INVESTIGATION ON AGING CHARACTERISTICS OF SILICONE RUBBER NANOCOMPOSITE INSULATORS IN AQUEOUS SALT ENVIRONMENTS

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THE DEGREE OF
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Abstract

This study investigates the aging characteristics of silicone rubber nanocomposite insulators exposed to aqueous salt environments. Silicone rubber, known for its electrical insulation and environmental resistance, is enhanced with nanomaterials to improve its properties. However, the impact of harsh conditions, such as salt-laden environments, on these advanced materials is critical for the practical applications.

It can be observed, silicone rubber nanocomposites with varying nanofiller concentrations were subjected to aqueous salt solutions at different concentrations and temperatures over extended periods. The aging effects were evaluated through mechanical testing, electrical performance analysis, and chemical characterization. Silicone rubber samples containing various nanofillers were subjected to accelerated aging tests in salt solutions like coastal and marine conditions. Results indicate that exposure to salt solutions significantly affects the mechanical strength, dielectric properties, and surface properties of the nanocomposites. The study provides insights that how different nanofillers influence the durability of silicone rubber insulators and highlights potential improvements for enhancing their performance in challenging environments.

It can be observed that, after adding the nanofiller composite to silicone rubber it enhances the properties of nanofillers, which can see in leakage current and hydrophobicity measurement. Nanofillers always added to the silicone rubber (SiR) base to improve their electrical and mechanical properties. In the nanofillers properties of Al_2O_3 & TiO_2, find that both of them increases the properties of SiR, but slightly different form each other: TiO_2-(Titanium dioxide) helps the SiR properties with thermal strength and relative permittivity and Al_2O_3- (Aluminum oxide) helps the SiR properties by electrical resistivity, mechanical strength and compressive strength. By this properties nanofillers helps to reduces the cost of composite insulators.

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Abbreviations	**Description**
SiR	Silicone rubbers
RTV	Room temperature vulcanized
Al_2O_3	Alumina or Aluminium oxide
TiO_2	Titanium dioxide
PDMS	Polydimethylsiloxane
LC	Leakage current
EPDM	Ethylene propylene diene monomer
NCLs	Non-Ceramic insulators
HA	Harmonics analysis
CAM	Contact angle measurement
HV	High Voltage
NaCl	Sodium Chloride
SEM	Scanning electron microscopy
MD	Molecular dynamics
LMW	Low molecular weight
ESDD	equivalent salt deposit density
NSDD	Non soluble salt deposit density

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CHAPTER-1

INTRODUCTION

Chapter-1

1.1 Background

In coming days, the increase in power consumption across all industries has made high-voltage distribution and transmission, as well as the use of high-voltage insulators, especially in high-voltage transmission lines, inevitable. Depending on whether they are located in semi-arid or coastal regions, these insulators are subject to electrical and mechanical stresses in addition to the whims of nature, such as rain, fog, humidity, snow, and pollution. The argument being made is that since insulators are considered to be the weakest link in the high-voltage insulation system—a failure in them leads to the breakdown of the transmission system as a whole—must ensure their dependable operation.

Conventional ceramic insulators, such as porcelain and glass, are inert, stable materials that do not deteriorate on the surface. However, when subjected to damp conditions such as rain, fog, or dew, these materials become highly wettable due to their high surface energy. When insulators are unclean and wet, leakage current increases, potentially leading to flashover and system failure. Polymeric insulators have started to gain traction because of their capacity to maintain high tensile strengths and get around the conventional problems with porcelain and glass insulators. They also have the obvious advantages of being much lighter, easier to install and maintain, and less susceptible to vandalism. From a technical standpoint, it offers a far higher resistance to flashover, puncture, tracking, and erosion. When exposed to contamination and pollution, polymeric insulators outperform ceramic insulators due to their superior hydrophobic characteristics or good water repellency.

All of these factors allow silicone rubber to be vulcanized at either high temperature (HTV) or room temperature (RTV) to be used as the bulk material for composite insulators in new installations. It is SiR. Advantage of the silicone rubber are corrosion resistance, thermal stability, compression set resistance, seal formation, weather resistance, vibration and sound dampening, the ability to repel water and its' natural flame-retardant properties. On the other hand, a 0.5-mm layer of RTV silicone rubber covers the ceramic insulators in cases where replacement is not feasible because of technical difficulties or budgetary constraints. This is where silicone rubber has been vulcanized at room temperature is employed.

1.2 Motivation

In recognition of its superior hydrophobic qualities, room-temperature and high-temperature vulcanized silicone rubber are now frequently utilized in power transmission systems due to recent advancements in polymeric insulators. Numerous studies have been conducted to ascertain the differences in the high-temperature vulcanized material's hydrophobic characteristics and the recovery of hydrophobicity in the event of contamination. Furthermore, studies on the hydrophobicity of room-temperature vulcanized silicone rubber are necessary.

Most of the research and analysis done so far has used the fast Fourier transform, which essentially transforms the leakage current signal from the time domain to the frequency domain. The analyses have focused on how aging affects variation in harmonic content, but it is also crucial to investigate harmonic content at different concentrations. It can be observed that the leakage current increasing with the increasing in humidity levels due to distortion at wave crest gain, that means more and more electrical discharges have started to occurs, but add nanofillers in it than less amount of leakage current can form. Many studies have been conducted on the leakage current analysis of polymeric insulators, and the fast Fourier transform has been used in the majority of these investigations and analyses.

1.3 Contribution

A comparative study was carried out to examine how the magnitude of leakage current (LC) fluctuated when the concentration of alumina nanofiller and titanium dioxide nanofiller changed in room-temperature vulcanized (RTV) silicone rubber (SiR). Furthermore, the result was confirmed using the generated LC pattern's root mean square value. Subsequently, the LC pattern underwent a Fast Fourier Transform (FFT), and the harmonic content fluctuation and the third harmonic content to fundamental ratio were the main topics of debate that followed.

A study on hydrophobicity measure by two-part RTV SiR was used in a study to determine the hydrophobicity of different concentrations of alumina and titanium dioxide nanofiller. In the hydrophobicity, it can be observed that aluminum oxide nanofiller is more hydrophobic than titanium dioxide nanofiller. The ensuing variation in contact angle was noted and discussed. The RTV samples were contaminated in a different experiment to provide a better understanding of their dynamic hydrophobicity. The hydrophobicity that was transferred to the contaminated insulator's surface and the percentage of hydrophobicity that was recovered after the contaminant was removed were both measured by the researchers. This was accomplished by combining a goniometer and the sessile drop technique to measure the contact angle of a water droplet. Next, the hydrophobicity transfer process to the surface of contaminated RTV samples with different alumina concentrations filler was discussed, as well as the hydrophobicity recovery.

1.4 Literature Review

1.4.1 Introduction

Insulators are essential in power systems because they are isolate live components from the ground and another while, also providing mechanical protection. In many different types of networks, such as substations, transmissions, and distributions, insulators are widely used [1].

Ceramic insulators are still very important in both the transmission and distribution networks, where they have long been a major component of the power system. In addition to their favourable mechanical and electrical qualities, ceramic insulators are reasonably priced.
Nevertheless, because they are meant to be used outside, they are prone to various defects, especially when exposed to specific environmental factors like pollution, moisture, or humid air, which all reduce their surface resistance. The amplitude of the leakage current flowing on the surface increases as a result of the decrease in surface resistance [2]. A significant leakage current (LC) that runs on the insulator surface for an extended period of time can be the cause of surface degradation [3]. Additionally, because ceramic insulators are hydrophilic by nature, they encourage the ongoing formation of water films in humid environments or during the rainy season.

With the increased, tracking as a result could eventually lead to a flashover. Regardless of whether the ceramic insulator in question is constructed of glass or porcelain, one way to address the problem it presents is to coat it with room-temperature vulcanized silicone rubber. Research on the leakage current, hydrophobicity, and surface smoothness of RTV silicone rubber-coated porcelain insulators compared to uncoated porcelain insulators was conducted by Suwarno and Pratomosiwi.

1.4.2 Sample preparation

Since positive results for the dielectric and surface characteristics of silicone rubber (SiR) composites have been obtained recently, there has been a great deal of attention focused on these materials for use in electrical insulation applications [5]. To enhance these characteristics of the underlying polymer even more, however, it is frequently combined with different fillers, the kind of which is chosen based on the property that needs to be improved [6]. For instance, it has been demonstrated in [7, 8] that SiR composites with a higher filler content perform worse than highly loaded SiR composites in terms of tracking and erosion resistance. Furthermore, it has been observed that higher loadings of the hydroxide filler might result in poor mechanical qualities such as a low tensile strength [9].

Accurately differentiating between the dielectric properties of micro and nanodielectrics presents a significant problem for researchers, even though they open up new potential in the electrical insulation business. The processing technique used to prepare these SiR composites is one of the elements that has directly impacted these properties, making it a significant problem. Conversely, the processing method should have a simple production process and be one that can be utilized profitably in the commercial world. To distribute micro- and nanoparticles on a polymeric basis, common processing techniques include direct mixing, mechanical stirring, ultrasonication, and in-situ polymerization [10].

Furthermore, a method has been provided in [10, 11] to achieve superior characteristics and good filler dispersion for polymer composites. The RTV SiR material datasheet [12] is cited when addressing the mechanical and dielectric properties of the composite.

A Khattak and M Amin [13] conducted a thorough investigation on a variety of organic, inorganic, and metallic fillers. Their results indicate that alumina filler is excellent at giving the polymer composite mechanical strength, while alumina trihydrate was only moderately successful at enhancing the material's electrical properties. The use of alumina filler, including modified precipitated alumina and precipitated alumina, as a reinforcing filler in silicone rubber composites was the subject of a thorough examination.

His investigation revealed that alumina fared remarkably well in tests that measured its hardness, elongation, and tear strength. Furthermore, its tensile strength was higher than that of its rivals. Transmission electron microscopy was used to examine the morphological features of the compound with these different alumina fillers. The results showed that the compound had long chain aggregates, which led to good mechanical performance. Additionally, the study showed that the alumina compound's moisture content was lower in its datasheet compared to the precipitated alumina compound [14, 18].

1.4.3 Leakage current

Transmission and distribution lines make considerable use of high-voltage-resistant insulators. Their main purpose is to physically divide electrical lines from towers and between two electrical conductors. Insulators located close to the coast or in areas that are prone to industrial activity are more likely to be contaminated by industrial dust and salt deposits, respectively. Rain and high humidity will make the layers conductive and wet, which will allow leakage current (LC) to flow across the insulator's surface. This will happen as a result of the layers becoming conductive following moisture exposure. A flash is produced by this LC sequence, during which short circuits between two lines or between a line and a tower happen. As a result, leakage currents are tracked and examined in a laboratory or, depending on the situation, in the field in order to make a comparative evaluation of the condition of the insulator surfaces [15]. It can be examine the magnitude and pattern of leakage currents, may be able to learn important information about the condition of the insulator surfaces [16, 17]. The leakage currents initially have a capacitive nature and a comparatively low magnitude. But over time, the leakage currents become more resistive and larger in amplitude; thus, the harmonic content of the leakage currents increases [16, 19, 20].

An increase in the LC results in the formation of a dry band on the insulator's surface. Dry-band arcing may be used to increase the harmonic richness even more [19]. As a result, leakage current analysis is frequently done in the frequency and time domains [15]. D. Pylarinas et al. [20, 21] have demonstrated that a number of features in the frequency and time domains can be used singly or in combination to analyze LC values. Both the frequency domain and the time domain exhibit these characteristics.

In addition to several LC measuring techniques, a study by M. Amin et al. [22] shows that the use of composite insulators greatly reduces the leakage current even in the presence of pollution. G. Momen and M. Farzaneh conducted a thorough investigation on the micro- and nano-filler to enhance the performance of outdoor silicone rubber insulators [23]. The survey's findings indicated that the two most widely used fillers were aluminum trihydrate (ATH) and alumina. ATH was used as an extending filler because it imparted tracking resistance and also served as a flame retardant, while alumina was used as a reinforcing filler because it increased tensile strength. Furthermore, studies have looked into the effects of various inorganic, metallic, carbonaceous, and organic fillers.

1.4.4 Hydrophobicity

Composite insulators have been utilized for outdoor electric power insulation since the early 1960s. The current generation of composite insulators has been developed over the last 25 years [24, 25]. Since the early 1960s, composite insulators have been in use. The most widely used insulator materials in the beginning were epoxy resin and ethylene-propylene-diene monomer (EPDM); but, in the 1990s, silicone rubber (SiR) composites started to get more attention for outdoor insulation, mostly because of their better hydrophobicity [26]. Since then, the use of epoxy resin and EPDM as insulators has decreased.

Because of its exceptional hydrophobicity and special ability to migrate, room temperature vulcanized (RTV) silicone rubber is starting to gain popularity. This causes the pollution flashover voltage for glass and porcelain insulators to climb significantly [27, 28]. This is the main cause of the rising popularity of RTV silicone rubber.

Numerous investigations have showed that RTV SiR's hydrophobicity degrades during corona discharge, with the majority of the degradation being attributed to the material's prolonged exposure to harsh environmental conditions [29]. Many factors, including measurement temperature, surface charge, surface roughness, and water droplet volume, among many others, affect hydrophobicity indices.

