polimer masih lagi berada di tahap yang rendah terutamanya terhadap keupayaan keadaan permukaannya untuk jangka masa panjang. Pelbagai kajian telah dijalankan oleh pengkaji dengan menggunakan keupayaan permukaan dan isyarat arus bocor sebagai alatan diagnostik. Dalam kajian ini, polimer polietilena berketumpatan tinggi telah dipilih sebagai bahan untuk menjalankan kajian. Untuk menentukan keadaan permukaan bahan penebat komposit, pengujian spesimen dikaitkan dengan ujian pengesanan dan hakisan telah dijalankan. Ujian yang dijalankan adalah di bawah ujian mengikut piawaian antarabangsa ujian satah condong (IPT) BS EN 60587 : 2007. IPT digunakan untuk mensimulasikan arus bocor pada awalan dan berterusam pengesanan voltan. Berbeza dengan parameter arus bocor, kajian ini member tekanan kepada mengenal pasti cirri – ciri terma sebagai alat analisis bagi menentukan prestasi permukaan bahan penebat polimer. Di samping itu, sampel profil haba semasa proses pengesanan dianalisis berdasarkan imej haba yang ditangkap pengimej haba inframerah IRISYS IRI – 4010. Hubungan antara pemerhatian visual kerosakan, tingkah laku semasa dan terma kebocoran specimen ujian di bawah tekanan voltan dikaji. Daripada keputusan yang diperolehi, ciri – ciri terma bagi pengesanan dan penghakisan boleh digunakan sebagai alatan diagnostik untuk keadaan permukaan.

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NOMENCLATURE

HV	High Voltage
BS	British Standard
IPT	Inclined-Plane Tracking
PVC	Polyvinyl Chloride
PE	Polyethylene
PEHD	Polyethylene High-Density
PP	Polypropylene
EPDM	Ethylene Propylene Dienemonomer
FEP	Fluroinated Ethylene Propylene
XLPE	Cross – Linked Polyethylene
P	Density
Ω·m	Resistivity
mS/cm	Conductivity
Mm	Millimeter
kV	Kilovolts
Rpm	Revolution Per Minute
NH4CL	Ammonium Chloride

CHAPTER 1

INTRODUCTION

1.1 Research Background

Electric utilities are now restructured worldwide according to a global de-regulation trend. This will give a new concept that cables and power equipment must be run in suitable way as long as possible. This requires the evaluation of future and the extension of residual life. In most cases, their life might be determined by insulating materials used for them. Organic insulating materials used for that purpose are subject to ageing and degradation. In order to improve quality and lengthen the life expectancy, it is necessary to investigate ageing phenomena. Many researchs have been done on ageing phenomena and mechanisms and it is hard to review all the issues related to ageing of insulating materials and systems [1].

Basically, to determine the surface condition of polymeric and composite materials, the standpoint of their interfacial performance are being reviewed. Insulating materials are divided into two categories that is simple polymers and composites. Simple polymers with some additives are used for power cables, transformers, insulators and rotating machines. They consist of thermoplastics, elastomers, and thermosets. Thermoplastics include polyethylene (PE), polyethylene terephthalate (PET) and polyphenylene sulphide (PPS). Elastomers are silicone, ethylene propylene rubber (EPR) and ethylene propylenedienemonometer (EPDM), for instance, while thermosets are represented by epoxy composite materials with inorganic substances are applied for gas - insulated system (GIs), rotating machines, and insulators. They constitute epoxy/glass, epoxy/silica, and/or alumina, and epoxy/mica system [2].

In practically, ageing processes are complicated and will undergo many stresses at the same time or sequentially. For example those stresses are such as electrical, mechanical, environmental and thermal. Some of the conditions are related with the degradation by tracking and erosion and the loss of hydrophobicity in case of surface properties, and with partial discharge (PD), electrical treeing, water keeing and combined phenomena. PD, electrical treeing and water treeing are of traditional interest, and are now understood~to such a deep degree that insulation systems might be improved with the aid of recent computer technology for calculation of electrical, thermal and mechanical stresses [2].

The relevant factors generally recognized as causing ageing of insulation include thermal stresses, electrical stresses, mechanical stresses, and moisture exposure. Thermal stresses are caused by internal heating due to current overloads and ambient temperature meanwhile the voltage gradient in the insulation is the cause if electrical stresses. Mechanical stresses are caused by manufacturing techniques, centrifugal forces, vibration and assembly configurations. Moisture exposure is an additional crucial cause of lowering dielectric properties that can form a conductive path on the surfaces of solid insulating material or react with it to initiate the chemical reversion. Above all aspects, thermal ageing is the main ageing factor [2,3].

While the gradual ageing becomes critical, the leakage current tends to get bigger and arcing discharge might come about. This can be explained as an sign of an incipient fault that will eventually lead to shorts between adjacent turns. Thus the key issue to anticipate and detect transformer incipient fault is to investigate the insulation performance. In this work, effect of thermal ageing on the dielectric performance of polymeric insulation material has been investigated experimentally [3].

1.1 Project Motivation

Nowadays, a lot of high voltage test was conducted. The high voltage testing used to investigate withstands voltage or other study cases. However, these tests required following the standard to get reliable results, by using the standard test procedure behaviour of insulating material in actual application can be determined. This project is driven by using the inclined plane test according to the international standard BS EN 60587 : 2007. This project also use the infrared camera in order to get the result on the surface of the specimen. The result from this study explain more detail the thermal characteristic of the polymeric insulation material after IPT test have been conducted. Then the result is used for further research and development of insulation material in term of their tracking and erosion performance.

1.2 Problem Statements

The studied of an ageing problem that is related to the polymer insulator has been studied for a few decades. Polymers and composites applied in the utility industry are subjected to multiple kinds of stresses under their normal and possible operating conditions. Insulating materials are then aged due to stresses, mainly represented by thermal, electrical, mechanical, and environmental, for long runs. Polymers and composites used for cables, power apparatus and insulators are aged according to some of the different aspects as stated above. Oxidation, decomposition, pitting, dry-band arcing, erosion, tracking, treeing, and cracking, for instance, represent phenomena of ageing possibly caused by those factors [1]. In this report, the determination of ageing of polymeric insulation material is measured based on its surface condition. There are several method that can be conducted to get the result but in this report, the appropriate method for conducting the ageing test was determined by choosing the inclined - plane test to get the satisfied result. In getting the result and effect to the insulation, the thermal endurance in ageing insulation was being analyzed. Furthermore, the thermal characteristic of the insulation material and the specimen change of temperature were also being analyzed to observe the physical change of the specimen. This method is carried out exactly according to the international standards of BS EN 60587.

1.3 Objectives of Study

The objectives of this project are :

1. To apply a new method by using thermal characteristic as diagnostic tool for polymer surface condition
2. To observe the thermal characteristic on the surface material under test based on its severity.
3. To show the correlation of thermal condition of polymeric material with voltage value based on thermal characteristic.

1.4 Scope of Works

The scope of this project are :

1. The thermal characteristic as diagnostic tool to determine the surface condition of polymeric material.
2. The new method that need to adopt standardized test according to incline – plane test (IPT) according to international standard of BS EN 60587.
3. The selected polymeric material that was chosen to run this test is HDPE.
4. The manipulated variable is the voltage value meanwhile the flow rate of the contaminant and the type of contaminant used are fixed.

1.5 Report Outline

The report is organized as follows :

Chapter 1 : An overview of the research project in whole. This chapter describe the research background, problem statements, objectives, scopes and outline report of the project.

Chapter 2 : Describes about the literature review related to this project, including theory of high voltage insulation and types of insulation in electrical system. Beside that this chapter also explained about temperature measuring units, tracking and erosion test, and incline-plane test.

Chapter 3 : Consists of the system design and the experimental set-up of incline-plane test. In addition the procedure taken throughout this experiment also discussed in this chapter.

Chapter 4 : Discuss about the results and discussion of this experiment. Consist of analysis of thermal characteristics of the specimen and followed by analysis of leakage current behaviour related to the surface tracking phenomenon.

Chapter 5 : Consist of conclusion of this study and some suggestions for future work.

CHAPTER 2

LITERATURE REVIEWS

2.1 Introduction

Insulation is a material that having great dielectric properties utilized on wire parts as a part of link as a rule as immediate covering on conductors. It is an important part of the wire. Insulation choice is controlled by various factors, for example, stability and long life, dielectric properties, resistance to high temperature, resistance to moisture, mechanical strength and flexibility. It is important to choose a cable with the kind of protection that completely meets the requirements of the application. There are a few applications where the wire must be resistance to fluids or chemicals. The best insulating material for an application is chosen focused around the requirements. The selection may include test of numerous different performance properties. Thermoplastic and thermoset are two significant subdivisions of the large group of insulation materials. The division is based on their behaviour to high temperature. Thermoplastic are materials which are softened by high temperature. The material will become rigid again upon cooling. This procedure of moulding and firming these materials by heating and cooling can be repeated. Thermoset are materials, which are softened once heated amid one phase of preparing. They can be moulded and extruded at this state after which they are cured. In the wake of finishing the setting process, they cannot be softened again on consequent heating [4].

2.2 Insulation In Electrical System

A non-conducting material that provides electric isolation of two parts at different voltages. To accomplish this, an insulator must meet two primary requirements : it must have an electrical resistivity and a dielectric strength sufficiently high for the given application. The secondary requirements relate to thermal and mechanical properties. Occasionally, tertiary requirements relating to dielectric loss and dielectric constant must also be reserved. A complementary requirement is that the required properties not deteriorate in a given environment and desired lifetime. Electric insulation is generally a vital factor in both the technical and economic feasibility of complex power and electronic systems. The generation and transmission of electric power depend critically upon the performance of electric insulation, and now plays an even more crucial role because of the energy shortage [5].

Flexible hydrocarbon insulation is generally either thermoplastic or thermosetting. Thermosets are initially soft, and can be extruded by using only pressure. Following heat treatment, when they return to ambient temperature, they are tougher and harder. After thermosetting, nonrubber thermosets are harder, stronger, and have more dimensional stability than the thermoplastics. Thermoplastics are softened by heating, and when cool become hard again. They are heat-extruded [4].

Cellulose paper insulation is neither thermoplastic nor thermosetting. It is widely used in cables and rotating machinery in multilayers and impregnated with oil. It has a relatively high dielectric loss that hardly decreases with decreasing temperature, which rules it out for cryogenic applications. Because of its high dielectric strength, the high loss has not been a deterrent to its use in conventional ambient-temperature applications. However, the high dielectric strength deteriorates quickly if moisture permeates the paper [4].

Rigid insulation includes glass, mica, epoxies, ceramoplastics, porcelain, alumina, and other ceramics. Rather than being used to insulate wires and cables, except for mica, these materials are used in equipment terminations (potheads) and as support insulators (in tension or compression) for overhead lines whose primary dielectric is air. These rigid structures must be shock-resistant, be relatively water-impervious, and be able to endure corona discharges over their surfaces [4].

2.3 Types Of Polymeric Insulation In Electrical System

2.3.1 Polyvinyl Chloride (PVC)

PVC compounds can be formulated to provide a broad range of properties from the standpoint of electrical, physical and chemical characteristics. PVC has high dielectric strength and good insulation resistance. It is inherently tough and resistant to flame, moisture, and abrasion. Resistance to ozone, acids, alkalies, 21 alcohols, and most solvents is also adequate. Compounding can impart resistance to oils and gasoline. PVC exhibits little or no water absorption. Since it is chlorinated, PVC also possesses natural flame retardant qualities. Based on the specific formulation, temperature ratings range from 60° to 105° C [5].

2.3.2 Polyethylene (PE)

Polyethylene (PE) is a great insulation in terms of electrical properties. It has a low and a stable dielectric constant over all frequencies, a high insulation resistance and resistance to chemicals and moisture. In terms to flexibility, polyethylene can be stiff to very hard, depending on molecular weight and density. As the density increases, the hardness, yield strength, stiffess, heat and chemical resistance additionally increment. Carbon black or a suitable inhibitor is added to screen out ultra-violet (UV) radiation, because UV radiation can degradeboth physical and electrical properties [6].

2.3.3 High Density Polyethylene (HDPE)

A linear polymer, High Density Polyethylene (HDPE) is prepared from ethylene by a catalytic process. The absence of branching results in a more closely packed structure with a higher density and somewhat higher chemical resistance than LDPE. HDPE is also somewhat harder and more opaque and it can withstand rather higher temperatures (120° Celsius for short periods, 110° Celsius continuously) [6].

2.3.4 Polypropylene (PP)

Polypropylene (PP) is similar in electrical properties to polyethylene [14]. This material is primarily used as insulation, and it is harder than polyethylene that makes it suitable for thin wall insulations. It has excellent insulating properties and is extremely light weight [6].

2.3.5 Fluroinated Ethylene Propylene (FEP)

It is extrudable in a manner similar to PVC and polyethylene. It has low dielectric constant and is flame and ignition resistant. Also, it is chemically inertness and has a service temperature of 200°C [6,7].

2.3.6 TFE Teflon

TFE Teflon is extrudable in a hydraulic ram type process. Lengths are limited due to the amount of material in the ram, thickness of the insulation, and preform size. TFE must be extruded over silver or nickel coated wire. The nickel and silver coated designs are rated at 260°C and 200°C respectively [7].

2.3.7 Silicone

It is a very soft insulation that has a typical temperature range from -80°C to 250°C. It has excellent electrical properties, ozone resistance, low moisture absorption, weather resistance and radiation resistance. It has low mechanical strength and poor scuff resistance. Silicone rubber burns slowly and forms a nonconductiveash. This in turn can maintain the integrity of the electrical circuit [7].

2.3.8 Cross-Linked Polyethylene (XLPE)

It is rated up to 150°C [17]. Cross-linking changes thermoplastic polyethylene to a thermosetting material which has greater resistance to environmental stress such as cracking, cut-through, ozone, solvents and soldering than either low or high density polyethylene or non-cross-linked polyethylene. It can be cross-linked either chemically or irradiated. [6,7]. Table 2.1 below show the typical properties of some insulating materials.

Table 2.1 : Typical Properties of Some Insulating Materials [7]

	PVC	PE	XLPE	FEP	TFE	SBR	Silicone Rubber
Specific Gravity	1.37	0.92	1.20-1.40	2.20	2.15	1.40	1.24
Tensile Strength (PSI x 1000)	1.5-3.8	1.4-2.4	1.8-2.5	2.3-3.1	2.6-6.0	0.5-1.5	0.6-1.2
Elongation, %	200-375	350-550	250-400	200-330	200-500	200-400	125-400
Service Temp. Range, °C	-55 to +105	-20 to +75	-65 to +150	-70 to +200	-70 to +260	-40 to +75	-70 to +200
Dielectric Strength V/MIL -.040" WALL	800	1050	700	950	950	500	400
Dielectric Constant 60 Hz to 1MHz	5.0	2.26	3.0	2.15	2.1	4.0	3.1
Water Absorption, % in 24 Hrs	<0.75	<0.02	<0.01	<0.01	<0.01	<1.0	<1.0
Flame Resistance	Self-Extinguishing	Supports Flame	Slow Burning	Non-Flammable	Non-Flammable	Slow Burning	Slow Burning
Ozone Resistance	Excellent	Good	Good	Excellent	Excellent	Excellent	Excellent
Flexibility	Good	Good	Good-Fair	Good	Good	Excellent	Excellent
Abrasion Resistance	Good	Good	Excellent	Excellent	Excellent	Poor	Poor

2.4 High Density Polyethylene (HDPE) Polymer

A linear polymer, High Density Polyethylene (HDPE) is prepared from ethylene by a catalytic process. The absence of branching results in a more closely packed structure with a higher density and somewhat higher chemical resistance than LDPE. HDPE is also somewhat harder and more opaque and it can withstand rather higher temperatures (120° Celsius for short periods, 110° Celsius continuously). Table 2.2 below shows the advantages and disadvantages of HDPE.

Table 2.2 : Advantages and Disadvantages of HDPE

ADVANTAGES	DISADVANTAGES
Low cost	High thermal expansion
- C	Poor weathering resistance
Moisture resistance	Subject to stress cracking
Good chemical resistance	Difficult to bond
Food grades available	Flammable
Readily processed by all thermoplastic methods	Poor temperature capability

2.5 Thermal Characteristics

A polymer clay or mouldable is over a certain temperature known as thermoplastic. Moreover, thermoplastic comprise of high molecular weight polymer chains and interfaced through intermolecular powers [8]. As indicated by this case, that allows the thermoplastic material for forming as the relationship between atoms expanded to restore mass properties amid cooling methodology. Thermosetting material was not dissolving when it achieves its thermal limit, however it w c, through a chemical reaction. Typically thermoset material was utilized to cure and is design to be formed into their last form, or utilized as the epoxy resin. Additionally, thermosetting materials are more suitable as compounds utilized as a part of semiconductor and integrated circuits. Besides, in the wake of thermosetting material hardens, this materials cannot be heated and melted to structure an alternate shape. Thermosetting polymer can vary with thermoplastic polymers are regularly created in pellet and formed into the shape of the final product by melting and pressing or injection moulding [9].

2.6 Tracking and Erosion Test

Ageing process of polymeric insulation is the fundamental driver to the tracking or erosion and flashover in contaminated solutions at normal working voltage. Accordingly, the mechanism of polymeric insulator and the elements that impacts the performance of polymer material against ageing need to be studied. The most ideal approach to study about the performance of the insulation material is to put it at the genuine condition [7]. Notwithstanding, the primary issue that the researcher needs to face is the time factor field observing that will set aside quite a while for the polymer demonstrates the impact. This gave a thought to researcher to do the test under the standard international test that comprise a brief time of time. In the international standard, the two sorts of test are sent which is incline-plane test and salt and fog chamber test [6].