The extent to which the materials' state has degraded is determined by these indices. Therefore, it is crucial to take note of how these measurement factors affect the hydrophobicity assessment. A few of the articles that carried out a study of these implications are [30–34]. The primary methods for assessing the hydrophobicity of RTV silicone rubber include contact angle measurement, discharge studies, and Fourier transform infrared spectroscopy (FTIR) research [35–39]. While FTIR shows the shift in the function groups on the surface, the contact angle is essentially a direct measure of the hydrophobicity of the surface.

In [40–42], the researchers examined the shift in hydrophobicity, which is the transfer mechanism connected to the diffusion of low molecular weight (LMW).

1.5. Thesis Organization

The next chapter that is chapter 2 will discuss the many outdoor insulators that have been in use, a comparative analysis of them, and the various insulator coatings that are employed, with a focus on silicone rubber.

Chapter 3, presented the different several methods for evaluating the condition of high-voltage insulators.

In Chapter 4, several raw materials and equipment are briefly described, along with the sample preparation technique employed and the experimental setup and procedure or protocol are follows for measuring hydrophobicity and leakage current.

In Chapter 5, the experimental results of the two-part room-temperature vulcanized silicone rubber leakage current measurement, leakage current analysis, and static and dynamic hydrophobicity measurement are shown and discussed.

Chapter 6, providing the conclusion of the current investigation and the future scope of the work.

CHAPTER-2

BACKGROUND OF OUTDOOR INSULATORS

Chapter-2

2.1 Introduction

Adequate electrical insulation has been vital ever since electricity was invented. When it came to insulators used outdoors, the great majority were known as ceramic insulators since they were composed of glass or porcelain. Although polymeric composite insulators are swiftly overtaking porcelain as the most popular type of outdoor insulator, porcelain is still one of the materials used outdoors. In the past, the most popular kind of outdoor insulation was porcelain. The disadvantages of ceramic insulators, the advantages of polymeric insulators, and the strategies for improving ceramic insulator performance to match that of polymeric insulators will all be thoroughly covered in the sections that follow.

2.2 Ceramic Insulators

Ceramic insulators have been used as exterior insulators since the 1850s. Before then, porcelain insulators were used because they could be used as telegraph insulators. Nonetheless, because glass and porcelain are both incredibly robust materials that can tolerate high levels of arcing without significantly degrading their surface, ceramic insulators are still utilized in the electrical industry for exterior insulators. Additionally, ceramic insulators can endure heat and dry-band discharges with great resistance [1,2]. But the main problem with ceramic insulators is that their surfaces are very wettable, which becomes an issue when they are exposed to humid weather conditions like dew, rain, or fog. This is because materials with very high surface energy include ceramics.

It is commonly known that a considerable quantity of leakage current happens in moist and contaminated insulators. Eventually, this leads to flashovers and electrical system disturbances. Contamination of the insulators is one of the biggest problems with electrical power systems. This is due to the fact that flashovers, which happen when the surface leakage current is raised, are mostly caused by polluted insulators. Massive amounts of leakage current form on the insulator's surface as a result of impurities. Flashover eventually occurs as a result of this uncontrollably high leakage current [3]. Water films frequently form on the surface of the insulator when there is moisture in the air.

One of the biggest issues with ceramic insulators is their susceptibility to contamination. Surface deterioration is frequently brought on by contaminants; the kind of deterioration that results depends on the geography and environment of the affected area. Aging studies can be broadly classified as occurring in an urban or industrial zone, a rural area, or a coastal site, depending on the type of polluted deposit under study. The following section [42] analyses the categories.

1. In a city or an industrial region, the main causes of the buildup of pollutants in these areas are the emissions of pollutants from factories and the production of automobiles. Industrial pollution comes in a variety of forms, most of which are based on the type of industry, such as chemical, metallurgical, petrochemical, textile, etc. industries.
2. In rural areas, dust particles are the main source of pollution since they are either comparatively undeveloped or still undergoing development. The extensive application of fertilizers, herbicides, and pesticides is another element that might be responsible for the pollution deposit seen, at least in part.
3. One area that is particularly affected by the deposition of contaminants is the coastal region; these contaminants mostly manifest as salt deposits and salted moisture. Because of this, the coastal region is among the worst off. These types of contaminants can be found on insulators that are positioned up to a significant distance away from the sea, in addition to those that are placed adjacent to them. Salty moisture is carried by coastal winds that blow in the direction of the wind and deposit it on the insulator's surface, aggravating the contamination problem and increasing the amount of current that leaks through. Increased contaminant deposits on the insulator result from this.

The following are the main tactics that are employed to get rid of the problems with surface degradation and contamination, especially when it comes to pollution increasing surface wetness:

1. The electrical sector is seeing a rise in the usage of polymeric insulators due to their improved resistance to weathering, erosion, and corrosion. When it comes to endurance and durability, these synthetic insulators outperform conventional ceramic or glass insulators. Additionally, polymeric insulators are easier to install and carry due to their lower weight. Furthermore, they are less likely to break or crack under pressure, which could cause expensive downtime for power systems.
2. Applying a protective layer to a ceramic insulator's insulator surface to halt the degradation process: - From an economic perspective, these are the two most viable options now available, and a review of each has brought us to the next section. The following section (2.3) goes into considerable detail about the first option. However, the following section (2.4) goes into considerable detail about the second option.

2.3 Polymeric Insulators

For a long time—roughly more than 40 years at this point—polymeric insulators have been used as exterior high-voltage electrical insulators. However, they have been available for a very short time and are still mostly unknown, in contrast to ceramic insulators. The polymeric insulators themselves have a very high tensile strength, and their cores are incredibly durable. They are regarded as the insulators of the modern day because they have proven to be incredibly successful in addressing the problems with contamination performance and resistance to weathering and erosion that beset conventional insulators composed of glass and porcelain. Large mechanical loads may be handled by them, which is very helpful for transmitting extremely high voltages. Furthermore, they can also be built for non-traditional insulating constructions. Polymer insulators are far lighter, more vandalism-resistant, and perform significantly better against contamination than ceramic insulators. A similar degrading process occurs in a polymeric insulator when it is exposed to extreme weather or electrical stress over an extended period of time.

Most polymeric insulators are composed of silicone rubber (SiR) and ethylene propylene diene monomer (EPDM). Although EPDM has significant hydrophobic properties, it is not weather- or hydrophobicity-resistant [23]. The other main type of polymeric insulator is silicone rubber (SiR). Furthermore, these insulators have the ability to lower leakage current and provide strong resistance to weathering. The composite polymeric insulator typically has a weather shed composed of SiR or EPDM, a fiber-glass rod for mechanical strength, and metal end fittings on both ends for connection. In the composite insulator in Figure 2.1.

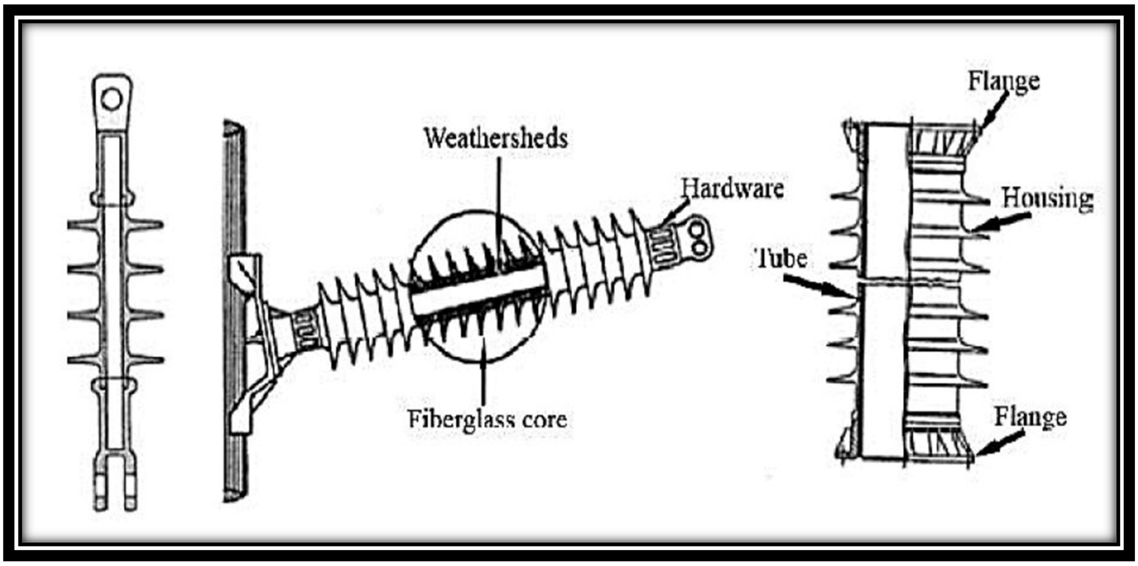


Figure 2.1: A composite polymeric insulator [23]

2.4 Coatings of Line Insulators

Ceramic insulators have always faced challenges from weathering and deterioration. The oil bath approach was used as early as the 1920s to prevent the insulator surface from becoming wet [42]. In the 1950s, petroleum jelly—a hydrocarbon coating technology—was widely used. However, it had drawbacks; therefore, silicone grease—a better coating—was used instead. Silicone rubber coatings, which are still in use today, supplanted silicone grease coatings in the 1980s.

2.4.1. Hydrocarbon Coatings

Petroleum-derived jelly was made up of hydrocarbon oils and a range of other petroleum fractions, the bulk of which were slack and microcrystalline waxes. It has been demonstrated that they soften with increasing temperatures and frequently melt near hot spots where electrical discharges occur. They ingest the pollutant as a result, but they return to their former state when they cool down. A minimum thickness of 3.2 millimetres and a maximum thickness of approximately 7.6 millimetres were shown to greatly reduce flashover, according to the results of multiple investigations [42]. They were expected to last three years in the workforce. As a result, it was found to be an economical decision in that regard.

The key issue was that because petroleum jelly melts easily, application could not be done in areas with moderate or high temperatures, despite the outstanding results in terms of the number of flashovers that occurred. It was found that after the tainted petroleum jelly had served its purpose, removing it was an extremely costly and labour-intensive process because the contaminants needed to be physically scraped off, which takes time [42]. Furthermore, materials containing silicone, which is known for its water-repellent qualities, became available due to technical advancements.

2.4.2. Silicone Grease Coatings

A material akin to silicone grease was used as an insulator's protective coating since hydrocarbon coatings on ceramic insulators were difficult to remove. Silicone compounds have also been employed for coatings on ceramic insulators due to advancements in these compounds, which are well-known for their high hydrophobicity and resistance to weathering. Silicone oil and silicone filler, the raw materials used to make silicone greases, decompose at temperatures above 200 degrees Celsius rather than melting. Unlike hydrocarbon coatings, they can be applied almost anywhere, in any weather condition [42].

The material's ability to maintain its greasy form even after being exposed to an electrical discharge is another noteworthy improvement over hydrocarbon grease. The insulator's high surface resistance was preserved by the grease-like components that prevented the surface from becoming wet, even in the presence of accumulated dust, salt, and other contaminants. A silicone rubber coating, even in damp conditions, was able to stop leakage current and maintain a high flashover voltage until the coating was totally saturated with the contaminant. It has been suggested that the coating's uniformity and thickness play a major influence in deciding how successful it is. It was found that a silicone grease containing aluminium trihydrate had much better antitracking resistance but a lessened ability to repel water. The silicone grease coating was prone to water erosion even though it was able to retain its hydrophobicity for a considerable amount of time. Furthermore, the coating needed to be reapplied more frequently than hydrocarbon coatings since the infusion and adsorption of particulate matter caused a loss of hydrophobicity after a set period of time. The process of eliminating silicone grease before reapplying took a lot of time and increased costs.

2.4.3. RTV Silicone Rubber Coatings

Room-temperature vulcanization (RTV) of silicone rubber (SiR) coatings has been applied to numerous electrical applications. They exhibit exceptional dielectric properties and flexibility over a wide temperature range, together with strong resistance to thermal degradation and corona discharges. The silicone rubber compounds, like all other silicone rubber compounds, exhibit strong water repellence because of their low surface energy. RTV SiR's hydrophobic surface aids in reducing the formation of dry bands and advancements in leakage current, both of which enhance contamination performance.

By adding filler to silicone rubber, a wide range of specific qualities can be achieved. The characteristics of the coatings are greatly influenced by the size, kind, and quantity of filler that is utilized. It is commonly known that the most effective fillers for enhancing mechanical qualities and providing anti-tracking resistance are aluminium trihydrate (ATH) and alumina [4,8].

After curing, a flexible elastomer with good dielectric properties is formed by spray-spraying the clean ceramic insulators with a thin layer of RTV SiR that is roughly 0.5 millimetres thick. It has been demonstrated that the coated surface of ceramic insulators typically maintains its hydrophobic qualities even after extended exposure to electrical stress. It has been noted that this exists. Moreover, the majority of SiR coatings contain low molecular weight (LMW) chemicals, which are responsible for the coatings' ability to recover hydrophobicity [42]. SiR coating has several advantages over silicone grease coatings, such as significantly less coating thickness applied, which lowers material consumption, labour savings, and a longer coating life that also proves to be cost-effective. SiR coatings last longer as well. The RTV coating application processes are simple and reasonably priced.

Furthermore, maintaining its water repellences and cleaning it is really easy. It has been demonstrated that RTV SiR coatings dramatically reduce the amount of money spent on insulator maintenance as a result of all of these factors.

2.4.3.1. Silicone Rubber Compounds

The surface resistance of ceramic insulators rapidly decreases in humid and coastal settings. This leads to an increase in leakage current, which in turn produces flashover and irreversible damage to the insulator. Polymeric insulators are being used in place of ceramic insulators in order to address this problem. The new insulators that are being installed are typically silicone rubber that has been heat-vulcanized, or HTV (SiR). On the other hand, room temperature vulcanized (RTV) SiR coating is added to the surface of in-use insulators in the case that they cannot be withdrawn from the system [4].

Synthetic, or man-made, silicone rubber is well renowned for its exceptional weatherability and capacity to maintain its properties across a wide temperature range. Another noteworthy quality of silicone rubber is its resistance to losing its flexibility in extremely hot or cold environments. Because of its low surface energy, resistance to oxidation, and ability to withstand UV light damage, SiR is employed as an electrical insulator. It can be utilized in this manner because of these qualities. The structure of the basic polymer used to make silicone rubber gives rise to these properties. Silicone rubber is resistant to weathering, heat stability, and oxidation because of the strength of the bonds between silicon and oxygen.

Moreover, silicone rubber has low surface energy and flexibility at low temperatures, both of which enhance its outstanding hydrophobicity. Its flexible polymer chains are primarily to blame for this.

Rubbers made of silicone are referred to as "polymers," and much like other polymers, they are made up of many molecules. The atoms in these molecules are arranged in a sequence like a chain, with the same fundamental structure at each link. Basic siloxane units that recur are assembled into a chain-like structure to form polysiloxane. The variable n indicates the total number of units that are repeated, and the structures are exactly the same. The molecules in issue are said to have a low molecular weight (LMW) and few discernible physical properties if this number, n, is quite low. The improvements to the physical properties persist as 'n' increases along with the molecular weight. Between 3000 and 10000 monomers can make up the length of a SiR polymer. The silicon atoms have organic side groups attached to them, most frequently carbon. Crosslinking and other specialized applications are made possible by this, including enhanced tracking resistance, weathering resistance, beat resistance, and so forth. SiR's methyl side group, which is attached to the siloxane unit, enables its water-repellent properties. Consequently, poly dimethyl siloxane (PDMS) is the word used to describe the polymer that is generated as a result of this procedure. Its basic unit is dimethyl siloxane [6]. SiR is classified as an organo-silicone compound due to the substantial bond that is formed between silicon, a member of the inorganic group, and carbon, a member of the organic group. This can be attributed to the link that forms between the inorganic group of silicon and the organic group of carbon. The basic building block of SiR, the dimethyl siloxane molecule, is shown in Figure 2.2. The poly dimethyl silicone basis of RTV silicone rubber is combined with extending and reinforcing fillers, low-molecular-weight silicone to increase its dynamic hydrophobic properties, and structuring additives to avoid crepe hardening. This rubber is frequently utilized in coatings for high-voltage insulators. The fundamental SiR unit, dimethyl siloxane, is shown in Figure 2.2.

The poly dimethyl silicone foundation of RTV silicone rubber, which is frequently used in high voltage insulator coatings, is combined with low molecular weight silicone to improve its dynamic hydrophobic qualities, extending and reinforcing filler, and structuring additives to lessen crepe hardening.

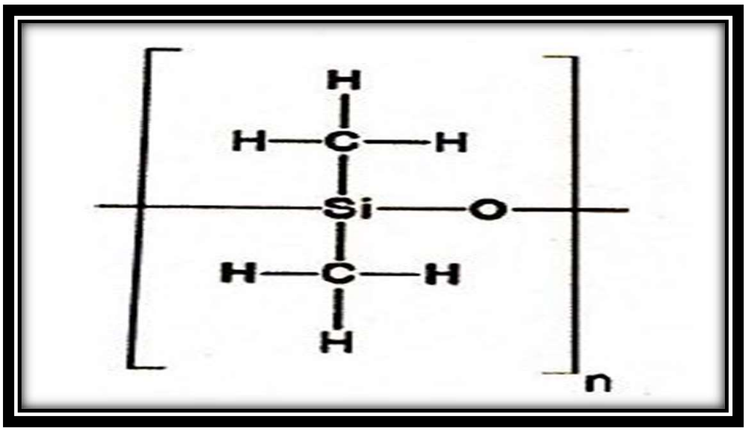


Figure 2.2: Dimethyl siloxane unit

2.4.3.2. Fillers

The base of silicone rubber (SiR) is frequently blended with fillers to improve the mechanical and electrical properties of the material. Another element that lowers the overall cost of composite insulators is fillers. Apart from the fact that fillers of the same kind can differ in size—micro filler and nanofiller, for instance, have very different properties—there are various other types of filler that can be used to improve a range of different aspects of SiR insulators. Due to varying surface treatments or surfactant compositions, fillers of the same type and size may accommodate diverse characteristics [23]. The extent to which filler enhances qualities depends on a number of factors, including filler particle size, structure, morphology, degree of dispersion, filler concentration, filler surface treatment, and adhesion and orientation in the matrix.

Depending on the properties it adds to the base polymer chain, the filler can be broadly classified as either an extending filler or a reinforcing filler. Generally speaking, the reinforcing filler increases the polymer's mechanical strength in areas like tensile strength, tear strength, abrasion resistance, and other such areas. While fillers that are longer generally enhance specific desired properties of the base polymer, Aerogel, carbon black, and alumina Fillers that are known for their ability to extend are titanium dioxide, zinc oxide, and aluminium trihydrate; fillers that are known for their ability to reinforce are alumina and zinc oxide. The most often used filler in silicone rubber is listed in Table 2.1, along with the attribute that is enhanced by utilizing it [23].

Table 2.1: Fillers details and the corresponding property enhanced [23]

FILLER TYPE	PROPERTY ENHANCED
Zinc oxide	Mechanical properties and electrical conductivity
Titanium dioxide	Thermal strength and relative permittivity
Alumina	Insulating, erosion resistance, high thermal conductivity
Silica	Mechanical properties and antitracking
Barium titanate	Thermal stability and relative permittivity
Calcium carbonate	Flame retardant and hydrophobicity
Carbon black	Mechanical and electrical properties

CHAPTER-3

CONDITION ASSESSMENT TECHNIQUES

Chapter-3

3.1 Introduction

Since the insulators' level of dependability affects the system's overall dependability, monitoring insulators is crucial for the power system to operate efficiently. Some of the most significant condition evaluation techniques now employed for effective system monitoring are hydrophobicity measures, Fourier transform infrared spectroscopy (FTIR), scanning electron microscopy (SEM), leakage current measurements, and FTIR. There are a ton of different condition evaluation techniques accessible these days. This section reviews several condition evaluation approaches, with an emphasis on the methodology for measuring hydrophobicity and leakage current. This is because the goal of this research was to evaluate the status of insulators using these methodologies.

3.2 ESDD Measurement

As a measure of contamination severity, researchers have proposed equivalent salt deposit density (ESDD) and non-soluble salt deposit density (NSDD) for simulating the polluted environmental situation and pollutant on the insulator surface. To obtain the required ESDD values, kaolin (Al Siz05(OH)4) and sodium chloride (NaCl) are often combined in distilled water.

Temperature and pollutant conductivity are used in ESDD estimates. Equation (3.1) provides the formula for conductivity at 20°C based on IEC 60507 [38].

$$\sigma 20=\sigma\theta[1-b(\theta-20)] \tag{3.1}$$

Were,

$\sigma 20=$ is the volume conductivity at 20oC (S/m)

$\sigma\theta$ = is the volume conductivity at θ°C (S/m)

$\theta=$ is the solution temperature in oC

b= is a factor depending on θ.

The relationship between salinity (Sa) and volume conductivity at $20o$ C is given in equation (3.2) as

$$Sa=(5.7\sigma 20)1.03 \tag{3.2}$$

And ESDD is calculated from the value of salinity using the equation (3.3)

$$ESDD=Sa\times V/A. \tag{3.3}$$

3.3 Scanning Electron Microscopy

The technology of scanning electron microscopy (SEM) has been crucial in clarifying the surface topography of insulating materials since its inception over forty years ago. It gives us a magnified image of the surface, just like an electron microscope does. An electron beam is accelerated and directed towards the surface whose topography is being studied using the scanning electron microscope (SEM) method. Four separate groups of electrons are formed when they collide with a surface: the stopped electrons, the absorbed electrons, the deflected or secondary electrons, and the reflected electrons, also known as back scattered electrons.
The electrons that are stopped when they strike a surface are known as stopped electrons. This causes energy to be transferred to the sample, which in turn excites the material's electrons and gives it a luminous appearance. X-rays are produced when another set of electrons is ejected from the surface as a result of the second set of electrons that are absorbed by the sample. The first set of electrons is also absorbed by the sample. While reflected electrons return back towards the source, deflected or secondary electrons move in their direction. In order to offer a comprehensive analysis of the surface shape, surface deterioration, and surface roughness down to the micro meter range [26], each of these electron groups is detected and collected.

3.4 Fourier Transform Infrared (FTIR) Spectroscopy

It is a similar technique to SEM for evaluating the quality of insulators, but instead of focusing on topographical changes, it emphasizes structural changes made to the insulator [26]. It is a quantitative measurement technique that can be applied to inorganic or organic chemicals, although it is most frequently employed for organic molecules. The underlying principle is that any material subjected to infrared light will absorb radiation at a specific frequency, which will then coincide with the frequency at which the material's constituent atoms vibrate. The principle of infrared heating is based on this notion.

Accordingly, in this method, the samples are subjected to infrared light, and they absorb radiation at frequencies that match the atoms' vibrational frequencies. As a result, the approach produces precise outcomes. As a result, when examining the obtained infrared spectra, a dip might be observed in that frequency range. The constituent parts are then identified by comparing an infrared spectrum with a predefined set of spectrum curves. Since it enables us to measure the FTIR response of fresh samples, compare it with the FTIR response of aged or deteriorated samples, and analyse variations in either of those responses, it is particularly useful for studies on sample degradation. This is a really practical method.

3.5 Leakage Current Measurements

One of the key elements that affects how effectively an electrical power system operates is insulation. These days, polymeric insulators are widely used in high-voltage distribution and transmission, and because of their affordability and adaptability, they are gradually capturing a sizable share of the market. The advantages that polymeric insulators offer over more conventional materials like glass and porcelain have led to their explosive growth in popularity. Among these advantages are reduced surface energy, lighter weight for equivalent capacity, enhanced mechanical strength, resistance to vandalism, and noticeably better functioning in wet and contaminated environments. Polymeric composites' ability to serve as a long-term high-voltage insulator is assessed by a design test that combines an accelerated aging test with a normal aging test. In order to perform diagnostics on the insulators, the performance of polymeric insulators is assessed using a range of measuring techniques. Comparable salt deposit density (ESDD), surface conductance, leakage current measurement, and non-soluble deposit density (NSDD) are the most widely used methods for tracking and studying the performance of polymeric insulators. Hydrophobicity and aging are two more important factors that affect how well insulators operate under electrical and environmental stress [22]. These circumstances could have a detrimental effect on the performance of insulators. Growing leakage currents (LC) and discharges cause a significant acceleration of the deteriorating process on the polymeric insulator's surface. The measurement of LC is frequently done in both lab and field research to assess the performance of polymeric insulators after accounting for their age. The process of understanding the surface condition and degeneration of the polymeric insulators is greatly aided by leakage current analysis, which is an essential component of this process. It was started by discussing the mechanism that generates the leakage current, and plotted against temporal and frequency respectively.

3.5.1. Leakage Current Analysis

A source voltage is used to drive the LC, which is collected at the ground end of the insulator and provides a wealth of useful information on how to determine the current condition of a polymeric insulator that has been polluted. When the applied voltage is low or the level of contamination is low, the LC frequently exhibits capacitive behaviour and a sinusoidal waveform. The LC will begin to act more resistantly if the applied voltage exceeds a certain threshold or if the level of contamination rises above a predetermined point. The discharge of dry bands causes the LC crest to become covered in spikes. This results in the LC current's waveform becoming distorted, which raises the harmonic content. There are five separate stages that are thought to comprise the alterations that occur in the LC waveforms before flashover occurs. The likelihood of a flashover increasing increases when the magnitudes and harmonic contents surpass a certain threshold that is deemed typical [17]. Surface discharge activity is ultimately caused by chemical processes occurring on the materials' surfaces, and this deterioration of the materials' mechanical and electrical properties follows. Deteriorations include the implementation of tracking and a decrease in material weight. Furthermore, tracking can be viewed as a degrading technique. When the surface state of polymeric insulators changes, it affects both the LC's form and size. The mathematical analysis reveals a nonlinear relationship between the length of the arc, the surface discharge, and the temporal fluctuations of the leakage current. If the surface discharge extension exceeds the air's electrical breakdown stress, this will happen. Consequently, this will cause the LC's size and form to change. Consequently, RMS and the present peak value are insufficient metrics to assess the surface condition. In the end, this gives rise to the notion of analysing the LC waveform in the frequency domain [15]. However, the moving average approach is applied to the LC waveform to smooth out the temporal fluctuation and produce a more realistic picture of the LC pattern before employing a tool for frequency domain analysis. Prior to doing frequency domain analysis with the tool, this was completed.