2.6.1 Inclined - Plane Test

The incline-plane test is one of the common test methods to evaluate the tracking and erosion of the polymeric insulation material [8]. This test has the guideline procedure according to the international standard. The standard that related to this test is the British Standard BS EN 60587:2007. According to this standard, the circuit of this test will set up as shown in the Figure 2.2.

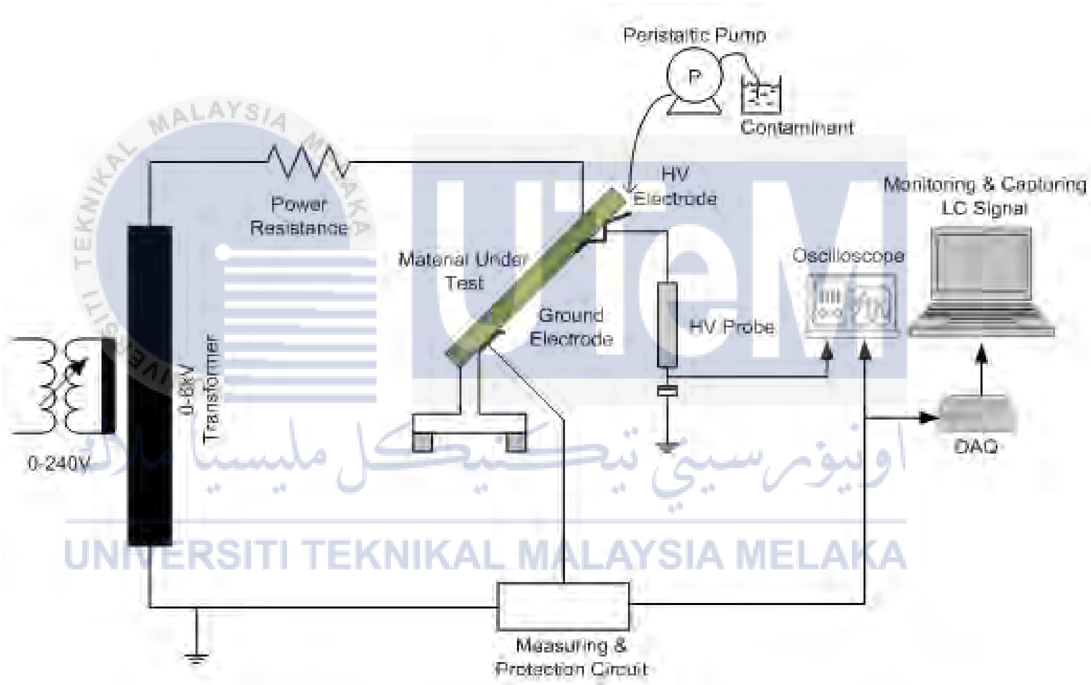

Figure 2.1 : Schematics Inclined - Plane Test Circuit [7]

As indicated by the standard, it comprises of two method. For the first method, the voltage is changed from 0 V to 6 kV and the impact of the leakage current is observed. At that point for the second method, the voltage was set up from 250v and the increasing of the voltage value is multiply by the addition of 250v until the failure happen.

2.6.2 Salt and Fog Test

The salt fog chamber size used is 1.1 x 1.1 x 1.0 m^3 and chamber roof has a slope of 15 degrees. Salt fog created by ultrasonic vibrating and sprayed with a rate of 9 m^1/m^2 min on examples. To examine the progress of ageing, contamination is a mist of salt with 2 ms/ cm and 8 ms/ cm is used and the electrical stress is subjected to 0.5 kV/ cm [7]. The artificial salt-fog generator was separate the salt-fog to the test specimen. The voltage meter was used as an indicator of the increase voltage value when the leakage current occur. The transformer that was utilized here is step up transformer that comprise the 110 V at the primary and 25 kV at the secondary. Then again, the transformer can be changed in the voltage value of 240v. After that, current leakage and discharged current measured over a 1 kΩ is put in series with the specimen under test [8]. During salt-fog test, the discharge current pulses of 0-5 mA and 5 mA respectively measured because the current pulses are more effective relief to the destruction of the material.

2.7 Temperature Measuring Units

Temperature measuring unit is the equipment used to measure the temperature over the span of this study. In this project there are two devices that are acquired to accomplish the goals set. Instruments that can be highlighted here is that the infrared pyrometer and IRI-4010 thermal imager. Both of these tools have a advantages and disadvantages of every, and the data can be seen below. These two gadgets likewise must be pleased with similitude in the resulting temperature of the recruitment process. Among equality picked up here is that both of these tools use infrared light amid the reading procedure. Additionally, the instrument utilized has a low weight and simple to handle. The instrument also has a display screen to demonstrate the values acquired sometime during this study.

2.7.1 Pyrometer

Pyrometer, an instrument for measuring temperature. Despite the fact that the term pyrometer is for the most part considered to apply to instruments that measure high temperatures just, a few pyrometers are intended to measure low temperatures. Two basic sorts of pyrometers are the optical pyrometer and the radiation pyrometer. A heated object gives off electromagnetic radiation. If the object is sufficiently hot, it will give off visible light, ranging from dull red to blue-white. Even if the object is not hot enough to glow, however, it gives off infrared radiation. An optical pyrometer determines the temperature of a very hot object by the color of the visible light it gives off. The color of the light can be determined by comparing it with the color of an electrically heated metal wire. In one type of pyrometer, the temperature of the wire is varied by varying the strength of the current until the operator of the instrument determines that the color of the wire matches the color of the object. A dial, operated by the current that heats the wire, indicates the temperature. A radiation pyrometer determines the temperature of an object from the radiation (infrared and, if present, visible light) given off by the object. The radiation is directed at a heat-sensitive element such as a thermocouple, a device that produces an electric current when part of it is heated. The hotter the object, the more current is generated by the thermocouple. The current operates a dial that indicates temperature. Figure 2.2 shows the image of pyrometer [9].

Figure 2.2 : The pyrometer used to take temperature reading [9]

2.7.2 IRI-4010 Thermal Imager

The IRI 4010 is an innovative thermal imager product, which offers outstanding imaging and temperature measurement performance together with the traditional IRISYS features of flexibility, ease of use, and minimal cost of ownership. The equipment has some important specifications to be utilized as a correlation with other supplies. Among the things that can be highlighted is that, as temperature reach, radiometry emissivity correction and precision. After that, equipment has a really decent temperat - C. With the information provided, it is clear that the equipment has a high sensitivity. Moreover, this equipment additionally has a convenient and simple radiometry for the purpose of diagnosis. This is because the equipment is outfitted with mocable cursors temperature measurement and calculation is also equipped with temperature changes [10].

Next, this equipment also provided with suitable emissivity correction. The emissivity that was provided for this equipment is selectable from 0.1 until 1.0 with the 0.01 decimal places with the ambient temperature compensation. This equipment also has good accuracy in the process of data related to temperature. To get more accurate temperature raeding, imaging should be in high concentration and to get a good reading, rotate the lens clockwise to get a good focus until the distance raches infinity, and if the lens is rotated anticlockwise direction, it will give display up close reach 30cm. Besides, recover the lens so it can display a good image definition and significant contrast around the object. Figure 2.3 shows the IRISYS IRI – 4010 thermal imager.

Figure 2.3 : IRISYS IRI – 4010 Thermal Imager

2.8 Summary of Literature Review

Figure 2.4 shows the summary of literature review of this study.

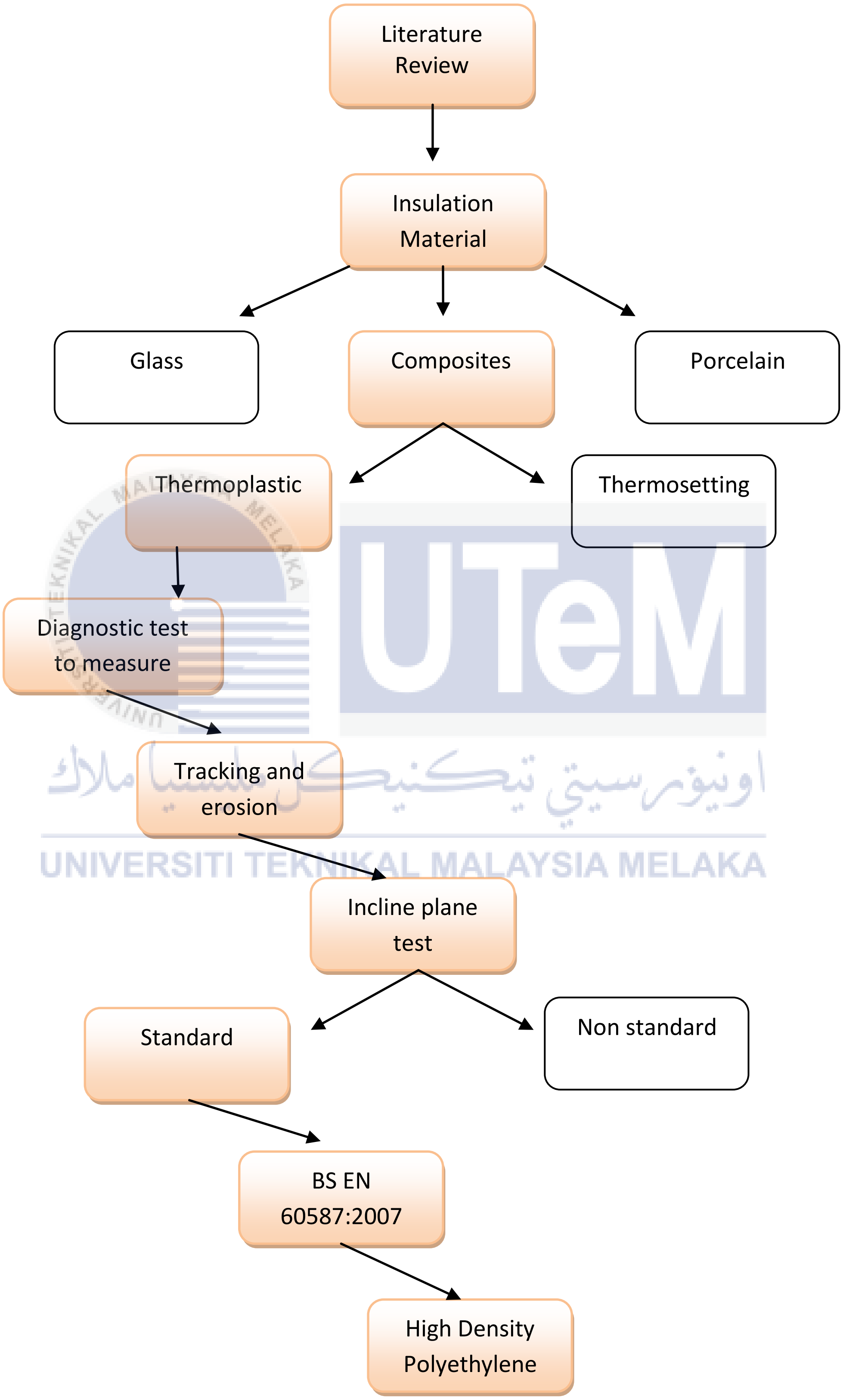

Figure 2.4 : Summary of Literature Review

CHAPTER 3

METHODOLOGY

3.1 Introduction

The experiment will be carried out using BS EN 60587:2007 as standard provides test methods for determining the ageing performance of polymeric insulation material. The polymer used in this experiment is high density polyethylene (HDPE). Based on international standard BS EN 60587:2007, it has two test methods and the method used in this experiment is method one that is constant tracking voltage.

3.2 Tracking and Erosion Test

Tracking is the process that is produce by an electrical discharge that happen on test specimen contaminated surfaces. This process carried on the surface formed by the slump testing specimen. Electrical erosion is quite utilized as electrical insulating materials by the action of an electric discharge and it may show up as surface erosion. These physical changes are associated with an increment of leakage current on the surface of the insulation. Adjacent to that, this is also related with the level of contaminaton, curved activities, pollution and ageing flashover are also nearly associated with the flows on the surface [10]. Electrical insulation materials are utilized under severe ambient conditions test method for assessing resistance to tracking and erosion. In addition, this standard is similar to IEC 60587, ASM 2303 and DIN IEC 60587. However, this test should be conducted to detect a performance of tracking and erosion, top materials, recording of the time taken to dorm a platform between the electrodes or the time needed to erode through the rest specimen materials.

3.2.1 Inclined Plane Tracking Test Set-Up

In order to carry out the test successfully and get the results according to standards, test should firmly fulfil with the international standard processes. Trial set-up with the test parameters including test methods, specimen dimensions, preparation of contaminants, electrical equipment, and procedures for conducting the test set out in international standards. Figure 3.1 shows the schematic diagram of incline plane tracking test. The complete schematic diagram experimental setup based on BS EN 60587:2007 [11] consists of :

1. Standard Incline Plane Tracking circuit complies with BS EN 60587:2007 [6].
2. Leakage current measurement and data acquisition system [11].
3. Change in temperature of the test substance for 6 hours [11].

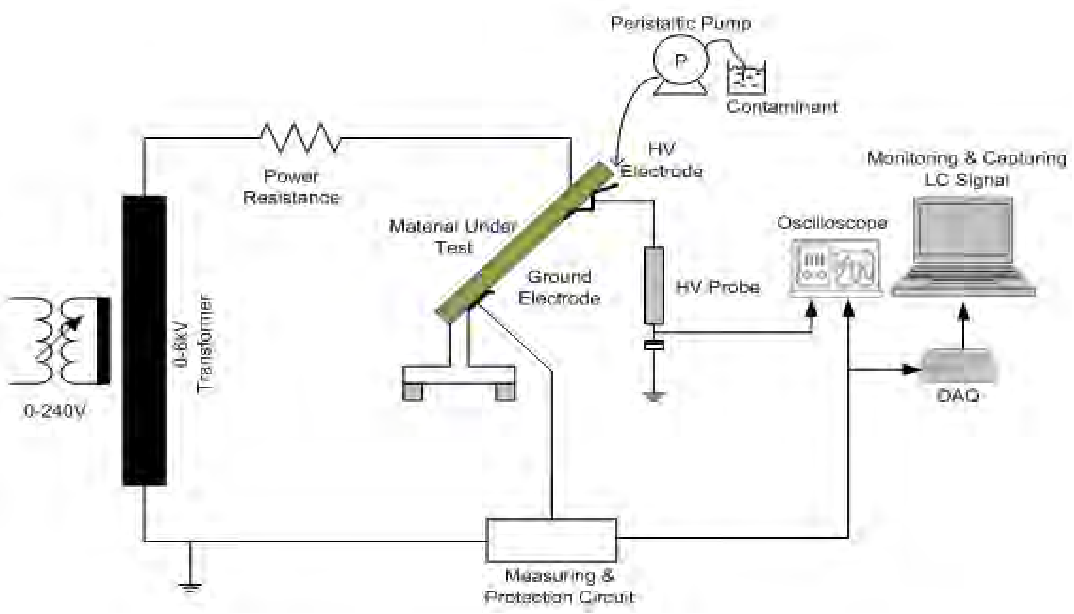

Figure 3.1 : Schematic Diagram of Incline Plane Tracking Test [12]

3.2.1.1 Electrical Apparatus

A variable high voltage transformer single phase 0 – 6 kV – 1A at a frequency of 50 Hz is used as a power supply for the high voltage test system tends to zero. After that, the 200W high power resistor connected to the terminal voltage of the high voltage electrode prior to the advantages associated with the test material under test. Figure 3.2 shows the schematic circuit diagram of incline plane tracking test while Figure 3.3 shows the incline plane tracking test set up.

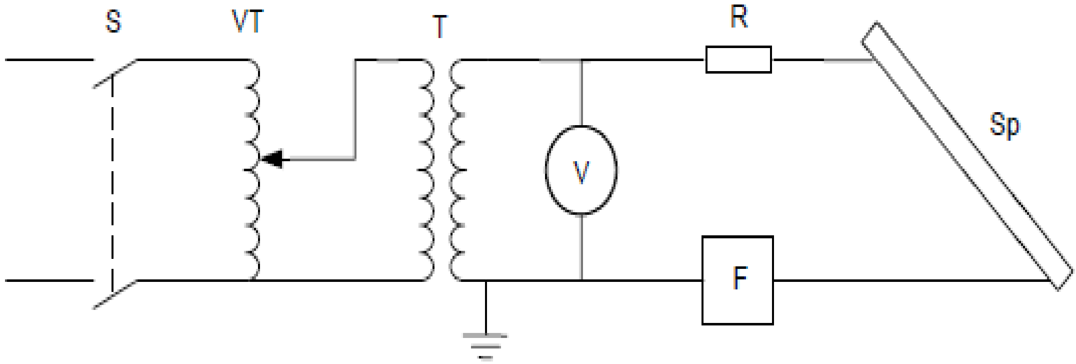

Figure 3.2 : Schematic Circuit Diagram of Incline Plane Tracking Test [11]

Figure 3.3 : Incline Plane Tracking Test Set Up

3.2.1.2 Electrode

Flat samples specimens with a size of 50 mm x 120 mm and 6 mm thick mounted on the bottom at an angle of from the horizontal with supporting examples. Next, stainless steel top and bottom electrodes were placed on the specimen mounted drilled 50 mm apart, and the electrode dimensions specified in the standard. In addition, prior to placing stainless steel electrodes, eight layers of filter paper are placed between the electrodes and the specimen to act as a reservoir for uniform flow contamination [11]. Figure 3.4 shows the image of specimen being attached to electrode.