3.5.2. Moving Average Technique

The moving average methodology is employed as a method to comprehend the usual variation of LC throughout time. There are fewer fluctuations over time and, as a result, a better indication of the trend in the variation of the LC magnitude throughout the period since the characteristic variations are smoothed out as a result of having an average magnitude of the LC that moves with the addition of new data points. A moving average can be defined as the average current value at a certain point in time. This is a concise definition of what a moving average is and does. Moving average techniques come in many different forms, including the time series moving average method, the exponential moving average method, and the basic moving average approach. The concept of employing a simple moving average has been applied in this investigation. The window size to be used when computing the moving average with the expression given in equation (3.4) is chosen to consist of k points.

$$\mathrm{X_i} = \sum_{N=i}^{N=i+k} Yn/\mathrm{k} \qquad (3.4)$$

In this case, the raw data points Y_N correspond to the calculated moving average points Xi. 25 data points have been collected for this work period.

3.5.3. Fast Fourier Transform

Frequency domain analysis is the process used to ascertain the precise harmonic composition of the leakage current signals. The technique used to extract the harmonic content from the signals is called Fast Fourier Transformation (FFT). Realistic results are produced using the efficient FFT analysis technique, which is ideal for large-scale signal processing. The signal can be transformed from the time domain to the frequency domain using either the Fourier series or the Fourier transform. The Discrete Fourier Transform, or DFT for short, is a highly effective computer tool. This tool can also be used to assess a discrete signal's Fourier transform. Using the symmetric properties of the trigonometric functions can reduce the number of complex multiplications required by the DFT, which is around N2. Tukey and Cooley created the Fast Fourier Transform (FFT) algorithm in 1965. By using this method, the number of operations needed to compute DFTs is lowered by a factor equivalent to N log N. Because of this, the FFT is regarded as an N log(N) algorithm. As a result, the speed increase is approximately equal to (log, N)/N, where N is the duration of the time series that was sampled.

Let x(t) be the time domain representation of the given signal x then the frequency domain representation of the signal x is given by in the equation (3.5).

$$X(f)=\int X(t)e-j2\pi\infty-\infty dt \qquad (3.5)$$

The amplitude spectrum of the leakage current in amperes rms is computed by the equation (3.6).

$$\text{Amplitude of LC } (I_{rms})= \frac{\sqrt{2}Magnitude[FFT(A)]}{\mathrm{N}} \qquad \text{for i = 1 to (N/2-1)}$$

Where A is the leakage current in the frequency domain.

3.6 Hydrophobicity Measurements

Hydrophobicity is the property of a substance that prevents water from passing through its surface. When water is dropped on a material, it is said to be hydrophobic if it stops the water from running off of it, and it is said to be least hydrophobic if the water flows off of the material's surface in a trail. A hydrophobic surface is one that resists absorbing water, while a hydrophilic surface is one that easily absorbs water. Any material's hydrophobicity can be determined by measuring the contact angle (c) formed by a drop of liquid coming into contact with a solid surface. This angle is frequently used to gauge how wettable a surface is. The ease with which a liquid can permeate a surface is known as its hydrophobicity. A material is referred to as "easily wettable" if it has a contact angle of much less than 90 degrees and permits water to come into contact with a sizable portion of its surface. On the other hand, a material that results in a contact angle greater than 90 degrees and permits less water contact with the surface is referred to as "hydrophobic."

The contact angle provides information regarding surface energy, surface heterogeneity, and surface roughness. The two main classifications for solid surfaces are high-energy surfaces and low-energy surfaces. A high-energy surface may be easily wetted, and the water will spread out to form a continuous film with a zero-contact angle over the entire surface. The creation of individual droplets on a surface with a contact angle greater than 90 degrees will occur when a surface with low energy rejects water nonetheless. The degree to which a surface is contaminated can also be ascertained using the contact angle.

An insulating substance's hydrophobicity can be measured quantitatively by looking at the contact angle formed between a water droplet and the surface of the material. The tension that exists between the material's atoms and the water interface is directly reflected in this angle. The type of solid material being tested for hydrophobicity, as well as the chemical and physical state of the solid substance's surface, have a significant impact on both the form of the liquid droplet and the contact angle [32].

A surface is considered hydrophilic when there is less than a 35-degree contact angle between a water droplet and it. A surface is considered hydrophobic when there is a contact angle greater than 90 degrees between the water droplet and the surface. It is stated that surfaces that have contact angles between 35 and 90 degrees are moderately wettable. It is noteworthy that the term "hydrophobicity" actually refers to "resistance to water," while it is sometimes used to denote "resistance to any liquid."

Static and dynamic hydrophobicity measurements are the two types of hydrophobicity performance measurements that can be made of a substance. The measurement that is regarded as static is the hydrophobicity of the raw material, or the hydrophobicity of the material under normal stresses [40]. Dynamic measurements include the following: hydrophobicity loss after prolonged exposure to electrical stress; hydrophobicity transfer after contamination; and, depending on the situation, hydrophobicity recovery after the electrical stress is eliminated or the contamination is cleaned off.

3.6.1. Hydrophobicity phenomenon

Understanding surface tension and surface energy is essential before attempting to understand the hydrophobicity phenomenon. The phrase "surface tension" refers to a fluid's tendency for its surface to constrict into the lowest feasible surface area. In the case of liquid air, it may be stated as follows: Surface tension is the result of a stronger force of attraction between liquid molecules due to cohesion than there is between air molecules due to adhesion. The surface becomes tight as a result of the imbalanced pressures, which is where the term "surface tension" comes from. Depending on how you look at it, force per unit length or energy per unit area is the dimension of surface tension. Although the two dimensions are similar, it is better to talk about surface energy when considering energy in terms of area because it is a more general idea that also applies to solids. The term "surface energy" describes the surplus energy present at a material's surface above its bulk. Stated differently, surface energy can be defined as the work required to split a bulk sample in half, resulting in two surfaces.

There is a relationship between a surface's contact angle and wettability [40–42]. A water droplet's contact angle depends on the surface's free energy, and the surface's wettability is correlated with its contact angle. The relationships between the free energies are established by Young's equation, represented as equation (3.7). There is no difference between surface tension and surface energy; they can be used interchangeably. Figure 3.1 shows the surface tension at the interface, as well as the generated contact angle and a droplet of water.

$$\cos\theta_y = \sigma_s - \sigma_{sl} / \sigma_l \tag{3.7}$$

where θ_y= *Young's* contact angle

σ_s= surface tension of the solid

σ_{sl}= surface tension of the solid-liquid surface

σ_l=surface tension of the liquid.

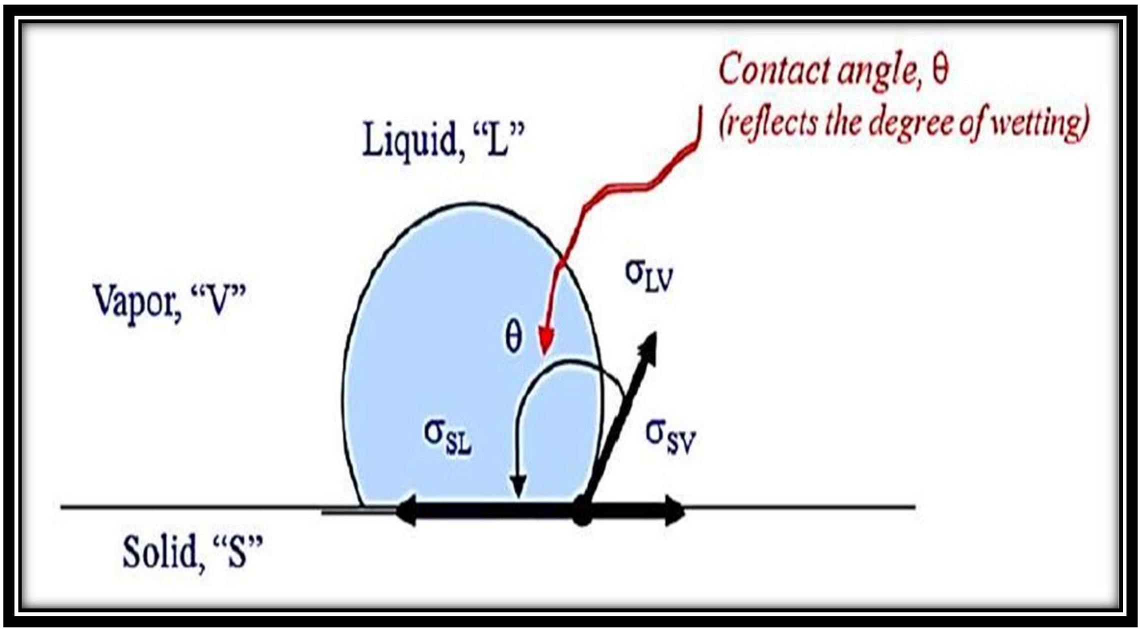


Figure 3.1: Contact angle and surface tension for water droplet

There will be some adhesion when separate phases of liquid and solid are brought together; this energy is represented as $wc=2\sigma$. The symbol a represents the energy needed to form two new surfaces, while the sign wsl represents the energy needed to keep the cohesiveness. The formula $W_{Sl} = 20$ represents the energy needed for a pure phase. The relationship between the surface energy of the liquid and solid given as a function of the unit area of contact and the energy required to separate them is explained by the Dupre equation (3.8).

$$\sigma_{sl}=\sigma_s+\sigma_l-w_{sl} \quad (3.8)$$

For two identical which adhere perfectly, $\sigma_s=\sigma_l$ and $W_{sl}=W_C$ therefore $\sigma_{sl}=0$

On combining equation (3.7) and (3.8) the resulting equation (3.9),

$$w_{sl}=\sigma_{sl}(1+cos\theta_y) \quad (3.9)$$

It will wet all solid surfaces with values of σs greater than the surface free energy of water, and it won't wet any surfaces with smaller values. The stronger the contact and angle, the lower the value of σs.

3.6.2. Hydrophobicity Measurement Methods

As the previous explanation has made quite evident, hydrophobicity measurements are required to assess the condition of outdoor insulators, especially those situated in wet and coastal environments. The two main methods for figuring out how hydrophobic a material is are the sessile drop technique, which measures the contact angle, and the STRI categorization guide.

3.6.3. STRI classification Method

The Swedish Transmission Research Institute, or STRI for short, developed a novel method of quantifying hydrophobicity by classifying the different stages of hydrophobicity. The STRI approach involves misting a cleaned surface that is between 50 and 100 cm³ with distilled water to determine how hydrophobic it is. This process is not too complicated. The drop pattern that remains on the surface is caused by one of the seven distinct classes of hydrophobicity, which range from HC1 to HC7 [27]. The symbol HC1 indicates the surface that is the most hydrophobic, while the letter HC7 indicates the least hydrophobic surface. A reference guide for the STRI classification is shown in Figure 3.2, which includes HC1 through HC6.

3.6.4. Contact Angle Measurement

The drawback of the STRI categorization method is that it depends on human judgment; hence, the outcomes could vary depending on the person using it. To overcome this challenge, the hydrophobicity is ascertained using the contact angle measurement or the sessile drop method [35]. To implement this method, a syringe is used to inject a drop of water onto the surface whose hydrophobicity is to be evaluated. The contact angle can be accurately measured with a goniometer. The contact angle measurement could fall within the category of contact angle measurements if the drop's volume is kept constant. A water droplet's volume is increased until it barely begins to flow for the advancing contact angle measurement, and its water content is decreased until the droplet starts to recede for the receding contact angle measurement. These steps are taken to determine the water droplet's advancing and receding contact angles. This makes it possible to analyse the advancing and retreating contact angles in more detail. Figure 3.3 displays the advancing and retreating contact angles.