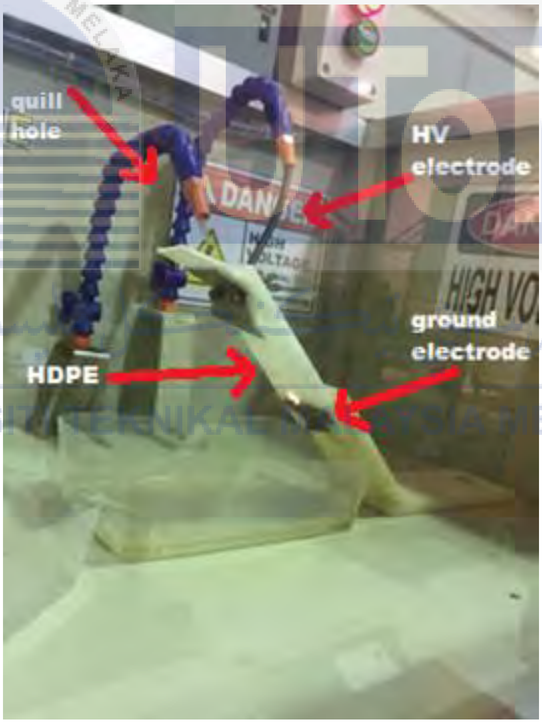

Figure 3.4 : Specimen Attached With Electrode

3.2.1.3 Contaminant

A solution consisting of 0.1% pollutants by mass of ammonium chloride (NH_4CL) in distilled water. To ensure salt water specimens out easily and rapidly to the surface of the polymeric specimen, non ionic wetting agent Triton X-100 (isooctylphenoxypolyethoxythanol) to 0.02% by mass is used in the solution. To confirm that the conductivity is in the range of a particular test, the conductivity of contaminant is measure using a conductivity meter test before each series of tests and the value of admittance for this salt water solution was set at 2.53mS/cm. The contaminant must have a resistivity of Ω Ω C. Beside that, preparation of the solution cannot be more that four weeks [11]. Figure 3.5, 3.6, 3.7, and 3.8 below shows the apparatus to make the contaminant.

Figure 3.5 : Distilled Water

Figure 3.6 : Ammonium Chloride

Figure 3.7 : Triton X – 100 Solution

Figure 3.8 : Contaminant With Conductivity of 2.53 mS/cm

3.2.1.4 Peristaltic Pump

A peristaltic pump is used to supply the pollution solution by dropping it into the paper filter and flow uniformly throughout the specimen between two electrodes. Pollutants are not allowed to flow from the side or on the filter paper. Rate pollutants flow through PVC tubes within a certain range is controlled by the speed of the peristaltic pump before voltage application and this peristaltic pump was set at 6 rpm with hose diameter 0.86mm x 0.86mm. Pollutants flowing right through it will bridge the electrodes with filament moisture. After that, tracking and erosion tests comply with BS EN 60587:2007 [11]. Figure 3.9 shows the image of peristaltic pump.

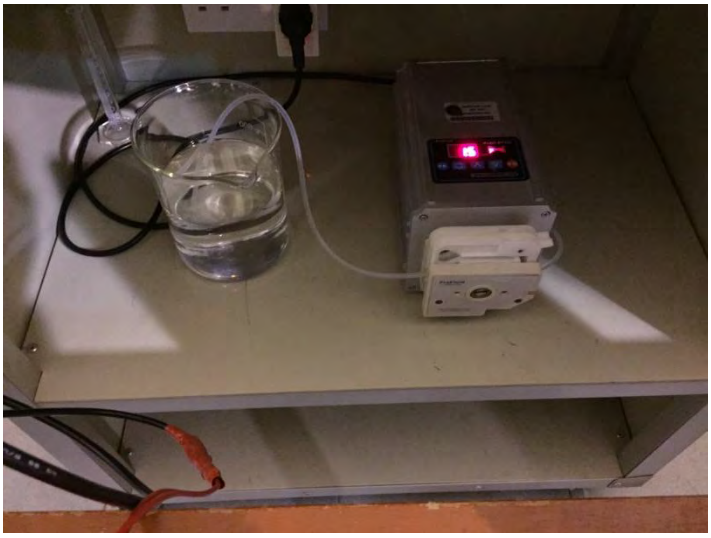

Figure 3.9 : Peristaltic Pump

3.2.1.5 Ventilation

The test chamber shall be equipped with a ventilation to allow an exhaust of steam and gaseous decomposition products. The ventilation of the test chamber should be moderate and constant to avoid permanent condensation of water. Direct airflow across the test specimens shall be avoided [11].

3.2.1.6 Variables

A steady, non-stop electrical discharge activity on the surface of the test material can be controlled by varying the experimental parameters such as voltage stresses, contaminant flow rate and resistance levels. Voltage is chosen as the manipulated variable in this project. The voltage used is 3.5 kV, 4.5 kV and 5.5kV.

3.2.1.7 Security

For security purposes and final determination criteria, 60 mA fuse over current protection device installed in a series of examples of potential low side. It will operate as 60 mA ± 6 mA or more has been going on the high voltage circuit for 2 to 3 seconds [11].

3.2.1.8 Methods

In this IPT test, method 1 has been chosen to verified the effect of surface tracking and erosion performance in HDPE material under standard BS EN 60587. The test parameter has been followed by referring table 3.1 and the test voltage of 3.0kV to 3.75kV is selected. 3 different tests are conducted with the different parameters. The parameters that have been varied are preferred voltage (3.5kV, 4.5kV, 5.5kV). The fixed variables are the / Ω The IPT test is conducted for 6 hours according to standard. Then, the surface tracking and erosion performance is observed during the experiment occurred and the result is compared. The criterion B is chosen to describe the end-point if there passes or fails the test.

3.3 Preparing the specimen for the Incline – Plane Test

The material that was used in this study is High Density Polyethylene (HDPE). HDPE is known for its large strength-to-density ratio. The density of HDPE can range from 0.93 to 0.97 g/cm^3 or 970 kg/m^3. Although the density of HDPE is only marginally higher than that of low-density polyethylene, HDPE has little branching, giving it stronger intermolecular forces and tensile strength than Low Density Polyethylene (LDPE). HDPE has little branching, giving it stronger intermolecular forces and tensile strength than LDPE. The difference in strength exceeds the difference in density, giving HDPE a higher specific strength. It is also harder and more opaque and can withstand somewhat higher temperatures (120 °C/ 248 °F for short periods, 110 °C /230 °F continuously). In order to make in form that required based on the standard BS EN 60587, this polymer need to go to the moulding process. This process is done by using the hydraulic hot moulding with the metal mould dimension that consists of 6 x 6 mm x 120 mm x 50 mm as shown in Figure 3.10. This process was done at Faculty of Manufacturing (FKP).

Figure 3.10 : Metal Mould Dimension

Firstly, the leftover that contain at the metal mould must be removed by using scrapers and wire brush that are provided in the laboratory. After that, rinse the metal mould with the cleaning material as shown in Figure 3.11 and wipe all the surface of the metal mould until the solution is gone and place the metal mould between two metal plate and. Cover the bottom of the metal mould with aluminium foil. The function is to ensure the specimen surface in perfect condition.

Figure 3.11 : Cleaning Material

Next step is to make HDPE in solid state from raw material. To make HDPE in solid state as shown in Figure 3.12, measure 36 gram of its raw material and put it in the space provided at the metal mould. The raw material of HDPE is shown in Figure 3.13. Afte / C as shown in Figure 3.14. Beside that, the pressure is set at 100 psi and the pressure only set once even for pre-heating, press-heating and cooling process. In this p C approximately within 2 minutes.

Figure 3.12 : Solid State HDPE

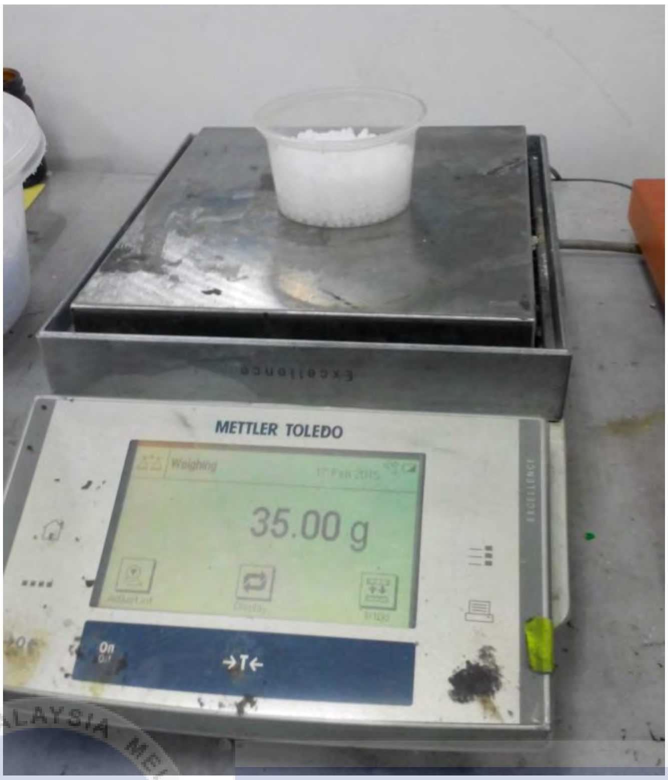

Figure 3.13 : Raw Material of HDPE 35gram

Figure 3.14 : Heat Compress Machine

3.4 Temperature Reading By Using an IRISYS IRI-4010 Thermal Imager

In this work, IRI – 4010 were used to obtain readings of temperature changes that occur during the process of Incline specimen-plane test run. This equipment has been used in a proper manner to get a more accurate temperature reading. In addition, this equipment can also produce temperature spectrum to facilitate the process of analysing and looking at the change in temperature obtained by the experiments conducted. Figure 3.15 shows the image of IRISYS IRI-4010 Thermal Imager.

Figure 3.15 : IRISYS IRI – 4010 Thermal Imager

3.5 Overall Flowchart of Methodology

Figure 3.16 below shows the overall flowchart of methodology of this project.

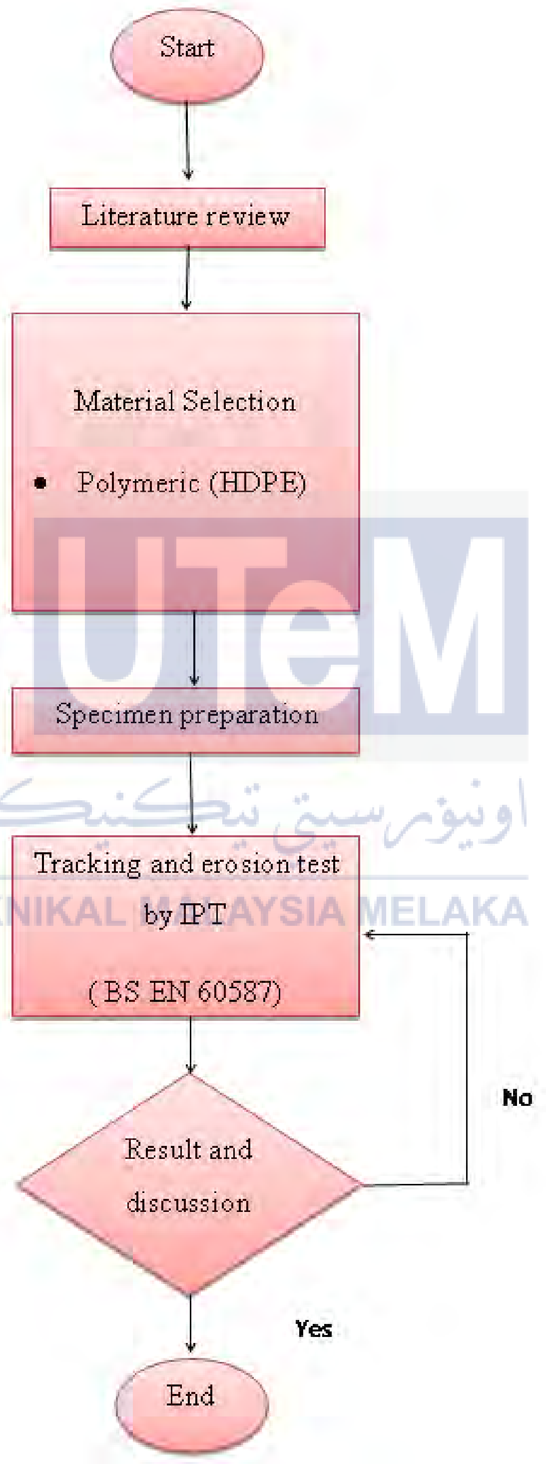

Figure 3.16 : Overall Flowchart of Methodology

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discuss the results obtained through the studies that have been made in accordance with established procedures of BS EN 60587 for thermal characteristic of HDPE during conducting this study. The results were obtained by using IRISYS – 4010 Thermal Imager. The results of this learning is to study the temperature changes that occur on the surface of the specimen during conducting this study. Temperature changes were studied by producing temperature spectrum and the information were collected by using IRISYS – 4010 thermal imager software. Not only that, the image that was captured by the imager is the image from the underneath surface of the specimen or at the surface that contaminant flow. In addition, this chapter also shows the leakage current pattern. The leakage current pattern has to be extracted through the use of oscilloscope meters provided in the laboratory. Beside that, during this study there are several things that need to be considered as constant variable such as the surrounding temperature, type of material, frequency and the flow rate of the contaminant. For this study the flow rate of the contaminant used is 0.3 ml / min or 6 rpm. Next is the material that is used

C.

4.2 The Temperature Image and Spectrum Of The Specimen

This section discusses the thermal characteristics of HDPE at certain time during conducting this experiment. There were three sets of test were taken. Each session last for 6 hours according to International Standard BS EN 60587. The manipulated variable used in this experiment is voltage. For the first set of the experiment, the procedure were following the International Standard BS EN 60587 that is voltage used is 3.5 kV while the second set is 4.5 kV and the third set is 5.5 kV. During six hours of the experiment, there were 12 images were captured using IRI–4010 thermal imager to determine its thermal characteristic. Each image captured within 30 minutes interval.

Figure 4.1 – 4.12 below show the thermal characteristic of HDPE during the first set of test. The voltage used in this test is 3.5 kV. Figure 4.1 shows the thermal characteristic of HDPE at 30 minutes. The range of

C.

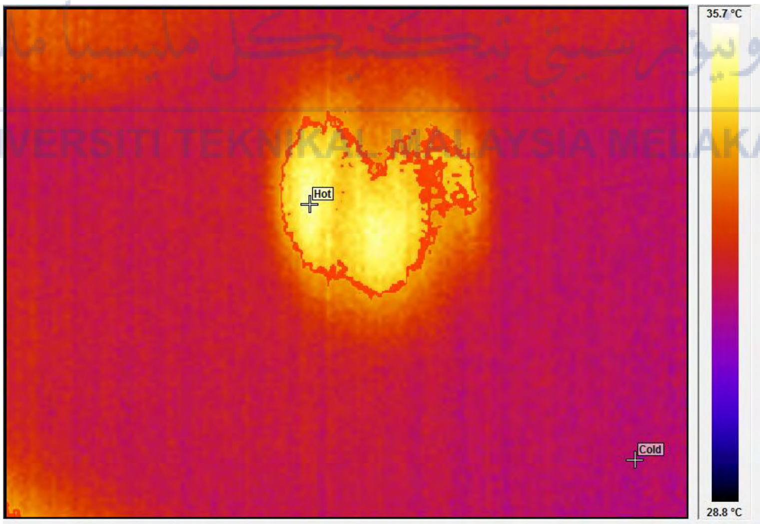

Figure 4.1 : Thermal Characteristic of Specimen at 30 Minutes

Figure 4.2 shows the thermal characteristic of HDPE at 60 minutes. The range of

C. The temperature is slightly increase from the previous temperature b C.

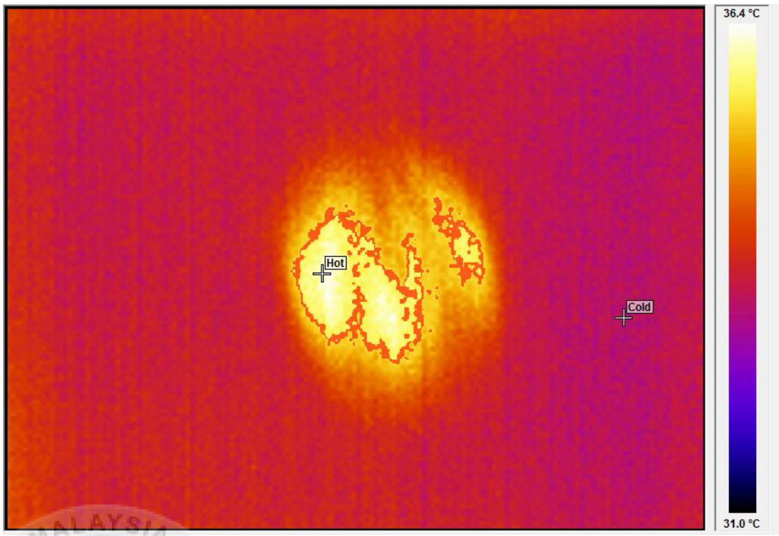

Figure 4.2 : Thermal Characteristic of Specimen at 60 Minutes

Figure 4.3 shows the thermal characteristic of HDPE at 90 minutes. The range of C and the highest temperature spotted at the specimen is 36 C.

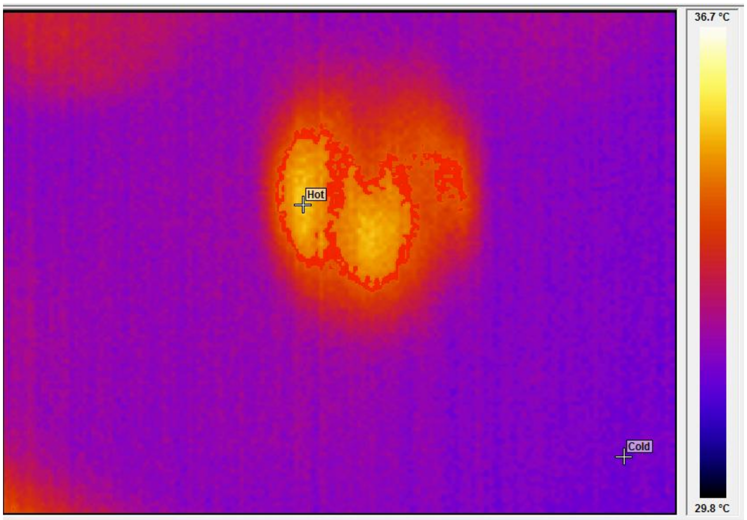

Figure 4.3 : Thermal Characteristic of Specimen at 90 Minutes

Figure 4.4 shows the thermal characteristic of HDPE at 120 minutes. The range of temperature are from 30.0

C.

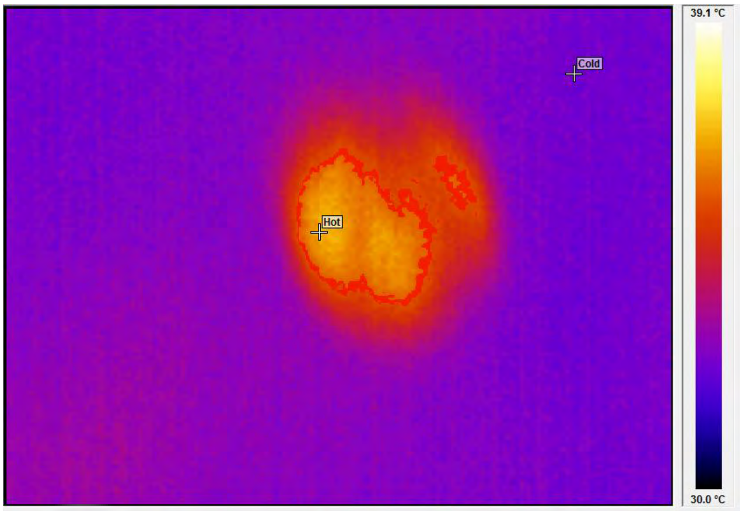

Figure 4.4 : Thermal Characteristic of Specimen at 120 Minutes.

Figure 4.5 shows the thermal characteristic of HDPE at 150 minutes. The range of

C.

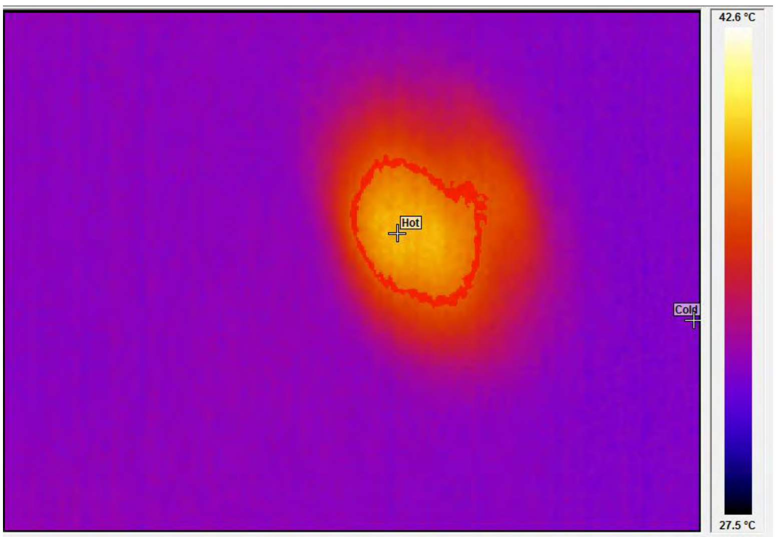

Figure 4.5 : Thermal Characteristic of Specimen at 150 Minutes

Figure 4.6 shows the thermal characteristic of HDPE at 180 minutes. The range of

C. The temperature is slig C.

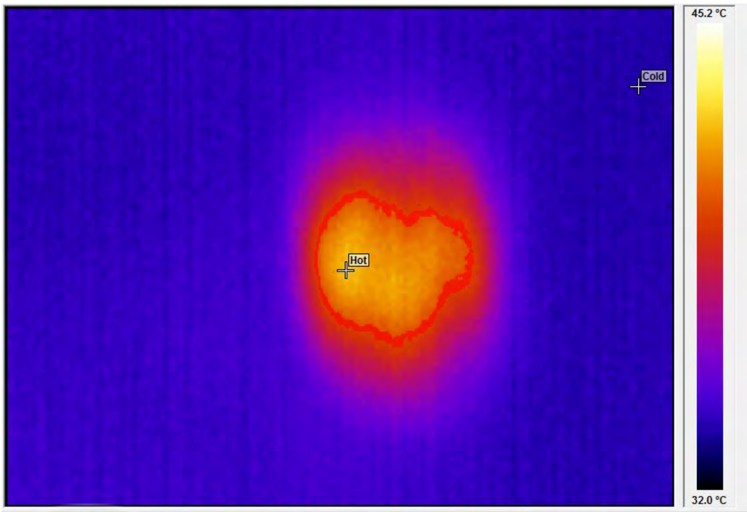

Figure 4.6 : Thermal Characteristic of Specimen at 180 Minutes.

Figure 4.7 shows the thermal characteristic of HDPE at 210 minutes. The range of C and the h C.

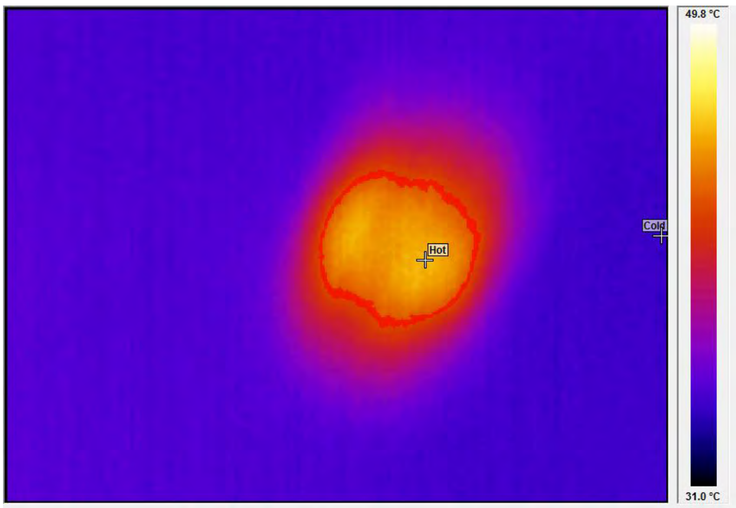

Figure 4.7 : Thermal Characteristic of Specimen at 210 Minutes.

Figure 4.8 shows the thermal characteristic of HDPE at 240 minutes. The range of

C.

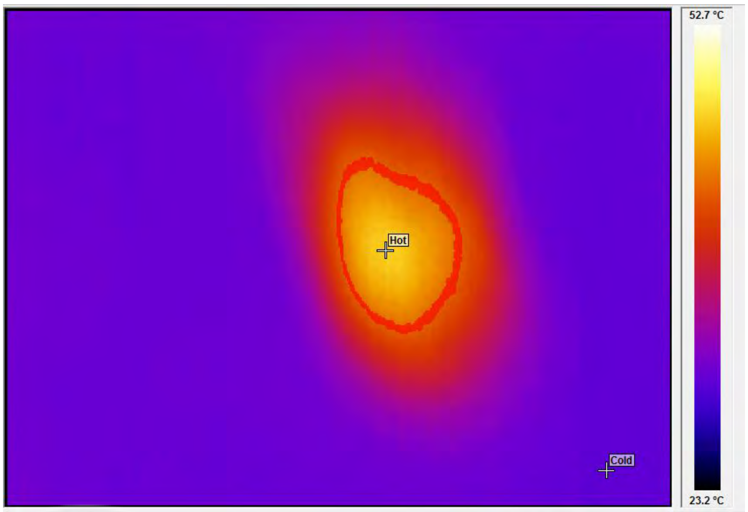

Figure 4.8 : Thermal Characteristic of Specimen at 240 Minutes

Figure 4.9 shows the thermal characteristic of HDPE at 270 minutes. The range of

C. The temperature is slightly increase from the previ C.

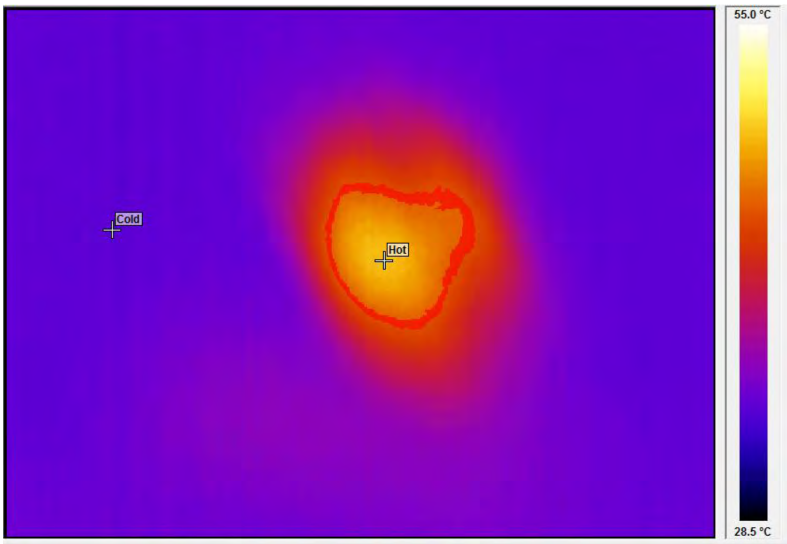

Figure 4.9 : Thermal Characteristic of Specimen at 270 Minutes

Figure 4.10 shows the thermal characteristic of HDPE at 300 minutes. The range of

C and the highest temperature spotted at t

C.

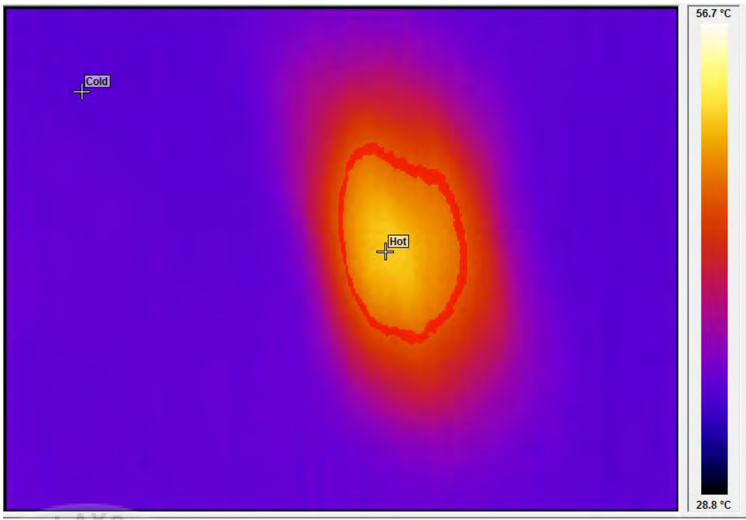

Figure 4.10 : Thermal Characteristic of Specimen at 300 Minutes

Figure 4.11 shows the thermal characteristic of HDPE at 330 minutes. The range of

tem

C.

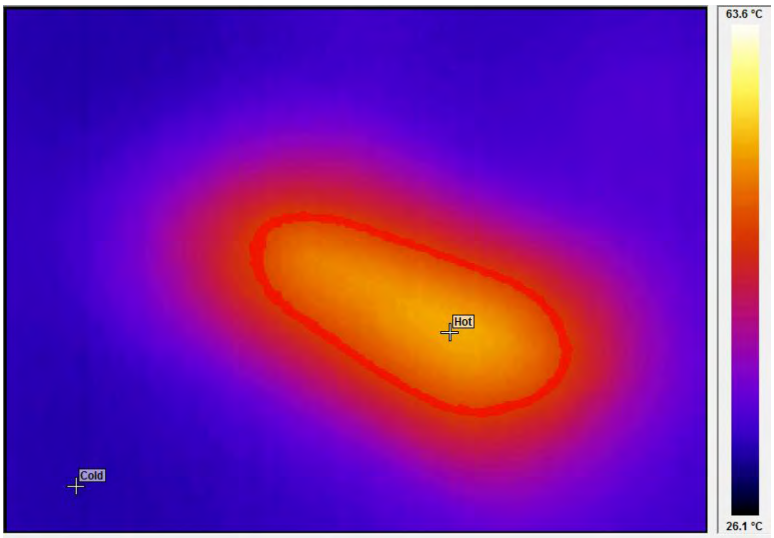

Figure 4.11 : Thermal Characteristic of Specimen at 330 Minutes

Figure 4.12 shows the thermal characteristic of HDPE at 360 minutes. The range of

C.

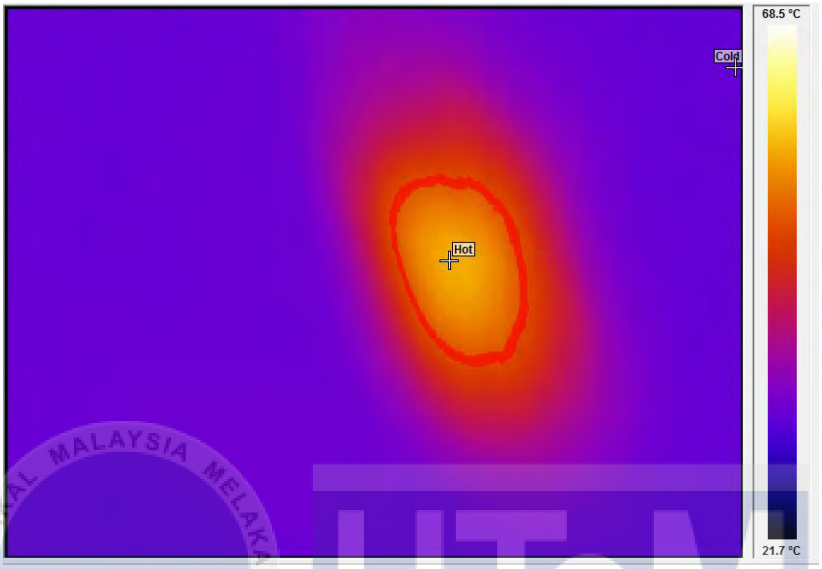

Figure 4.12 : Thermal Characteristic of Specimen at 360 Minutes

After six hours conducting this experiment, it can be conclude that the value of temperature increase as the time increase. The data were shown as in graph below. Beside that, the tracking and erosion at the surface of HDPE were clearly visible. Based on the observation, the track has reached a mark on the specimen surface 25 mm from the lower electrode which means the specimen does not survive 6 hours at 3.5kV and has failed the test. This end-point criteria is according to criterion B. Figure 4.13 shows the graph of value of temperature against time while Figure 4.14 shows condition of HDPE specimen after six hours.

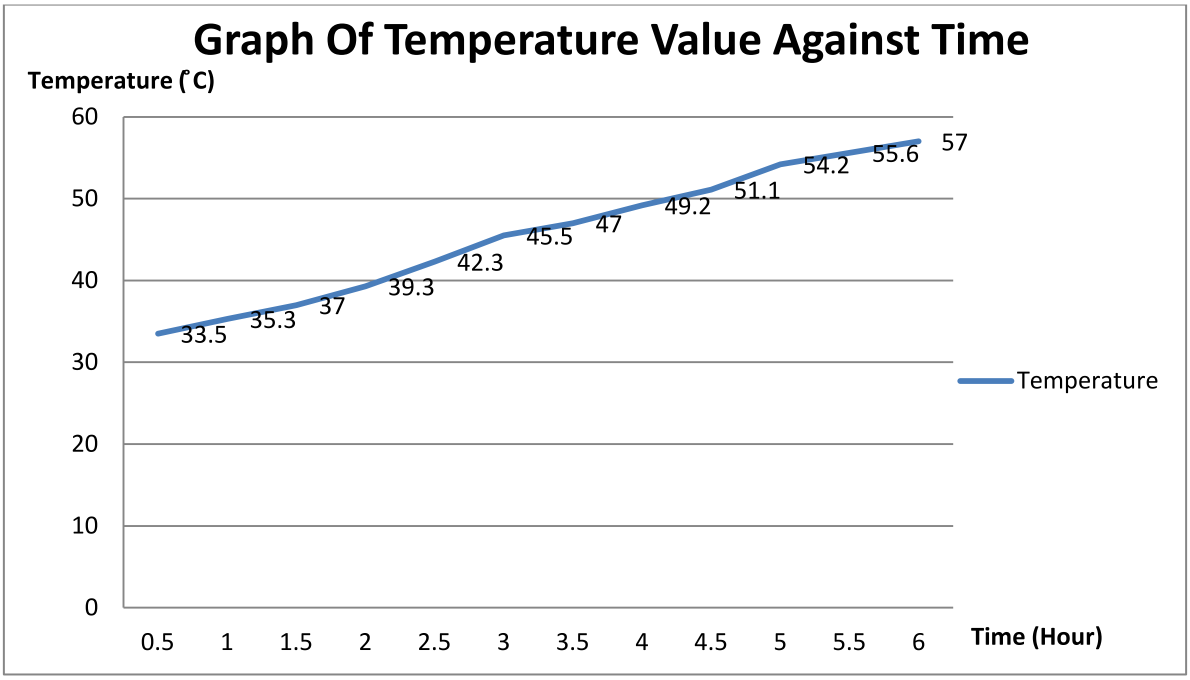

Figure 4.13 : Graph of Temperature Value Against Time

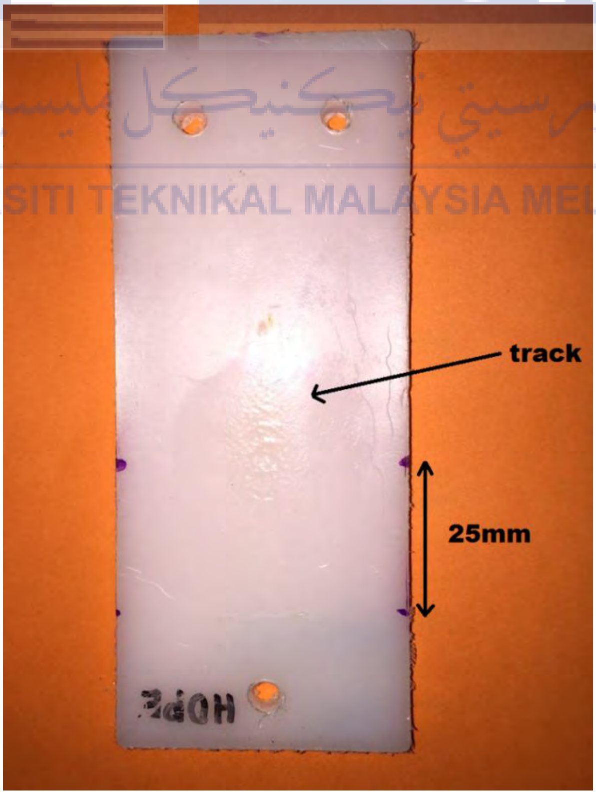

Figure 4.14 : HDPE Specimen Tested With Standard 3.5 kV Selected Voltage

Figure 4.15 – 4.26 show the thermal characteristic of HDPE during the second set of test. The voltage used is 4.5 kV. Figure 4.15 shows the thermal characteristic of HDPE at 30 minutes. The range of

C.