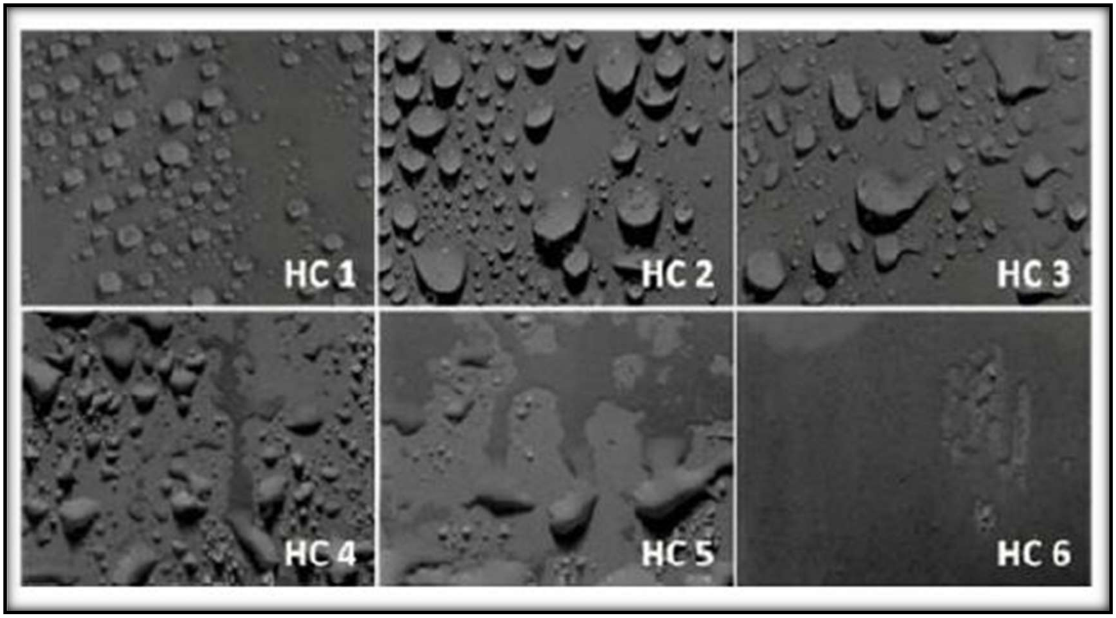


Figure 3.2: Hydrophobicity classification from HC1 to HC7[39]

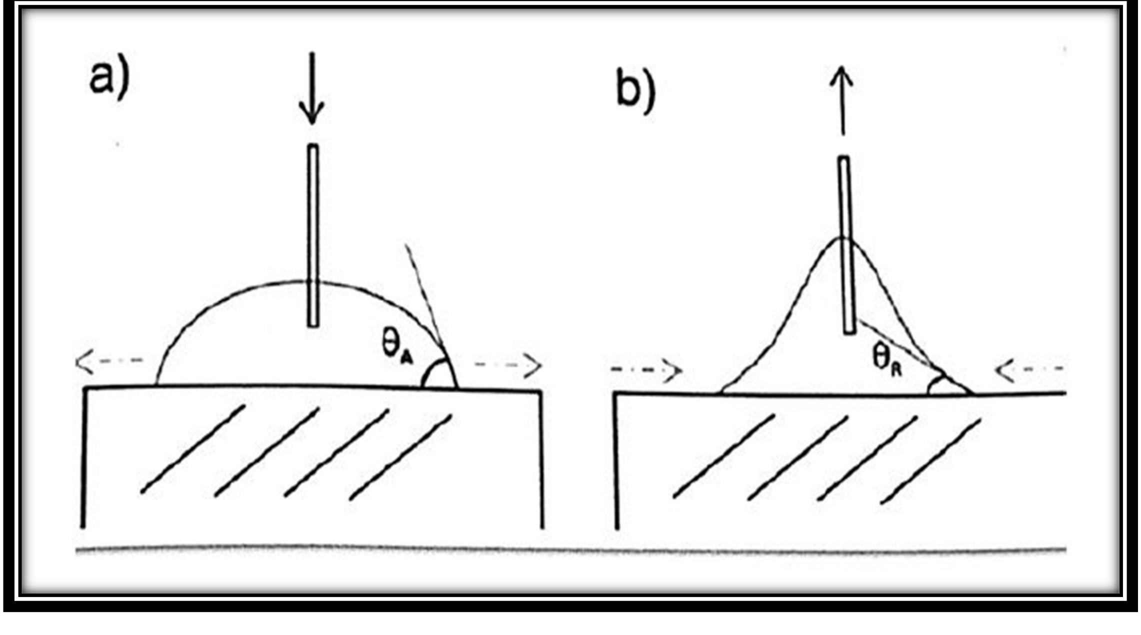


Figure 3.3: (a) Advancing contact angle; (b) Receding contact angle [43]

CHAPTER-4

SAMPLE PREPARATION AND EXPERIMENTAL PROCEDURE

Chapter-4

4.1 Introduction

Two tests were primarily conducted on samples of vulcanized silicone rubber that were manufactured at room temperature with varying concentrations of alumina nanofiller: the hydrophobicity test and the leakage current test. This part covers the specifics of the raw materials utilized, the laboratory apparatus used, the experimental setup, their schematic diagram, and the experimental protocols.

4.2. Material Used

The use of various extending and reinforcing fillers was covered in the previous chapter, along with a thorough structure of Silicone Rubber's (SIR) base polymer. A two-part room-temperature vulcanized (RTV) SIR without any preloaded filler was employed in this investigation. It was purchased from a Chemzest Technoproducts Pvt. Ltd. distributor because it included a catalyst for hardening the LSR-2 series. Figures 4.1 and 4.2 display the catalyst and the potting glue. This potting gel is used for embedding and potting electrical and electronic equipment, as well as coating insulating material. It is a transparent, viscous, thick liquid with a specific gravity of 0.97 at 25°C when it is uncured. The technical data sheet has been consulted for a comprehensive grasp of its usage and duration of operation [12].

Like to be focused on alumina filler, which has historically been employed as a reinforcing filler to provide mechanical strength, in order to assess the performance of SiR with the inclusion of filler. It can be discovered that alumina filler worked the best out of all the commercially available fillers, including silica, zinc oxide, titanium oxide, and aluminium trihydrate. The three primary types of alumina filler that can be utilized as reinforcing filler are silica, precipitate alumina, and a combination of fumed and precipitate alumina. The most popular kind of alumina filler is alumina. FANG Su [14] together with others carried out studies to find out how each of these three different fillers affected the tensile and shear strengths of the RTV SIR. The main goal of this inquiry is to observe the impact. Alumina filler affects SR's surface characteristics and dielectrics. In this experiment, fillers such as Aerosol fibre and fumed silica gel were employed. A container for alumina & TiO_2 nanofillers is depicted in Figure 4.4 & 4.5. Ninety-mm alumina casts have been employed. The aluminium cast that is used for mixing is shown in Figure 4.3.

Figure 4.1: RTV SiR Liquid

Figure 4.2: Hardener

Figure 4.3: 90mm diameter aluminium cast

Figure 4.4: Alumina Nano fillers

Figure 4.5: Titanium dioxide Nano fillers

4.3. Equipment

This experimental effort requires a large amount of laboratory equipment to be completed. The high-tension laboratory at Jadavpur University houses this apparatus in addition to others for detecting leakage current, mixing samples, degassing, and figuring out hydrophobicity. This section lists all of the several pieces of equipment that were utilized, describes their purpose, and provides a graphical representation of that purpose.

4.3.1. Electronic Analytical Balancing Unit

Small amounts of mass, such as sub-milligram amounts, are measured using a kind of balance known as an "analytical balance," as illustrated in Figure 4.6. An analytical balance (0.1 mg or better) has a measuring pan housed inside a clear box with doors to keep dust out and air currents in the room from affecting the balance. This building is commonly referred to as a draft guard. The balance does not shift when you use a manually ventilated safety cage with specially designed acrylic air foils because the airflow is smooth and turbulence-free, allowing you to measure mass down to 1 g without experiencing any shifts or product loss.

In order to prevent air currents from forming inside the container as a result of natural convection, which could skew the results, the sample must also be at room temperature. Throughout their useful lives, single-pan mechanical replacement balances have reacted consistently. This is accomplished by removing mass from the same side of the beam as the sample is inserted while maintaining a constant weight on the balancing beam and, consequently, the pivot. Electronic analytical scales measure without the need for actual masses. Rather, the force required to oppose the mass being measured is measured. They must therefore be re-calibrated to take variations in gravity pull into account. In order to find the answer, they measure the amount of force required to get the sample to balance out using an electromagnet to create a force. An instrument used to measure things like this is called an electromagnetic force repair monitor.

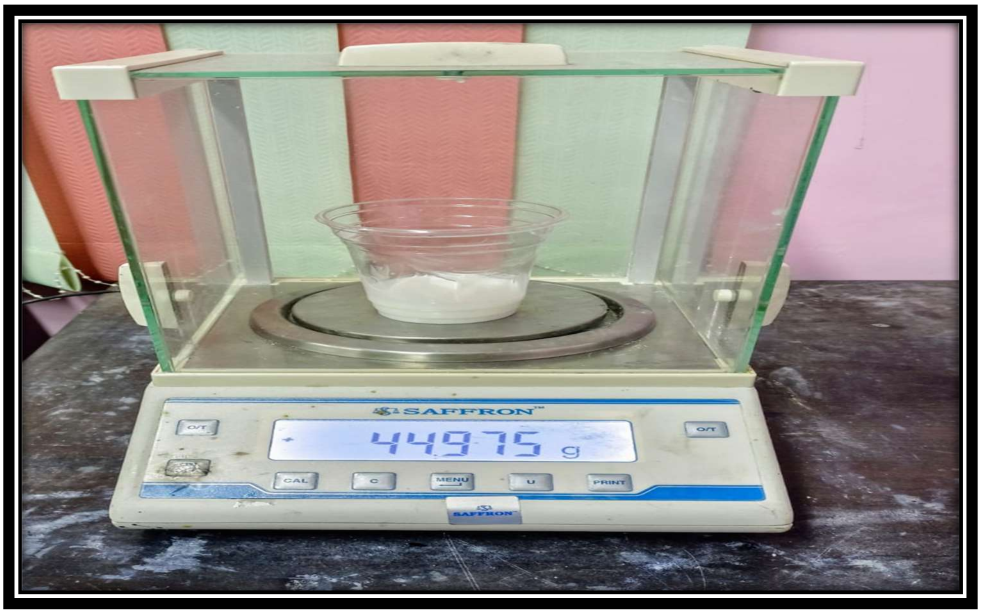


Figure 4.6: Analytical Balancing Unit

4.3.2. Goniometer

The STRI classification is one way to determine a substance's hydrophobicity, while the measurement of the contact angle is another. The tool that helps us determine the contact angle is a goniometer, and the configuration of the goniometer in the laboratory is depicted in Figure 4.7. First, it takes a picture of the water droplet on the sample, and then it uses a process called pixel calibration to determine where the triple point of contact is between the air, the water droplet, and the sample. Next, it determines the angle of contact between the water droplet and the sample surface using a number of approaches, including the tangent, the ellipse, and the half angle, among others. The device comes with a manually operated water delivery mechanism with a minimum controllable volume of 0.20 l. The device uses a regulated light source to measure contact angles with accuracy and contrast across a variety of sample colors. Furthermore, it is equipped with a tilting mechanism to measure the contact angles of deformed and uneven samples. It has a fairly high pixel resolution of 744 by 480. Five magnification powers are used, and the frame rate is fixed at 75 frames per second. The accuracy of the goniometer that Apex Instruments sells is up to +0.5 degrees.

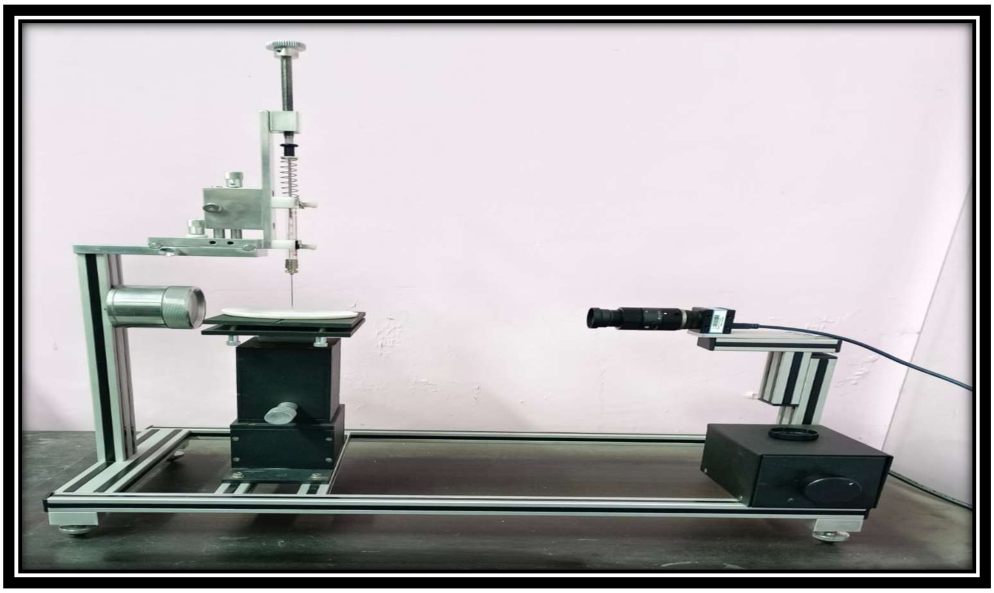


Figure 4.7: Goniometer

4.3.3 Heating Chamber

During the initial stage of sample preparation, a heating chamber—a device that uses a thermostat to maintain a constant temperature inside the system—was employed. A thermostat is a device that senses the system's temperature and then takes the necessary action to maintain the temperature at a given level. The fumed silica nanofiller used in the experiment needs to be de-stirred for half an hour. The presence of particles causes the filler to agglomerate and increases surface area, which prevents the filler from dispersing sufficiently in the RTV slicone rubber. It has a temperature indicator that is digital. The heating chamber arrangement is shown in Figure 4.8.