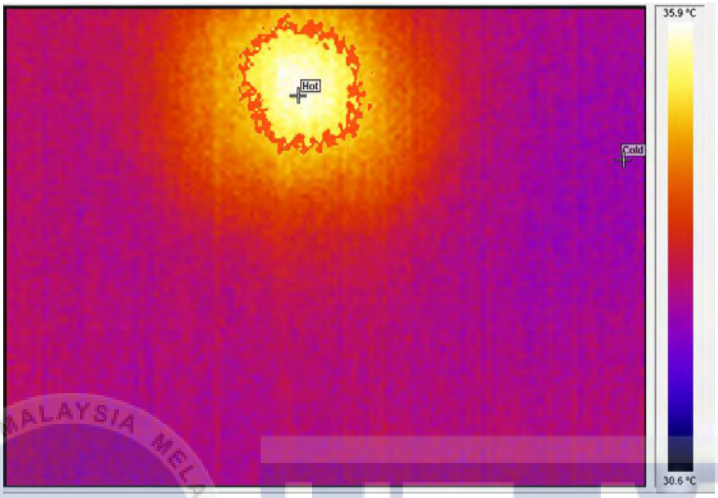

Figure 4.15 : Thermal Characteristic of Specimen at 30 Minutes

Figure 4.16 shows the thermal characteristic of HDPE at 60 minutes. The range of

C. The temperature is slightly increase from the previous temperatu C.

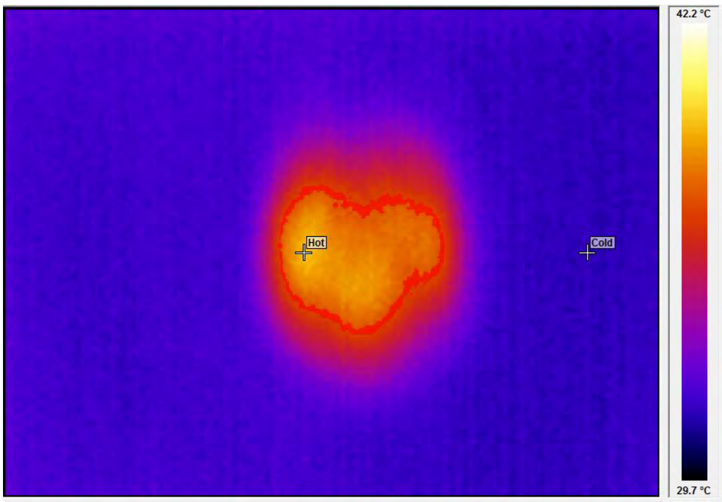

Figure 4.16 : Thermal Characteristic of Specimen at 60 Minutes

Figure 4.17 shows the thermal characteristic of HDPE at 90 minutes. The range of C and the highest temperature spotted at the specimen is C.

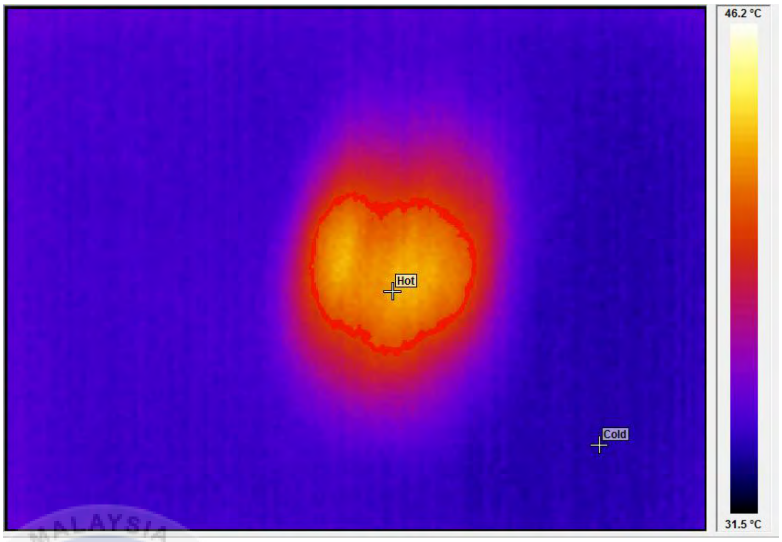

Figure 4.17 : Thermal Characteristic of Specimen at 90 Minutes

Figure 4.18 shows the thermal characteristic of HDPE at 120 minutes. The range of temperature are fro C.

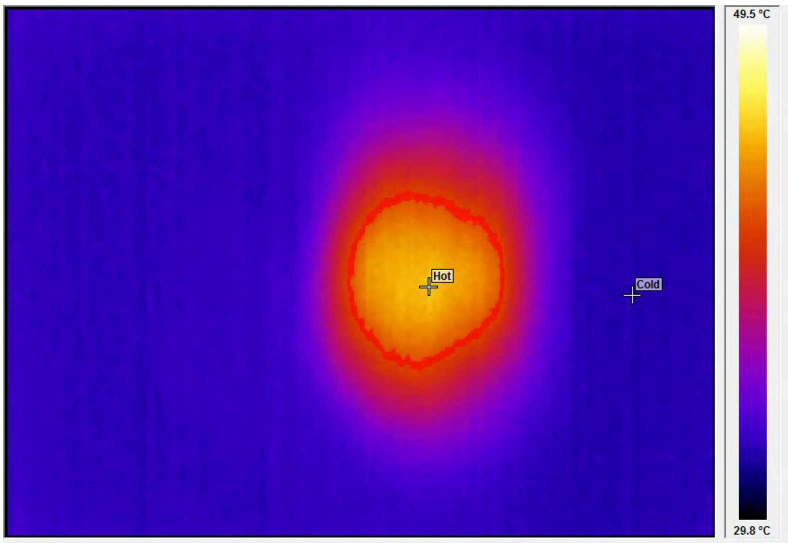

Figure 4.18 : Thermal Characteristic of Specimen at 120 Minutes

Figure 4.19 shows the thermal characteristic of HDPE at 150 minutes. The range of temperature are from 24.0 °

C.

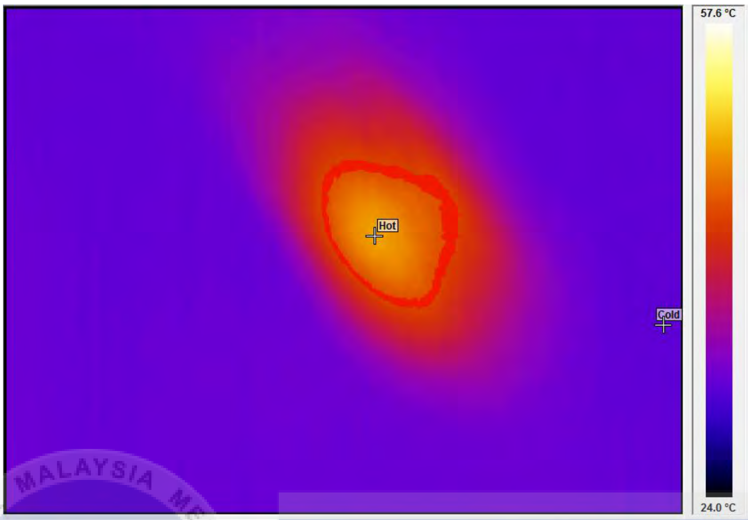

Figure 4.19 : Thermal Characteristic of Specimen at 150 Minutes

Figure 4.20 shows the thermal characteristic of HDPE at 180 minutes. The range of

C. The temperature C.

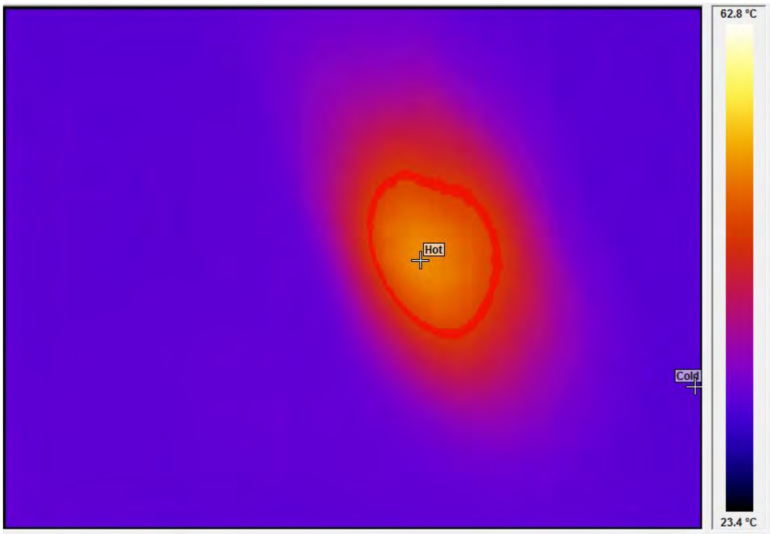

Figure 4.20 : Thermal Characteristic of Specimen at 180 Minutes

Figure 4.21 shows the thermal characteristic of HDPE at 210 minutes. The range of C and

C.

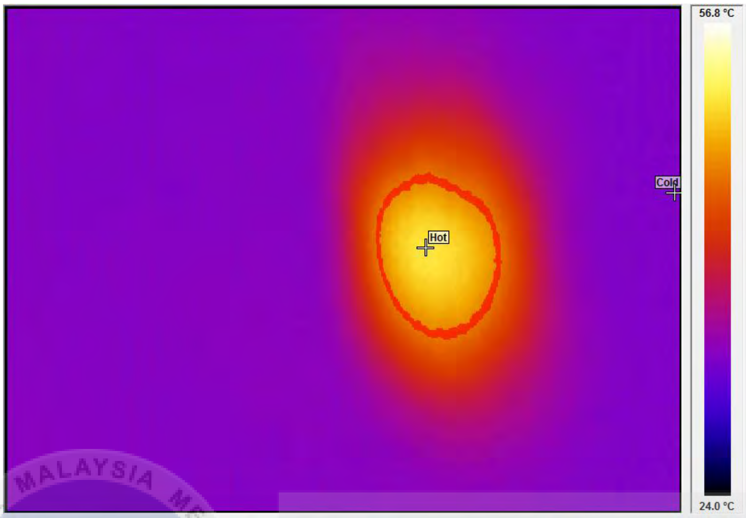

Figure 4.21 : Thermal Characteristic of Specimen at 210 Minutes

Figure 4.22 shows the thermal characteristic of HDPE at 240 minutes. The range of

C.

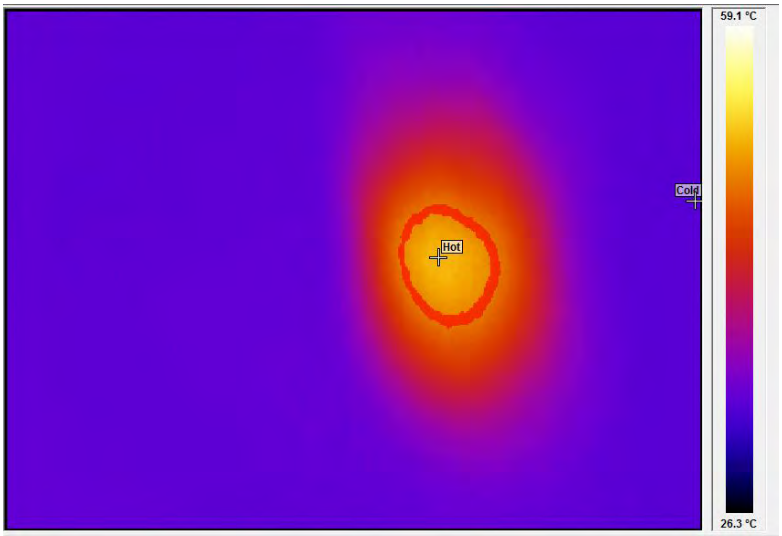

Figure 4.22 : Thermal Characteristic of Specimen at 240 Minutes

Figure 4.23 shows the thermal characteristic of HDPE at 270 minutes. The range of

C. The temperature is slightly increase from C.

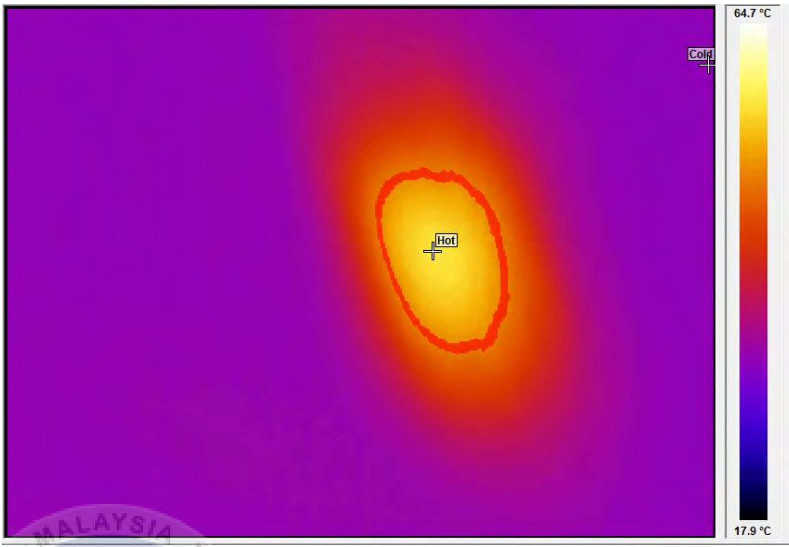

Figure 4.23 : Thermal Characteristic of Specimen at 270 Minutes

Figure 4.24 shows the thermal characteristic of HDPE at 300 minutes. The range of

C and the highest temperature s

C.

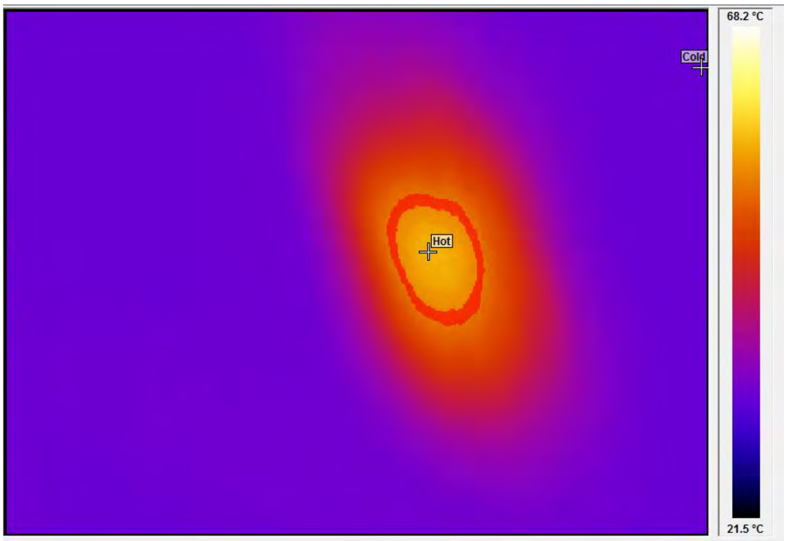

Figure 4.24 : Thermal Characteristic of Specimen at 300 Minutes

Figure 4.25 shows the thermal characteristic of HDPE at 330 minutes. The range of

C.

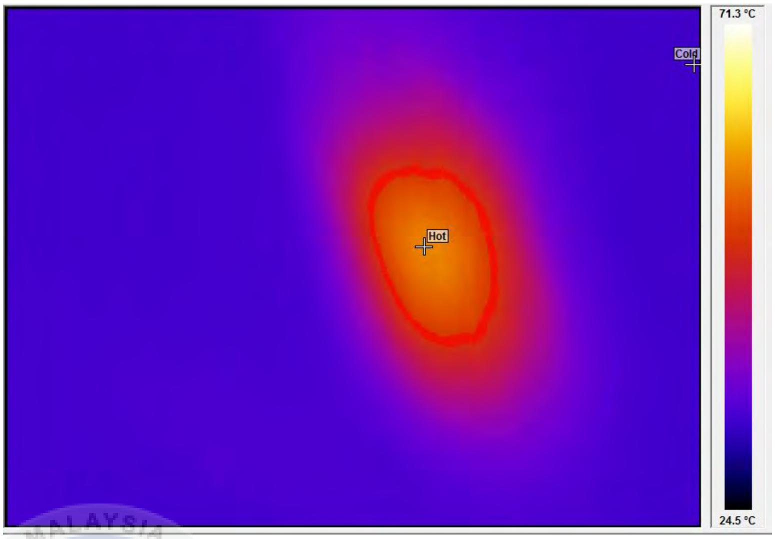

Figure 4.25 : Thermal Characteristic of Specimen at 330 Minutes

Figure 4.26 shows the thermal characteristic of HDPE at 360 minutes. The range of

C. The temperature is slightly increase from the previous temperature b C.

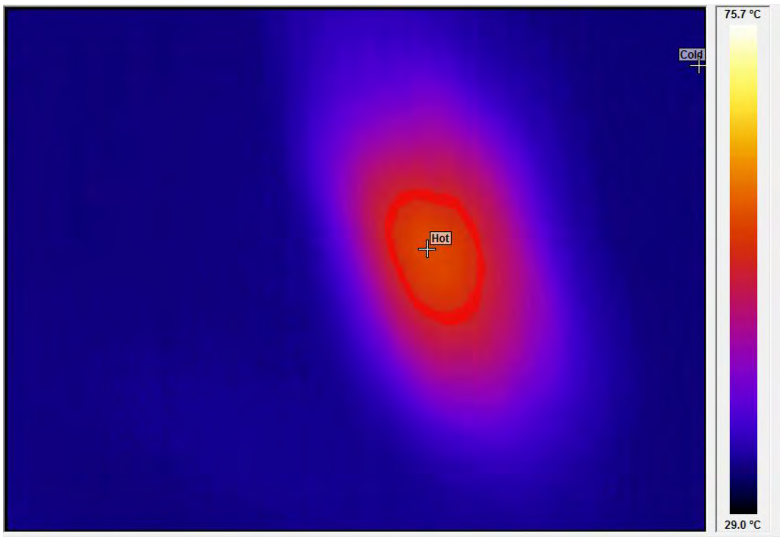

Figure 4.26 : Thermal Characteristic of Specimen at 360 Minutes

After six hours conducting this experiment, it can be conclude that the value of temperature increase as the time increase. The data were shown as in graph below. Beside that, the tracking and erosion at the surface of HDPE were clearly visible. Based on the observation, the track has reached a mark on the specimen surface 25 mm from the lower electrode which means the specimen does not survive 6 hours at 4.5 kV and has failed the test. This end-point criteria is according to criterion B. Figure 4.27 shows the graph of value of temperature against time while Figure 4.28 shows the condition of HDPE specimen.

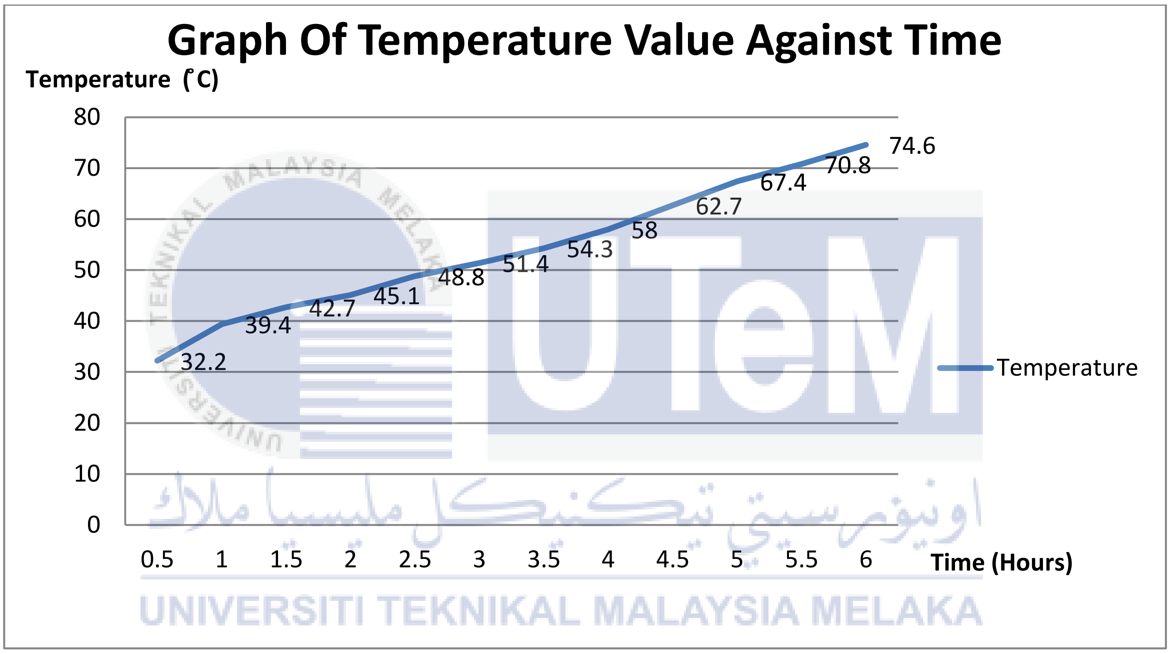

Figure 4.27 : Graph of Temperature Value Against Time

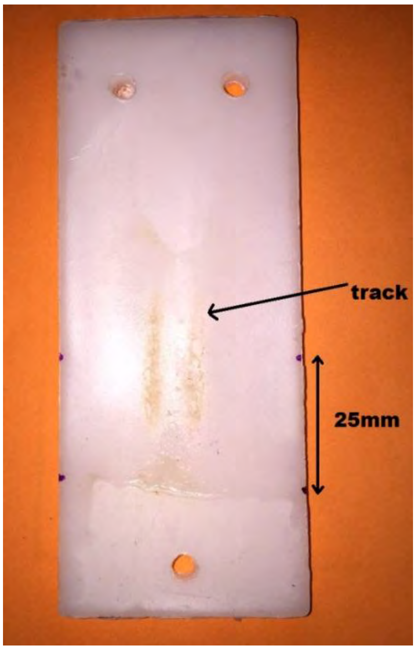

Figure 4.28 : HDPE Specimen Tested With 4.5 kV Selected Voltage

Figure 4.29 – 4.40 show the thermal characteristics of HDPE during the third set of test. The voltage used is 5.5 kV. Figure 4.28 shows the thermal characteristic of HDPE at 30 minutes. The range of tem

C.

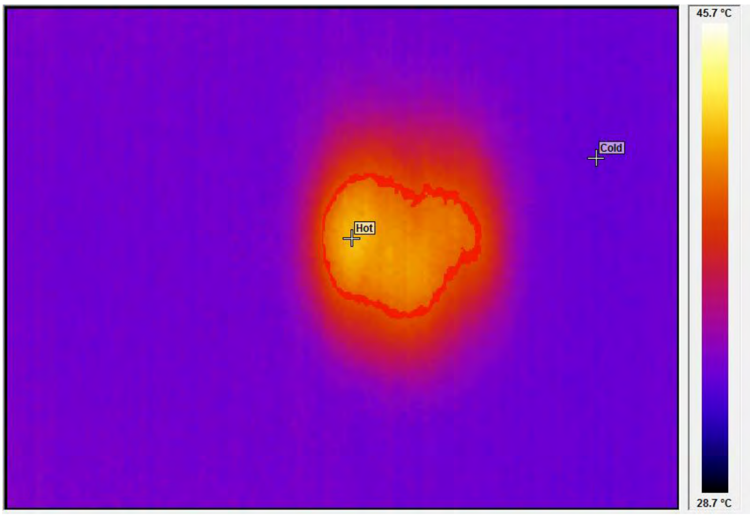

Figure 4.29 : Thermal Characteristic of Specimen at 30 Minutes

Figure 4.30 shows the thermal characteristic of HDPE at 60 minutes. The range of

C.

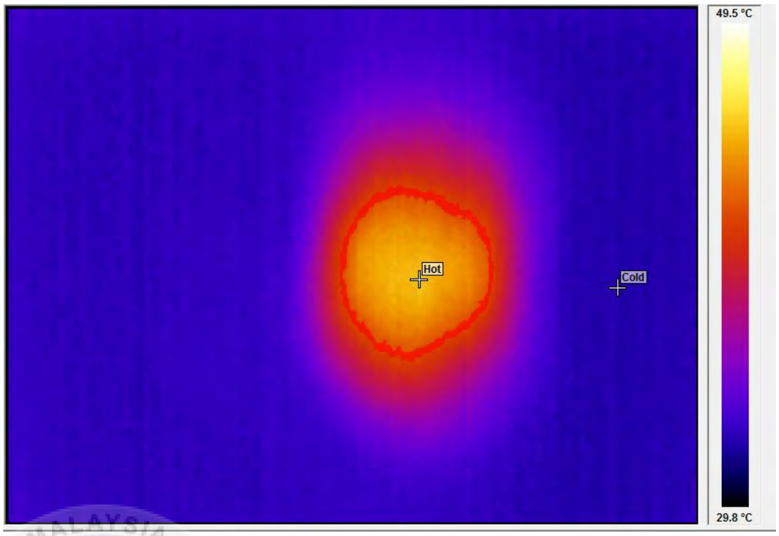

Figure 4.30 : Thermal Characteristic of Specimen at 60 Minutes

Figure 4.31 shows the thermal characteristic of HDPE at 90 minutes. The range of

C.

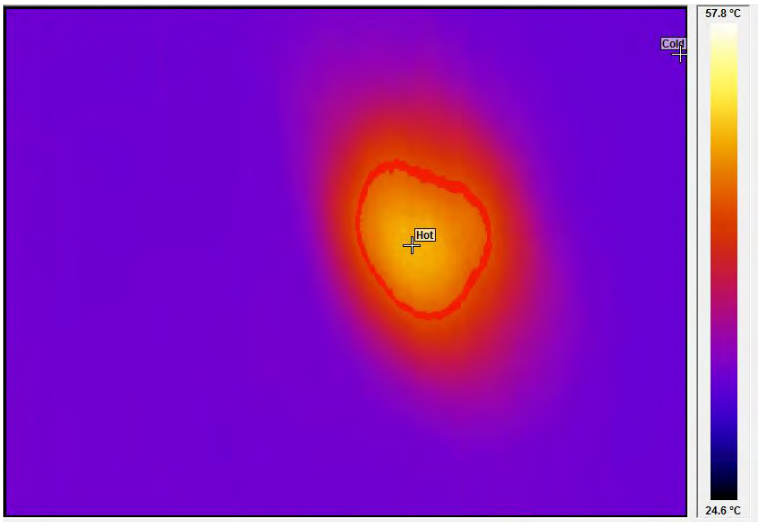

Figure 4.31 : Thermal Characteristic of Specimen at 90 Minutes

Figure 4.32 shows the thermal characteristic of HDPE at 120 minutes. The range of

C. T C.

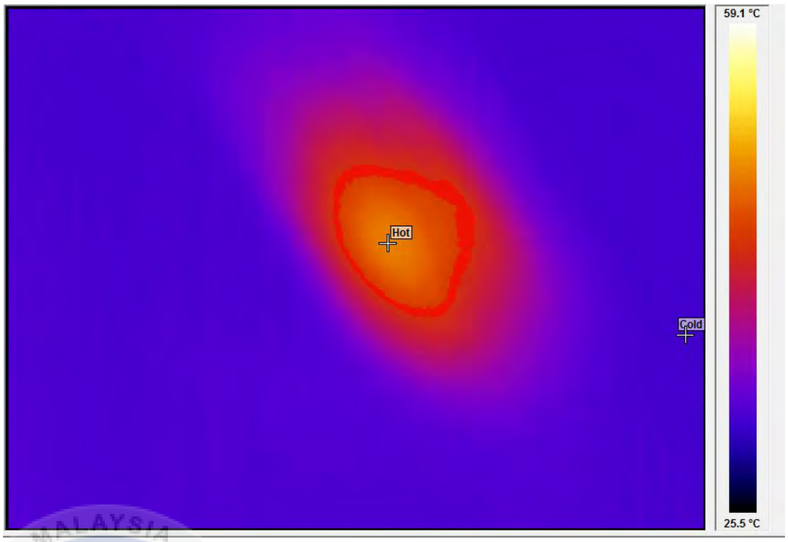

Figure 4.32 : Thermal Characteristic of Specimen at 120 Minutes

Figure 4.33 shows the thermal characteristic of HDPE at 150 minutes. The range of

C.

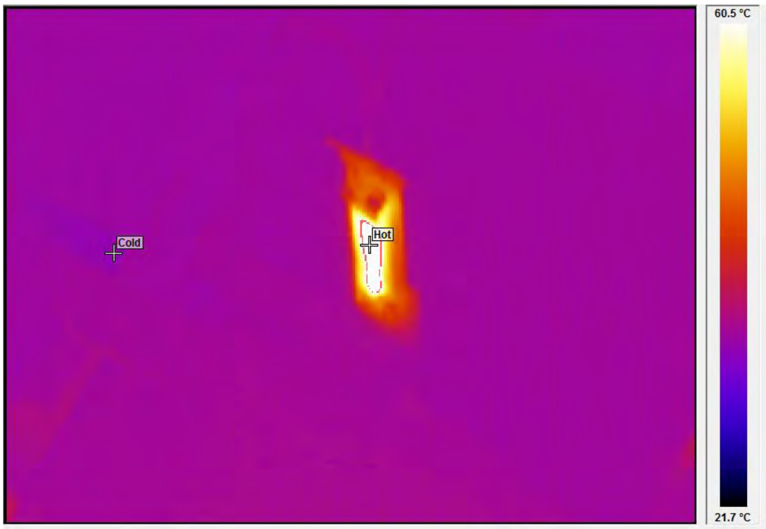

Figure 4.33 : Thermal Characteristic of Specimen at 150 Minutes

Figure 4.34 shows the thermal characteristic of HDPE at 180 minutes. The range of

C.

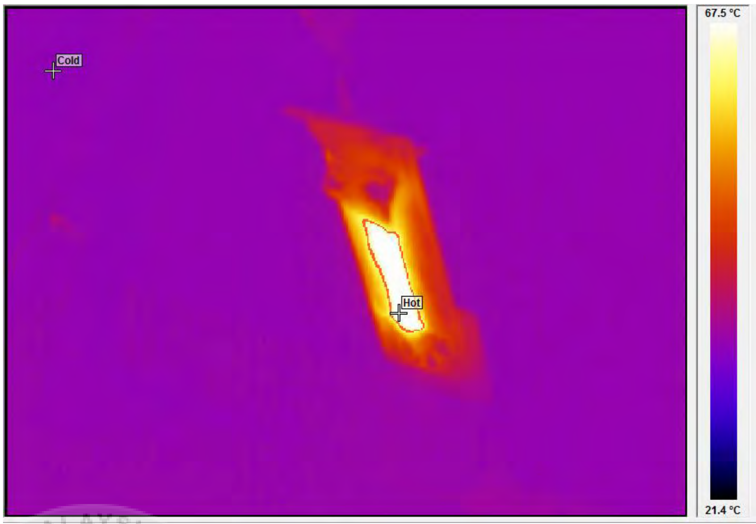

Figure 4.34 : Thermal Characteristic of Specimen at 180 Minutes

Figure 4.35 shows the thermal characteristic of HDPE at 210 minutes. The range of

C. The temperature is slig C.

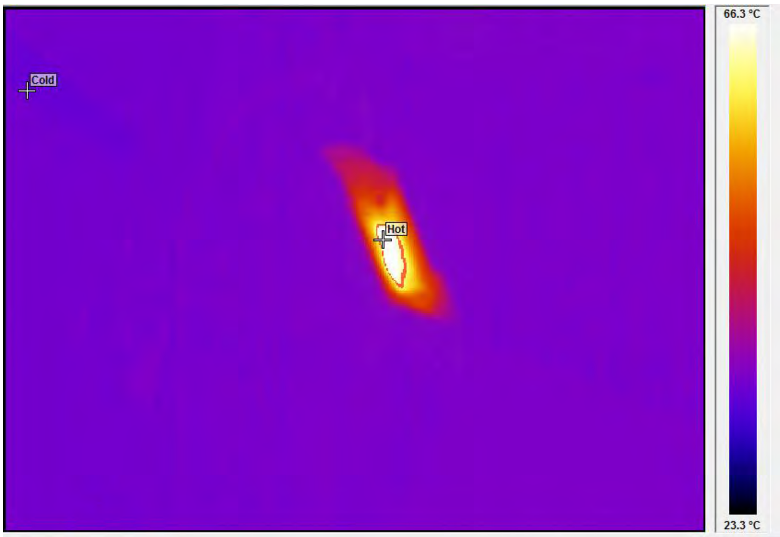

Figure 4.35 : Thermal Characteristic of Specimen at 210 Minutes

Figure 4.36 shows the thermal characteristic of HDPE at 240 minutes. The range of

C and the hig

C.

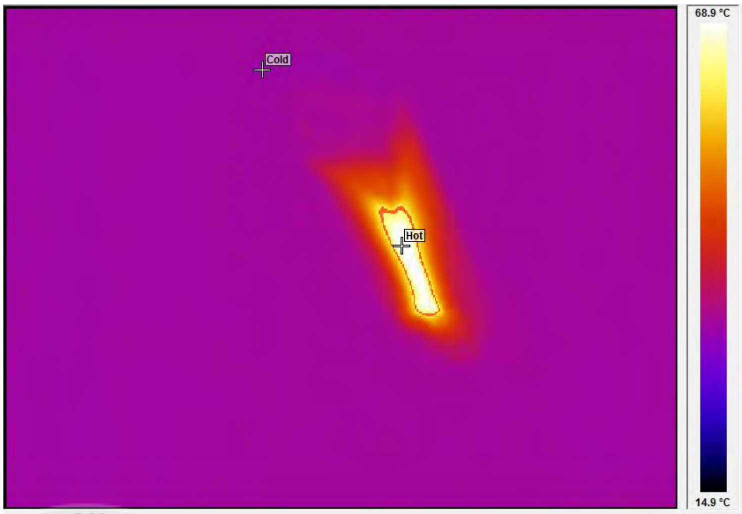

Figure 4.36 : Thermal Characteristic of Specimen at 240 Minutes

Figure 4.37 shows the thermal characteristic of HDPE at 270 minutes. The range of

C.