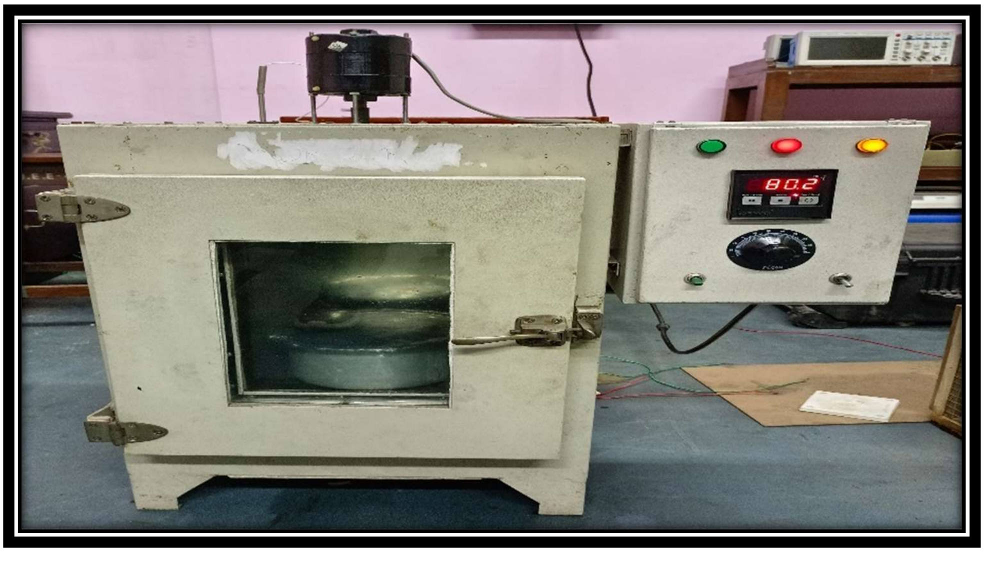


Figure 4.8: Heating Chamber

4.3.4 Degassing Unit

The degassing or vacuuming stage of the sample preparation procedure is very important because trapped gas bubbles or holes in a material greatly reduce its insulating properties. As part of the degassing procedure, elastomer-containing Molds are inserted into the degassing unit. The application of vacuum lowers the pressure within the chamber, which causes the evolution of gases and air bubbles since Henry's Law states that a reduction in pressure lowers the solubility of gases and air bubbles in elastomers and causes their development. This happens as a result of the vacuum applying a reduction in the internal pressure of the chamber. The typical procedure for vacuuming involves connecting a pump to the chamber's outlet and sucking air out of it to generate a vacuum, which lowers pressure. Two vacuuming are done while the sample is being prepared: one right after the uncured rubber is poured, and the other right after the catalyst and filler are added. Up to -1 atmosphere pressure can be reached using the degassing apparatus. Figure 4.9 shows the degassing unit that is available in the lab.

Figure 4.9: The Degassing unit

4.3.5. Magnetic stirrer

The electrode magnetic stirrer used to mix the liquid with the catalyst is shown in Figure 4.10. A revolving magnetic field is used by magnetic stirrers to move a stir bar through a liquid sample. A hot plate that stirs the liquid is another feature of some magnetic stirrers. The samples are well mixed thanks to the rapid movement and agitation of this stir bar. The magnetic field's speed can be adjusted by the operator to suit the sample being mixed. Use glass or other non-metal beakers with these stirrers to avoid tampering with the magnetic field.

Figure 4.10: Magnetic Stirrer

4.3.6. Digital Storage Oscilloscope

To test the leakage current, a TEKTRONIX TBS1152 digital storage oscilloscope was employed. It is utilized to enable the quick and simple saving of leakage current data inside a flash drive via the USB 2.0 host port on the front panel. It has a 150 MHz bandwidth, a maximum sampling rate of 1 GS/s, and a 2500-point data record length on both channels. One GS/s is the maximum sampling rate. Figure 4.11 displays an image of a digital storage oscilloscope.

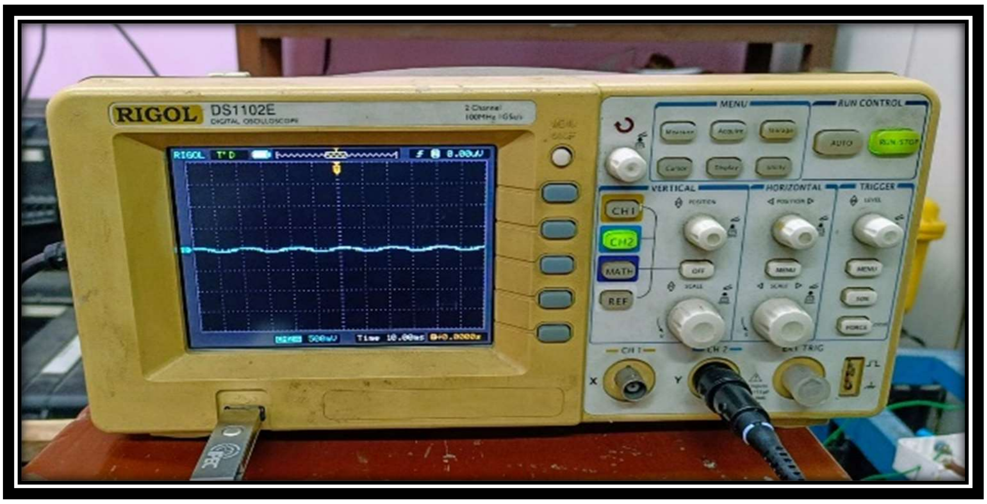


Figure 4.11: Digital Storage Oscilloscope

4.4. Sample Preparation

The preparation procedures used while creating insulating material samples in a lab always impact the material's surface properties and dielectric properties. Thus, as previously discussed in this part, the following are the significant activities that were undertaken:

1. Ethyl alcohol is used to thoroughly clean the mixing container and the castings in order to get rid of any potential contaminants.

2. Next, the RTV silicone rubber and hardener are put on a degassing device at 40 degrees Celsius for two hours. Afterward, the rubber is carefully poured into the mixing container to release as much air as possible.

3. To dehumidify the nanofiller, the measured weight percentage of filler is placed in the heating chamber and heated to a steady 1500 °C for 24 hours. After that, the catalyst and nanofiller are combined in a mechanical stirrer for an hour at 750 r.p.m. with the RTV silicone rubber. The mixture was then put back into the degassing machine for another 15 minutes at a steady pressure of -1 atm.

4. The influence of uniform dispersion achieved by mixing with ultrasonic agitation at 24 kHz for 1 hour, followed by degassing, is significant because degassing releases previously confined air pockets. The mixture is then mechanically mixed for ten minutes after the predetermined amount of catalyst (1 ml of catalyst for every 30 ml of RTV silicone rubber) is added. It is then put in a degassing machine set at -1 atmosphere pressure for fifteen minutes.

5. In order to maintain the samples' 3millimeter thickness throughout the batch, 18.5 grams of samples were added to each cast after the degassing step. Each cast was re-inserted into the degassing apparatus and allowed to sit for five minutes in order to release any trapped air while the samples were being poured.

6. To prevent dust or other particles from landing on the object's surface, the castings are kept in a protected environment. The formation of the skin will start once the samples have been left undisturbed for about six hours. The samples can be removed from the cast after four hours because they have reached the point of ultimate cure.

7. In order to account for the likelihood that sample settling and internal bond formation are still developing, tests on samples should be performed 48 hours after the samples have been fully cured.

Figure 4.12 displays the laboratory's output in the form of six alumina samples and six titanium dioxide and one pure with different filler concentrations, and Figure 4.13 displays the flow chart for the entire project.

Table 4.1: Sample details of Silicone rubber composite.

Name	Description
S1	Pure Silicone rubber
S2	Silicone Rubber + 0.25%wt aluminium oxide
S3	Silicone Rubber + 0.50%wt aluminium oxide
S4	Silicone Rubber + 1%wt aluminium oxide
S5	Silicone Rubber + 1.5%wt aluminium oxide
S6	Silicone Rubber + 2%wt aluminium oxide
S7	Silicone Rubber + 2.5%wt aluminium oxide
S8	Silicone Rubber + 0.25%wt titanium dioxide
S9	Silicone Rubber + 0.50%wt titanium dioxide
S10	Silicone Rubber + 1%wt titanium dioxide
S11	Silicone Rubber + 1.5%wt titanium dioxide
S12	Silicone Rubber + 2%wt titanium dioxide
S13	Silicone Rubber + 2.5%wt titanium dioxide

Figure 4.12: RTV SiR samples with difference filler concentration.

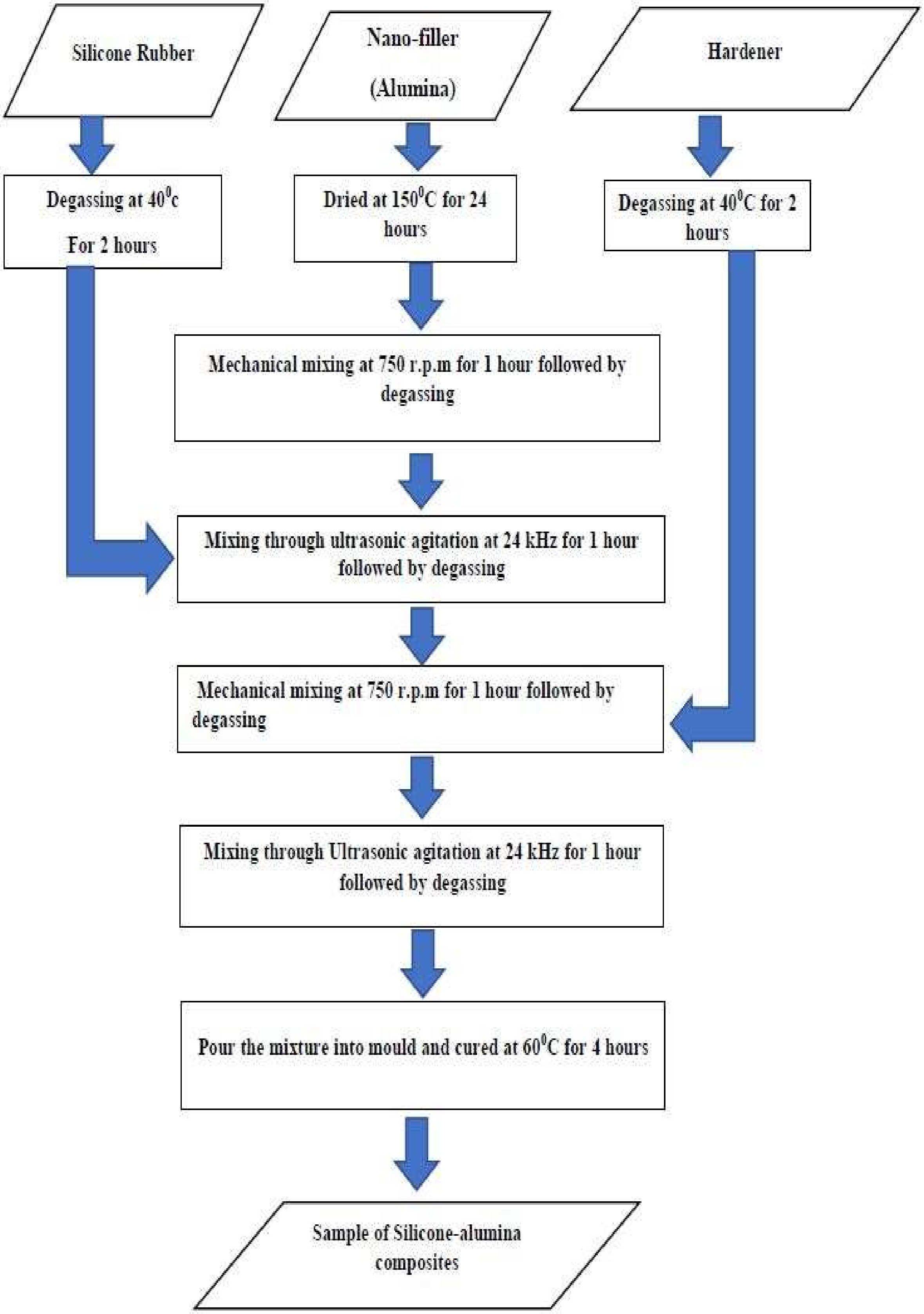


Figure 4.13: Flowchart of the preparation of silicone rubber nanocomposites samples.

4.5. Experimental set up of aging process

Silicone rubber samples were immersed in 3% salt for five liters at 80 degrees Celsius in a glass beaker. The 40 days aging period is used in the same experimental setting as that described in time selected to add to the 1000-hour experimental aging period that was used previously. This experiment's accelerated aging was meant to serve as an extreme example of polymer deterioration.

The temperature of 80°C was chosen for aging in order to simulate potential in-service circumstances. About once a day, the salt solution was manually stirred. One sample was taken out of the solution for analysis once a week. After giving the samples, a quick wash with deionized water, they were left to dry for 72 hours under a heat lamp at room temperature and 20% relative humidity.

Using a thermometer, the surfaces temperature was recorded while they were drying and was discovered to be roughly 30°C. Measurements of mass changes were made on a fully dried samples, and mass loss was tracked using the mass change percentage. A typical Shore A Durometer with a measurement range of 1HA to 100HA was used to conduct the hardness testing. When the sample was flush against the Durometer plate, readings were taken using a Durometer needle that was positioned perpendicular to the samples. SEM analysis was performed on all aged samples, and a subset of SEM images was chosen to accurately depict the sample surface. Following drying, samples were photographed, and for appropriate comparisons, changes were noted at the same magnifications.