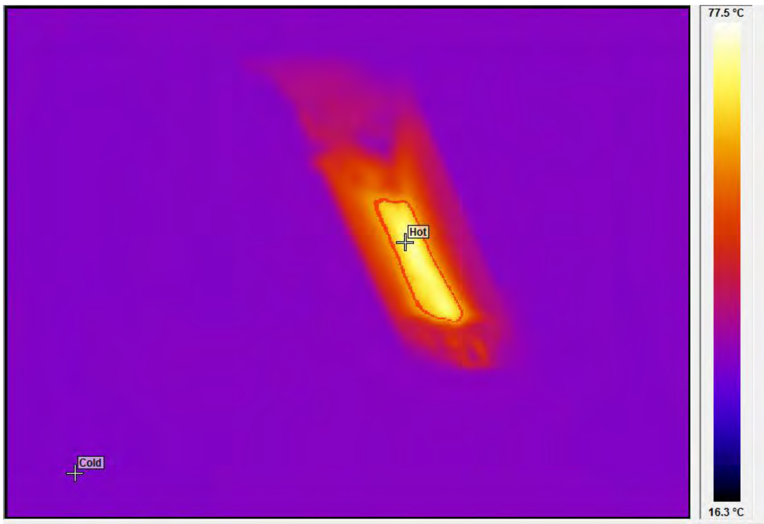

Figure 4.37 : Thermal Characteristic of Specimen at 270 Minutes

Figure 4.38 shows the thermal characteristic of HDPE at 300 minutes. The range of

C. The temperature is slightly increase from the pre C.

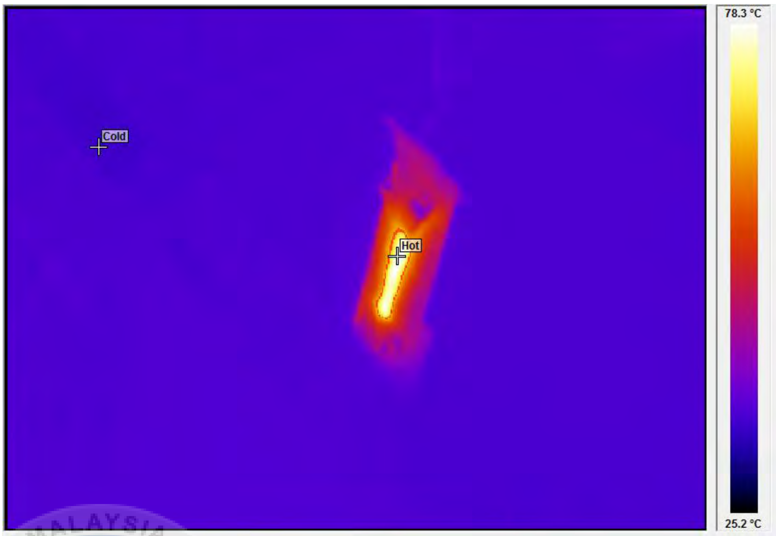

Figure 4.38 : Thermal Characteristic of Specimen at 300 Minutes

Figure 4.39 shows the thermal characteristic of HDPE at 330 minutes. The range of C and the highest temperature spotte C.

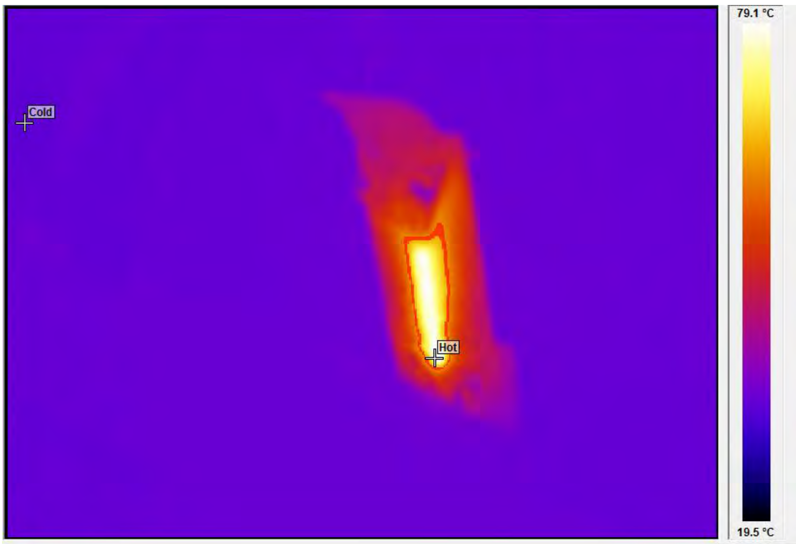

Figure 4.39 : Thermal Characteristic of Specimen at 330 Minutes

Figure 4.40 shows the thermal characteristic of HDPE at 360 minutes. The range of t

C.

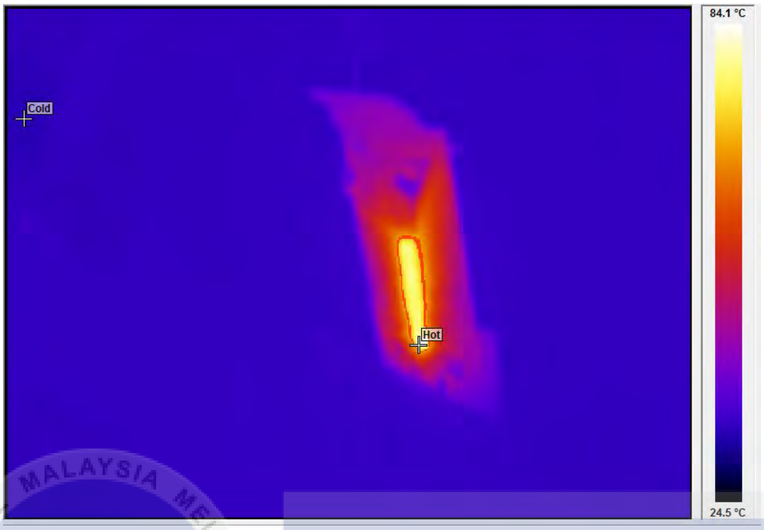

Figure 4.40 : Thermal Characteristic of Specimen at 360 Minutes

After six hours conducting this experiment, it can be conclude that the value of temperature increase as the time increase. The data were show as in graph below. Beside that, the tracking and erosion at the surface of HDPE were clearly visible. Based on the observation, the track has reached a mark on the specimen surface 25 mm from the lower electrode which means the specimen does not survive 6 hours at 5.5kV and has failed the test. This end-point criteria is according to criterion B. Figure 4.41 shows the graph of value of temperature against time while Figure 4.42 shows the condition of HDPE specimen after six hours.

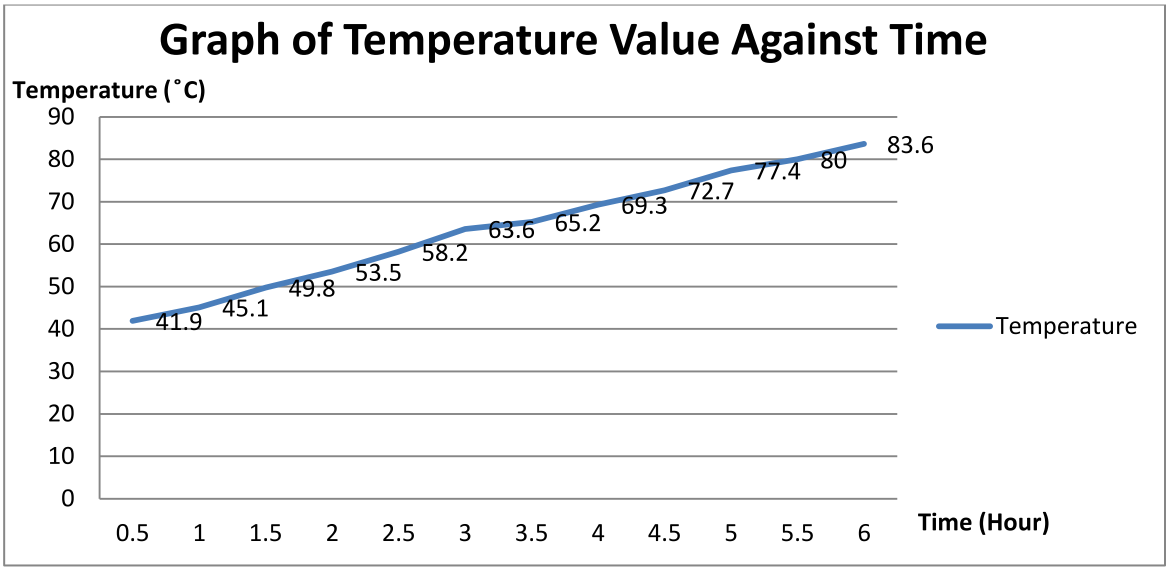

Figure 4.41 : Graph of Temperature Value Against Time

Figure 4.42: HDPE Specimen Tested With 5.5 kV Selected Voltage

Based on three tests that have been taken, the tracking on specimen that were test using 5.5 kV are the most visible of all specimen. Thus it can be conclude that the higher selected test voltage is set up, the more visible surface tracking and erosion will appear.

4.3 Data Analysis from Oscilloscope

The data that been observed and collected from oscilloscope is to analyze the graph patterns of leakage current that occurred during the IPT test. Then the data is convert into graph patterns using MATLAB. The patterns collected are capacitive, resistive, symmetrical and unsymmetrical. When leakage current pattern is in capacitive state, it is mean that there is no erosion and arcing activities occured on the insulation material. This is because the contaminant does not flow completely on the surface of the specimen. The resistive graph pattern can be obtained when the contaminant flow completely on the surface of the specimen. At this time, the arcing and sound activities occured on the insulation material. Resistive waveform of leakage current condition can be defined as hydrophilic state of insulation surface. Next, the symmetrical state shows that the forming of dry-band on the surface which then leads to fast tracking and erosion. This happened due to the decrement of hydrophobicity properties in HDPE material and it may raise the temperature as well as evaporate the electrolyte to form a dry band and symmetrical waveform is developed.. Lastly, for unsymmetrical state it will show the variation of leakage current pattern in sinusoidal, lower on-linear symmetrical and serve distorted non-linear unsymmetrical. At this condition also the arcing and sound activities occur. The graph pattern becomes unstable because the forming of dry-band on the specimen happen simultaneously with tracking and erosion.

4.3.1 Data Analysis using 3.5 kV

Figure 4.43 – 4.46 shows the leakage current pattern in capacitive, resistive, symmetrical and unsymmetrical state.

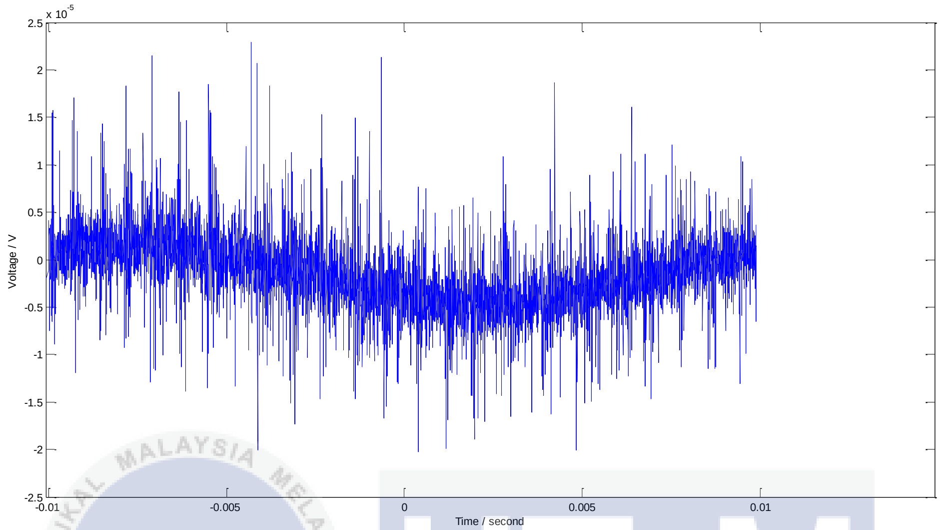

Figure 4.43 : Capacitive for 3.5 kV from MATLAB

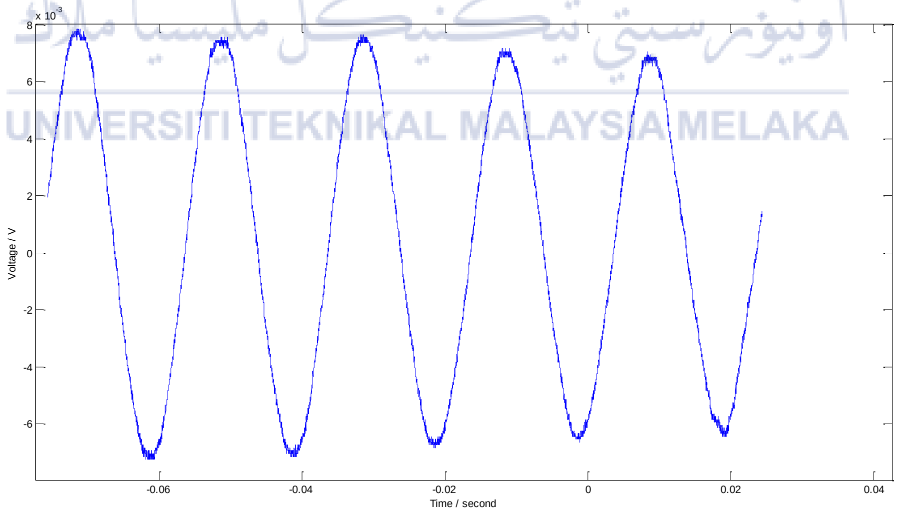

Figure 4.44 : Resistive for 3.5 kV from MATLAB

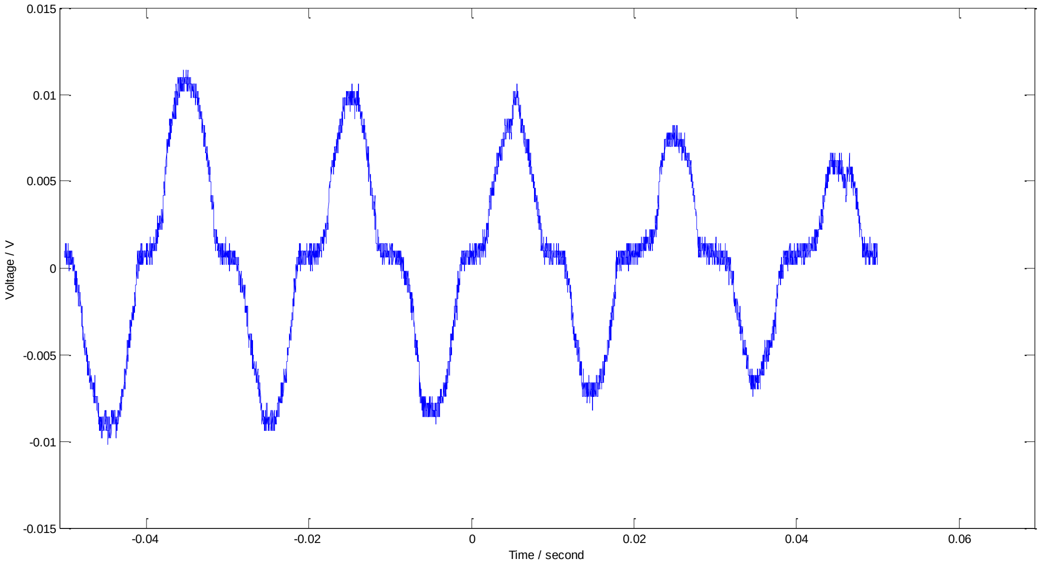

Figure 4.45 : Symmetrical for 3.5 kV from MATLAB

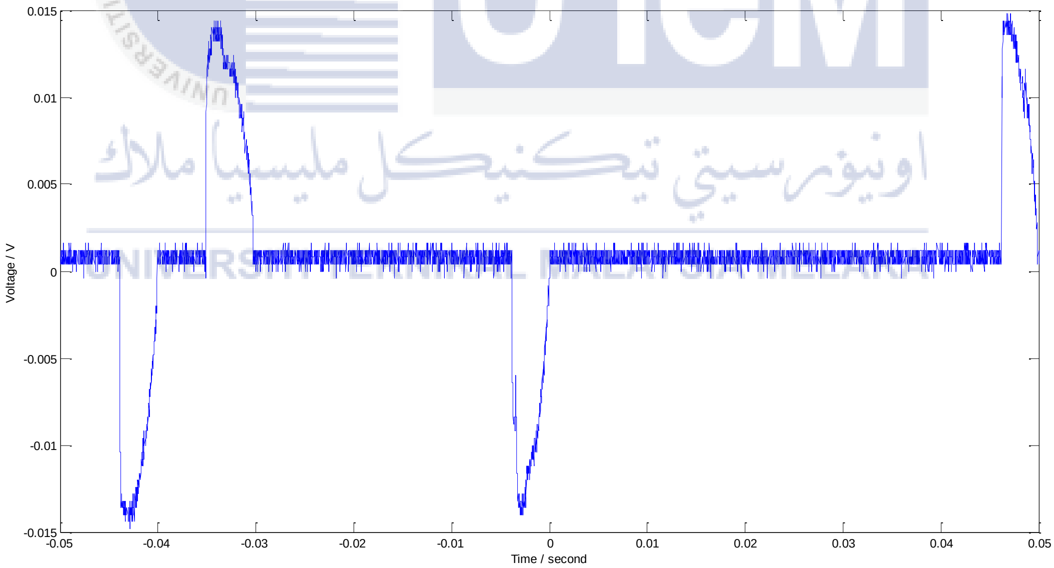

Figure 4.46 : Unsymmetrical for 3.5 kV from MATLAB

4.3.2 Data analysis for 4.5 kV

Figure 4.47 – 4.50 shows the leakage current pattern in capacitive, resistive, symmetrical and unsymmetrical state.