4.6. Leakage Current Measurement

The experimental arrangement is diagrammatically shown in Figure 4.14, and the full experimental setup is shown in Figure 4.13. The top electrode of the electrode arrangement is connected to the high-voltage source, which can have a voltage of any value between zero and ten kilovolts. To make sure that the sample and electrode centre are correctly aligned, the sample is placed as precisely as possible in the space between the electrodes. If this isn't done, there's a chance that each side's current leakage route will have a different length. From the ground electrode to the current divider circuit, the leakage current flows. After that, the digital storage oscilloscope (DSO), which measures the LC across the samples that are situated between the electrodes, receives the voltage magnitude across the series resistor. To facilitate additional analysis utilizing the captured LC waveform, the data saved to the DSO's flash memory is copied to a personal computer. Furthermore, to protect the measuring instrument from any overvoltage that might happen in the event of an accident involving the experimental setup, an overvoltage safety circuit is attached to it.

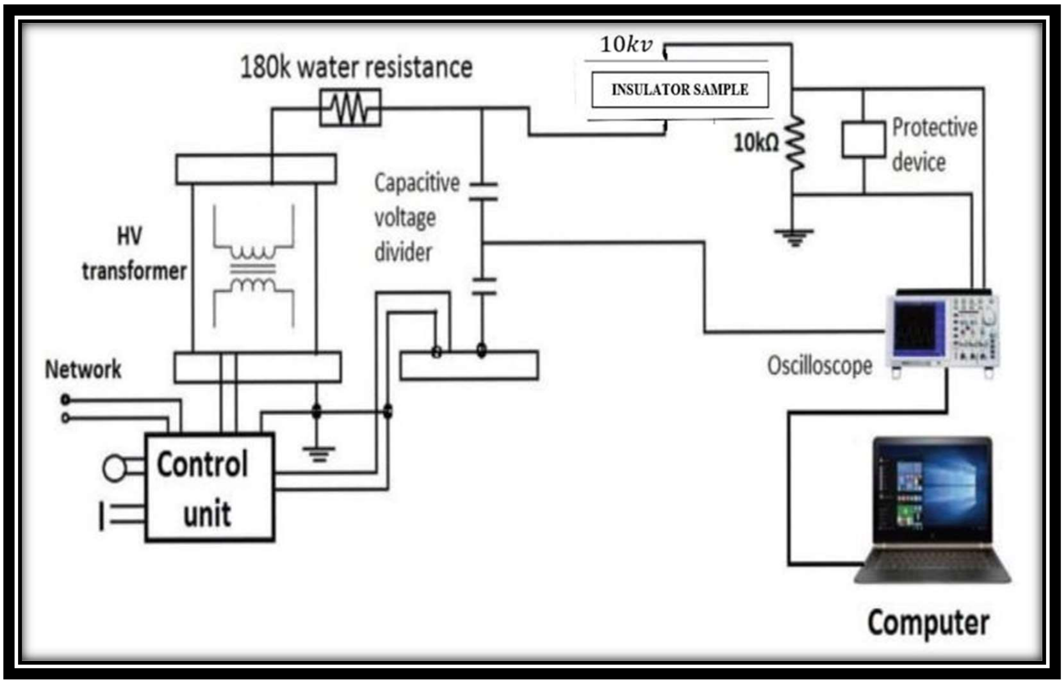


Figure.4.14: Schematic diagram of the LC measurement setup

Figure.4.15: Actual diagram of the LC measurement setup

4.7. Hydrophobicity Measurement

Hydrophobicity testing was carried out in the laboratory using the goniometer. In Figure 4.16, the experimental setup is displayed. The surface that will be used for the contact angle measurements was thoroughly cleaned to get rid of any possible dust before the measurements started. Subsequently, the surface was grounded by applying a grounded electrode to it for five minutes. This process guaranteed that no charge remained on the surface, which is crucial because the accuracy of contact angle measurements is greatly impacted by the existence of charges on the surface [39]. The camera takes the picture, which some software then analyses after it has been captured. The sample is subsequently placed on the surface, and the water droplet, 1 is positioned in the ACAM which has been provided by the apex instruments, is placed in the ACAM with a volume between 4.97 and 5.17. Figure 4.17 displays the image that was sent by the goniometer. After determining the location of the base line, a fitting method is chosen; in this case, the tangent approach was chosen because it performs best when the contact angle is greater than 90 degrees. After that, the reading was exported to an Excel file, where it shows the average of the two measurements made from the droplet's left and right sides as the final contact angle. The measurement shows the droplet's contact angle as seen from both sides. Since this complicates the test and results in an incorrect estimate of the contact angle, it was always ensured that there were no other particles in the vicinity of the droplet. Second, because the size of the water droplet has a significant impact on the contact angle value, it was kept within the previously indicated range for the purposes of this comparison study. To ensure that there were no inconsistencies or inaccurate results, five measurements were averaged for every sample.

Dynamic hydrophobicity measurements required the samples to be artificially contaminated to a level of approximately 0.1 mg/cm2 for equivalent salt deposit density (ESDD) and approximately 1 mg/cm2 for non-soluble salt deposit density (NSDD), both of which correspond to a medium level of pollution severity, in accordance with the standards outlined in IEC 60507. After 96 hours, the contaminated sample was allowed to dry out before the hydrophobicity transfer was evaluated. After utilizing water to remove the contamination, acetone was used to clean and wash the samples in order to get them ready for the hydrophobicity recovery measurement. An additional measurement of the contact angle was made 48 hours after the pollutant was removed.

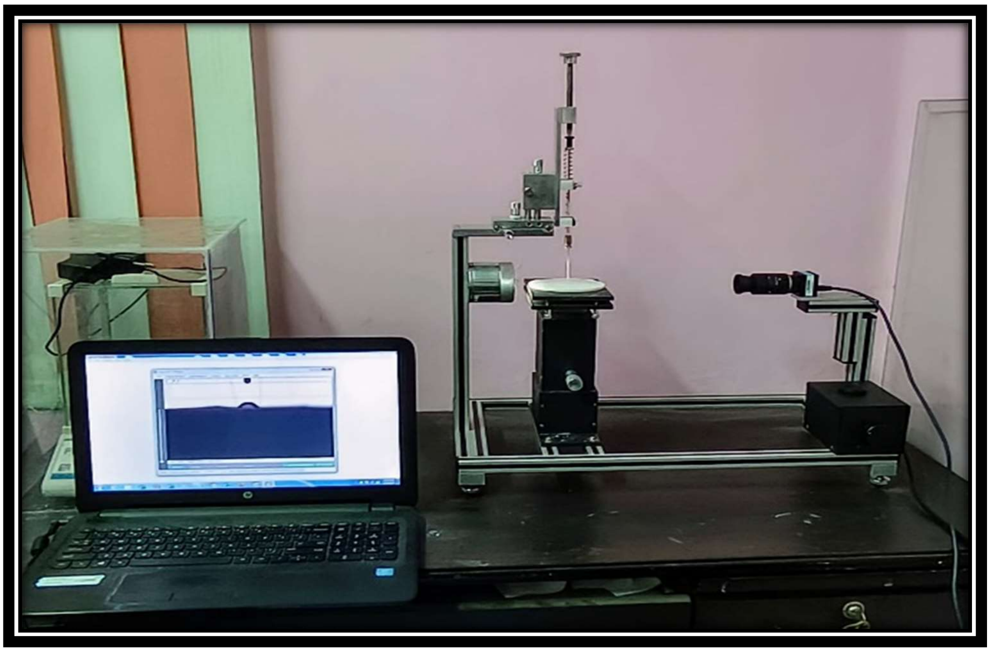
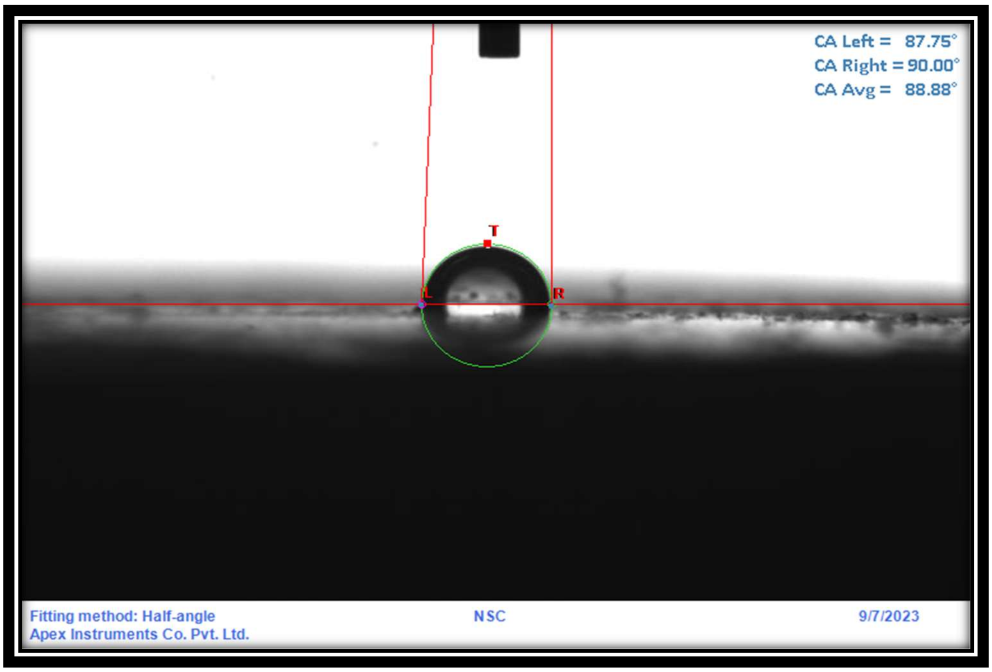


Figure 4.16: Contact Angle measurement setup.



CA Left = 87.75°
CA Right = 90.00°
CA Avg = 88.88°

Fitting method: Half-angle
Apex Instruments Co. Pvt. Ltd.
NSC
9/7/2023

Figure 4.17: Image transmitted to ACAM software.

CHAPTER-5

RESULTS AND DISCUSSIONS

Chapter-5

5.1. Introduction

Silicone rubber (SiR) insulators have long been used in electrical power systems, mainly due to their ability to suppress a sizable amount of leakage current (LC) even in very humid and polluted settings. Their widespread use has primarily been attributed to this ability. Furthermore, it is commonly recognized that SiR insulators exhibit exceptional hydrophobic properties, so using nanofillers to determine the hydrophobicity variation in SiR is necessary. The impact of different alumina (Alpha) fillers in SiR is covered in this chapter. The experiment results that have been obtained can be broadly classified as:

I. Study of the effect of filler material on Leakage Current.

II. Study the effect of filler material on Harmonic present in Leakage Current (LC).

III. Study the effect of filler material on Hydrophobicity.

5.2. Study of the effect of filler material on Leakage Current

I. Variation of Maximum Leakage current waveform for different voltage level.

II. Percentage change in maximum current at different voltage level.

5.2.1. Variation of Maximum value of leakage Current for different harmonics:

The variation of leakage current with different prepared nano composite SiR samples without aging and with several duration (10 days, 20 days, 30 days and 40 days) of aging has been presented in Figure 5.1. From Figure 5.1, it can be summarized that, the value of Leakage Current has been found to be decreasing with the increase in concentration of nanofillers in SiR samples. Based on the information in Table 5.1, it can be seen that the value leakage current of samples S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12 and S13 are lower than the reference sample (S1) or pure sample. Another important fact that can be observed from Figure 5.1 and 5.2 is that, the aluminium oxide SiR composite insulation is better than titanium dioxide SiR composite insulation with respect to leakage current response. This fact is due to the properties of alumina likes electrical resistivity, mechanical strength and compressive strength which are better than titania nanoparticles. The change in maximum current value is increasing as shown down are going from upward to downward of the Table 5.1 which means that current is decreasing in a linear manner. The maximum change in current at unageing condition is 0.166

and maximum change in current at 40 days of aging situations is 0.754, it has been shown that an increase in the quantity of nanoparticles in the mixture leads to a decrease in the amount of current that leaks out of the silicon rubber barrier. This finding is important because it shows how nanoparticles could be used to improve the electrical qualities of materials.

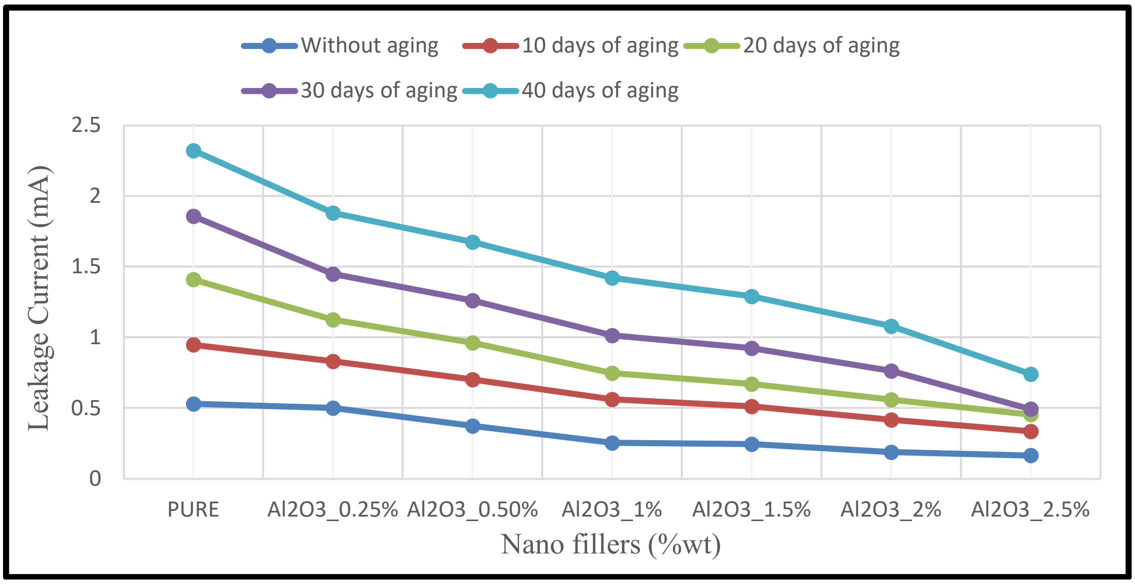


Figure 5.1: Variation of the maximum value of Leakage Current with different filler concentration of Al_2O_3 in SiR.