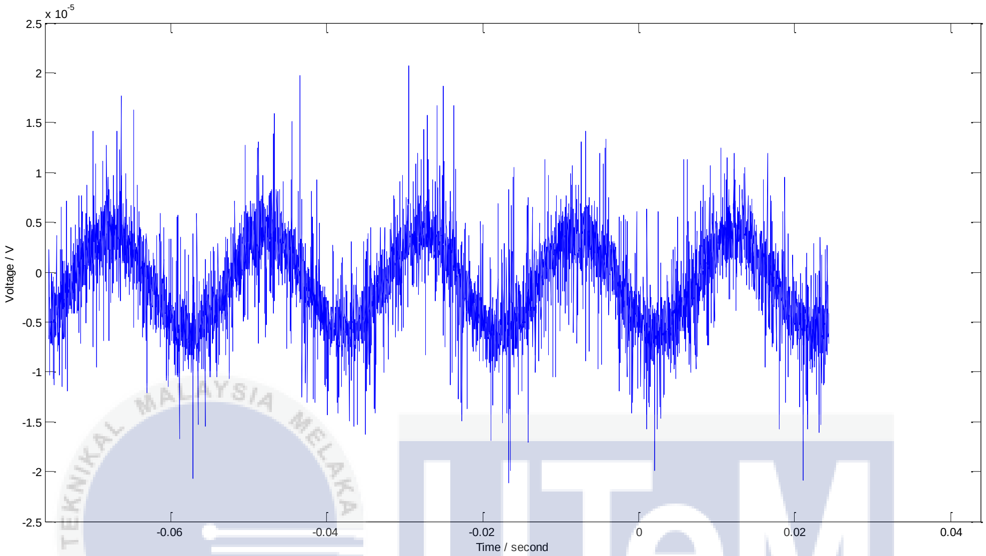

Figure 4.47 : Capacitive for 4.5 kV from MATLAB

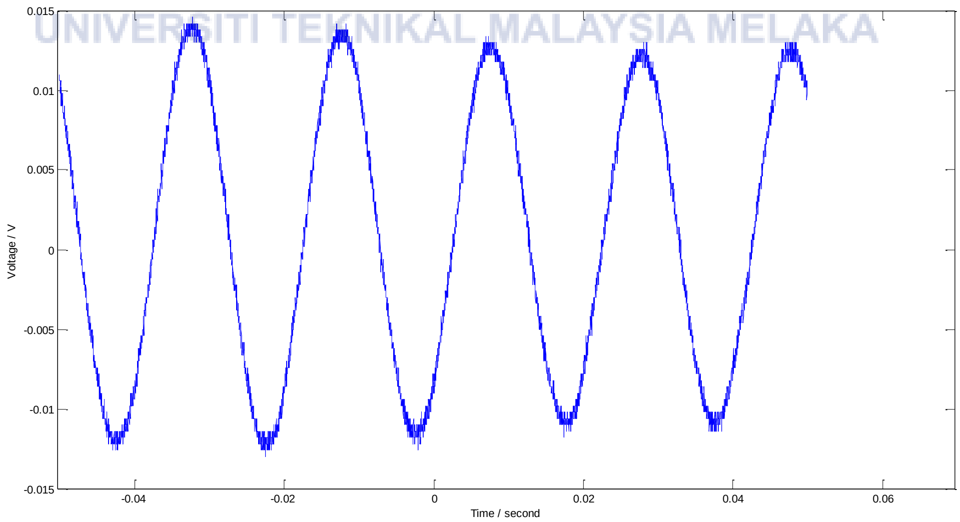

Figure 4.48 : Resistive for 4.5 kV from MATLAB

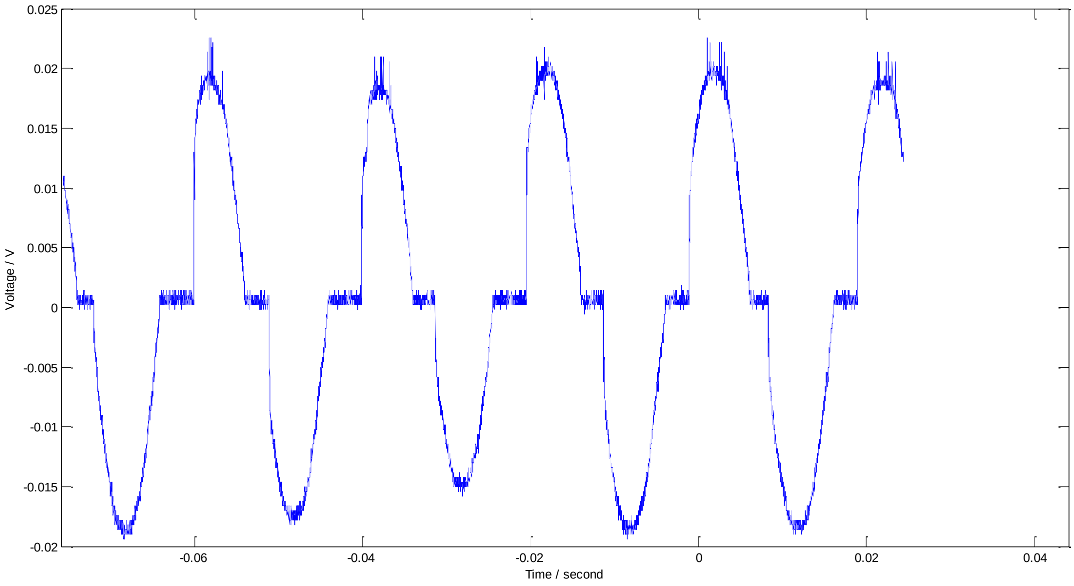

Figure 4.49 : Symmetrical for 4.5 kV from MATLAB

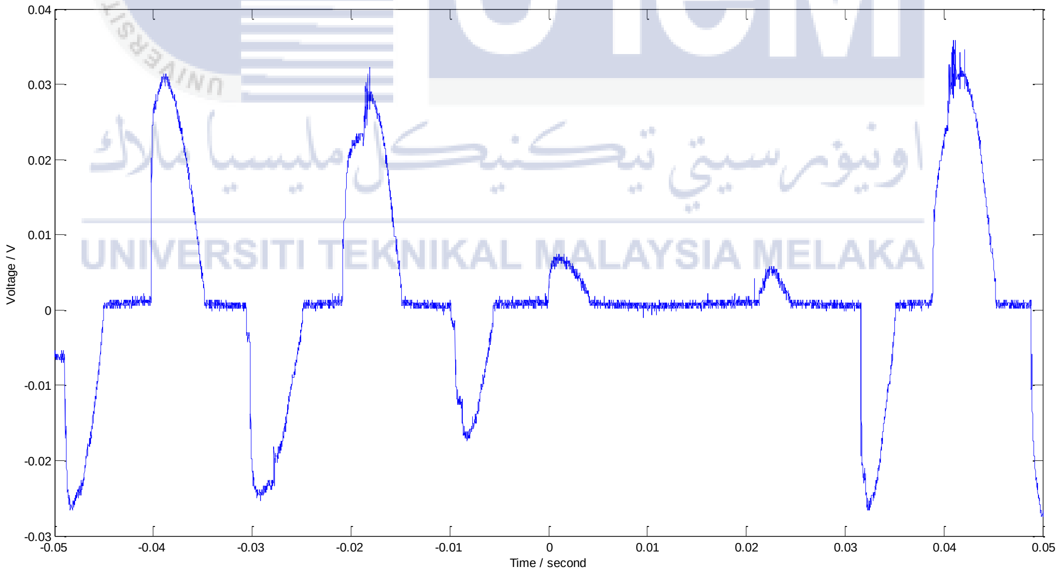

Figure 4.50 : Unsymmetrical for 4.5 kV from MATLAB

4.3.3 Data analysis for 5.5 kV

Figure 4.51 – 4.54 shows the leakage current pattern in capacitive, resistive, symmetrical and unsymmetrical state.

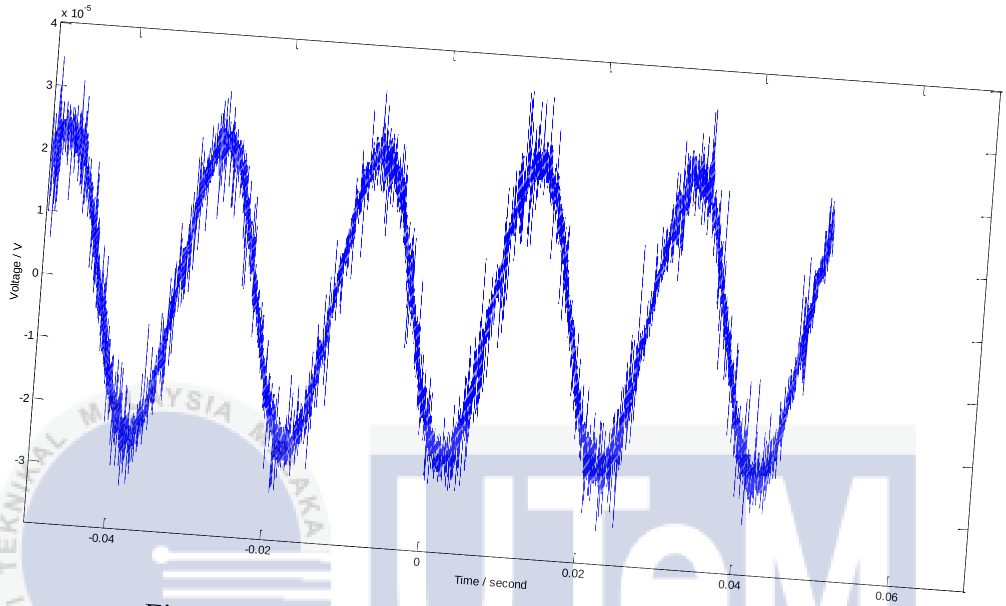

Figure 4.51 : Capacitive for 5.5 kV from MATLAB

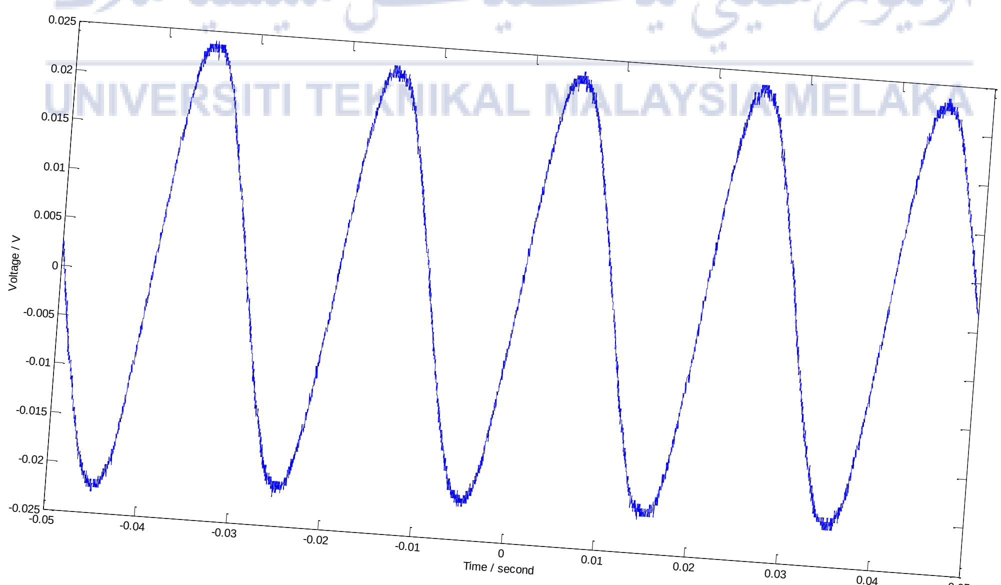

Figure 4.52 : Resistive for 5.5 kV from MATLAB

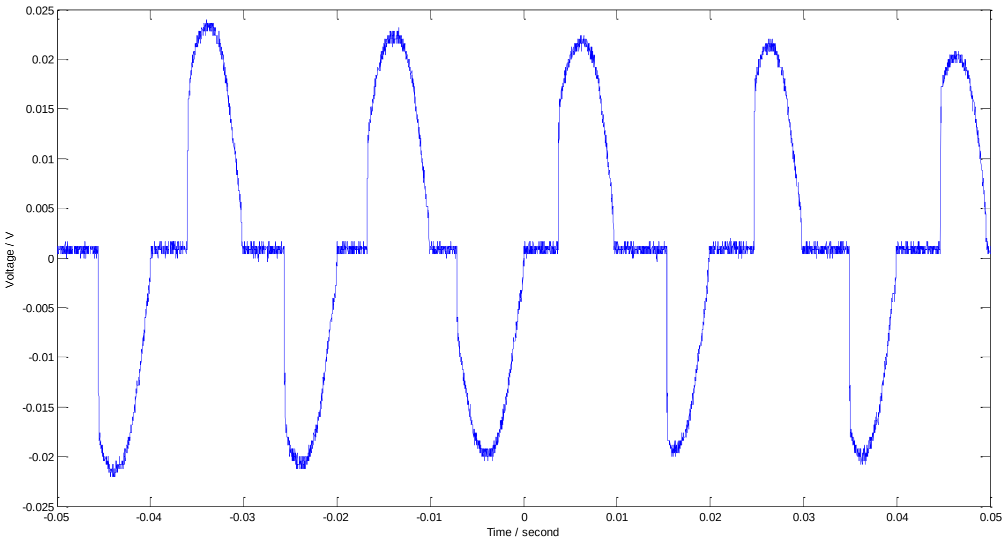

Figure 4.53 : Symmetrical for 5.5 kV from MATLAB

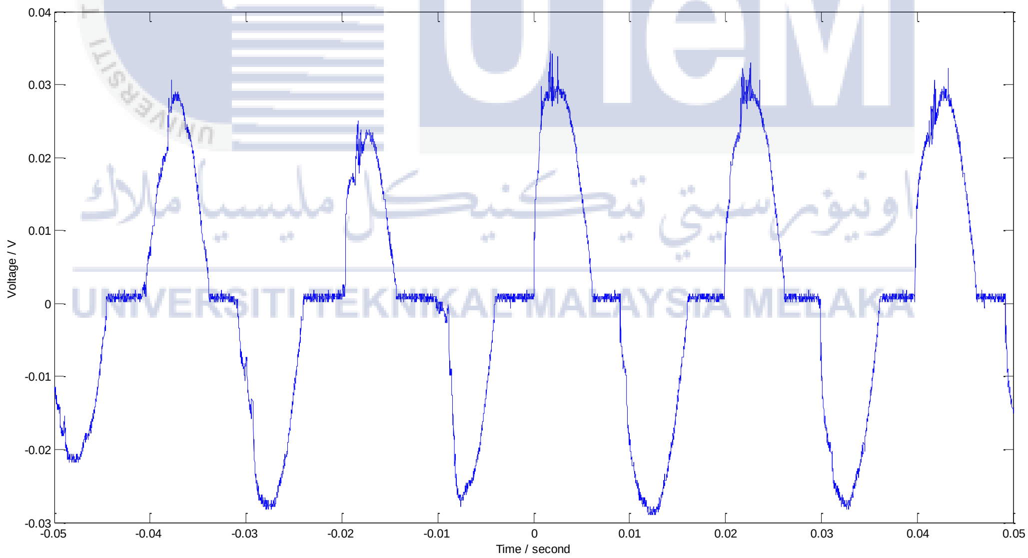

Figure 4.54 : Unsymmetrical for 5.5 kV from MATLAB

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

The objectives and scopes of this project are achieved. This study focused on thermal characteristics and the evaluation on surface tracking and erosion of High Density Polyethylene (HDPE) by complying BS EN 60587 standard. Based on the experiments that have been conducted, it can be concluded that the temperature increase is proportional to the increase in time taken and voltage applied to the specimen during testing process is carried out. The higher the voltage and time taken, the higher the temperature. This can be said because the temperature of the specimen during six hours of the experiments are differents between all the three voltages applied. When higher voltage were applied, the temperature of the specimen increase rapidly. Beside that, the leakage current pattern waveform of HDPE in capacitive, resistive, symmetrical, and unsymmetrical were also obtained. From the results, the magnitude of leakage current pattern depends on the voltage applied. Higher voltage applied will result in the losses of hydrophobicity properties of HDPE causes the higher magnitude of leakage current.

5.2 Recommendation

In this study, the use of HDPE as an insulating material in high voltage application has been extensively investigated in the laboratory. However there are still many aspects that may affect the performance of the developed material and continued research is suggested to optimize the insulating performance. One of the aspects is to run the test under different and multiple stresses. In outdoor applications, the insulator will be exposed to many environmental stresses. These stresses are such as humidity, ultra-violet radiation, surrounding temperature, and etc. In actual service, several stresses happen simultaneously on the insulator material and will contribute to more degradation on the material. By conducting a test under these conditions, the environmental stresses that give more defects to the insulating performance of the developed material can be identified.

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