Table 5.1: Variation of Maximum Current Value of Al_2O_3 without aging and with aging at 10 kV.

Leakage current (mA)					
Samples	**without aging**	**10 days of aging**	**20 days of aging**	**30 days of aging**	**40 days of aging**
PURE	0.531	0.982	1.461	1.817	2.404
Al_2O_3_0.25%	0.501	0.820	1.292	1.484	1.902
Al_2O_3_0.50%	0.374	0.752	0.996	1.319	1.713
Al_2O_3_1%	0.253	0.620	0.756	1.067	1.406
Al_2O_3_1.5%	0.244	0.507	0.658	0.952	1.367
Al_2O_3_2%	0.189	0.418	0.581	0.804	1.115
Al_2O_3_2.5%	0.166	0.350	0.486	0.538	0.754

It can be help in investigation of samples after examining the graph of leakage current value has been dropping while the concentration of various fillers has been growing. According to the data in the table, it is possible to deduce the values of the samples S2, S3, S4, S5, S6 and

S7 for the parameter "Leakage Current" are lower than the value for the "reference sample" (S1). As it is gone from the top to the bottom of the table, the change in maximum current value increases, which indicates that current is dropping in a linear fashion. When it comes to unaged leakage current is 0.166, while when it comes to aged situations, the maximum change in current is different into four parts are 10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging.

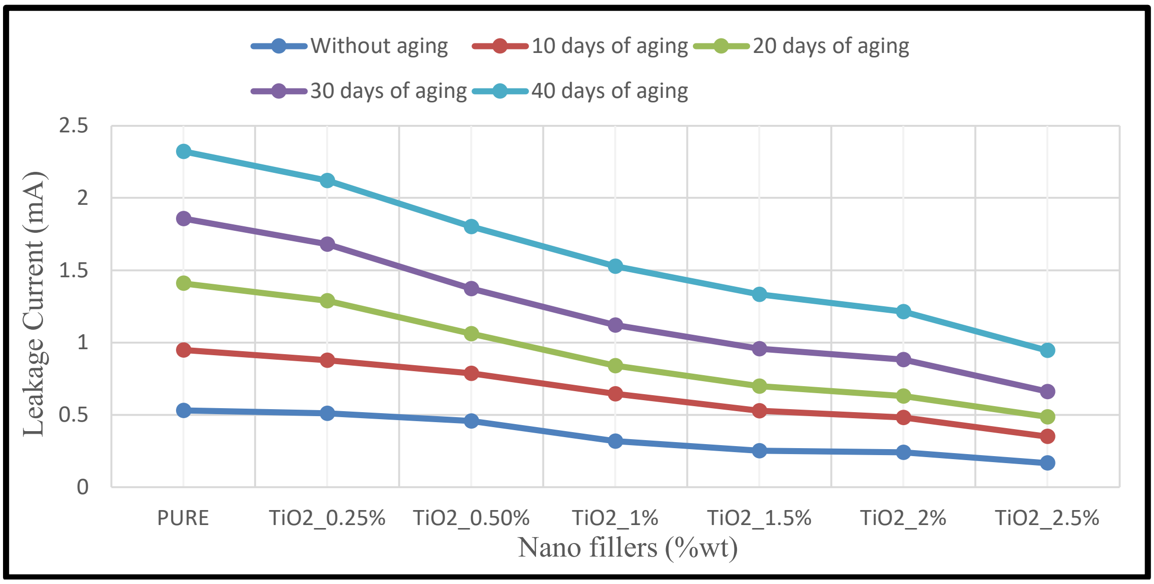


Figure 5.2: Variation of the maximum value of Leakage Current with different filler concentration of TiO_2 in SiR.

Table 5.2: Variation of Maximum Current Value of TiO_2 without aging and with aging at 10 kV.

Leakage current (mA)					
Samples	**without aging**	**10 days of aging**	**20 days of aging**	**30 days of aging**	**40 days of aging**
PURE	0.531	0.986	1.461	1.817	2.404
TiO_2_0.25%	0.509	0.910	1.310	1.792	2.198
TiO_2_0.50%	0.457	0.828	1.107	1.411	1.830
TiO_2_1%	0.319	0.676	0.819	1.232	1.507
TiO_2_1.5%	0.250	0.516	0.717	1.033	1.395
TiO_2_2%	0.241	0.509	0.684	0.920	1.252
TiO_2_2.5%	0.166	0.394	0.503	0.739	0.984

The above Figure 5.2 shows the decrement of the Leakage Current with the variation of the nano fillers. In that Table 5.2, it can be seen that the maximum value of the Leakage Current at unaged value is “0.166” and the minimum value is “0.984”, therefore it can be said that the percentage decrement is almost 50% which is positive outcome for this experiment.

From looking at tables 5.1 and 5.2 it is clear that the value of the leakage current at different voltages goes down as the number of nanoparticles in silicon rubber goes up. This phenomenon occurs in both scenario (with and without aging), as the tables show. It is also possible to deduce, using the table that has just been shown that the difference in current between the two scenarios without nano particles and with nano particles is enormous, although the difference in current between the two nano particles of difference % is smaller. This indicates that the value of reducing leakage current in percentage terms is fairly low, despite the fact that the proportion of nanoparticles is increased. However, this does not suggest that the percentage of nanoparticles is increasing. Nevertheless, nanoparticles contribute to a reduction in the amount of current lost via leakage. In fact, studies have shown that even a small proportion of nanoparticles can significantly reduce leakage current. This is because nanoparticles have a high surface area and volume ratio, which allows them to form a dense and uniform layer on the surface of the material. This layer acts as a barrier, preventing electrons from escaping and reducing the amount of current lost through leakage. Additionally, nanoparticles can also improve the overall performance of insulators devices by enhancing conductivity and increasing the efficiency of charge transport. As such, incorporating nanoparticles into electronic materials has become an increasingly popular strategy for reducing leakage current and improving device performance. While there may be some limitations to this approach, such as cost and scalability issues, it is clear that nanoparticles hold great promise for advancing the field of insulation and paving the way for new technologies in the future.

5.2.2. Study the effect of filler material on Harmonic present in Leakage Current (without aging)

A Fourier transform is applied to the leakage current data collected for the samples at the five different voltage levels. The Fast Fourier Transform (FFT) results of the LC at various voltages are displayed in the tables5.3 below. It is evident that an increase in the concentration of alumina and titanium dioxide filler causes a decrease in the LC harmonic components, aluminium oxide nanofiller is better than titanium dioxide, which is also supported by thevalues given in the tables, which show the values of odd harmonics up to the maximum harmonic.

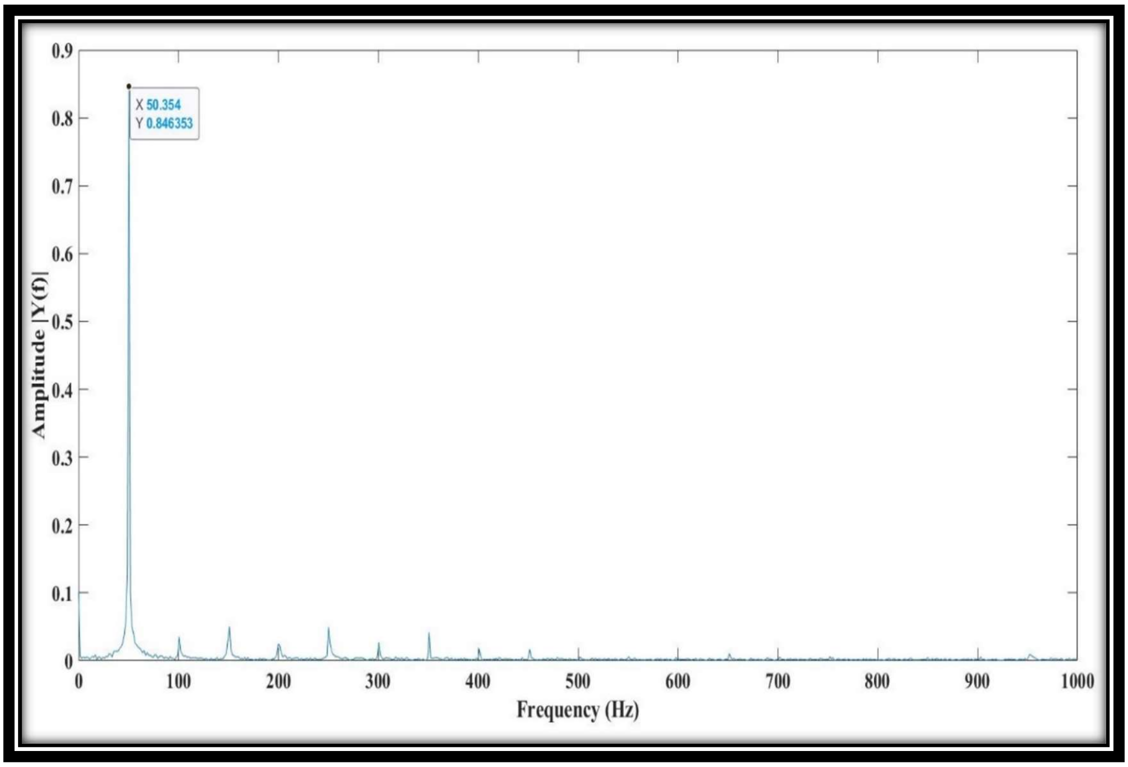


Figure 5.3: Harmonic content of SiR with 0wt% nano fillers concentration at 2kV

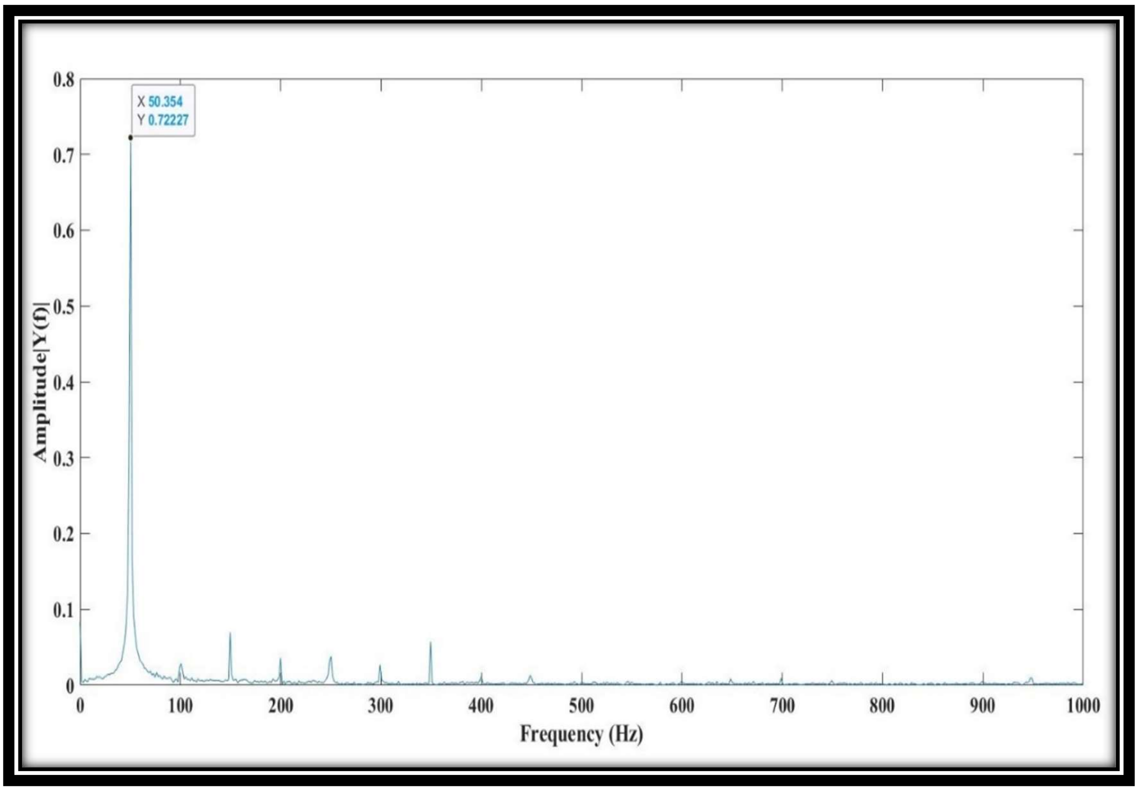


Figure 5.4: Harmonic content of SiR with Al_2O_3_0.50wt% nano fillers concentration at 2kV

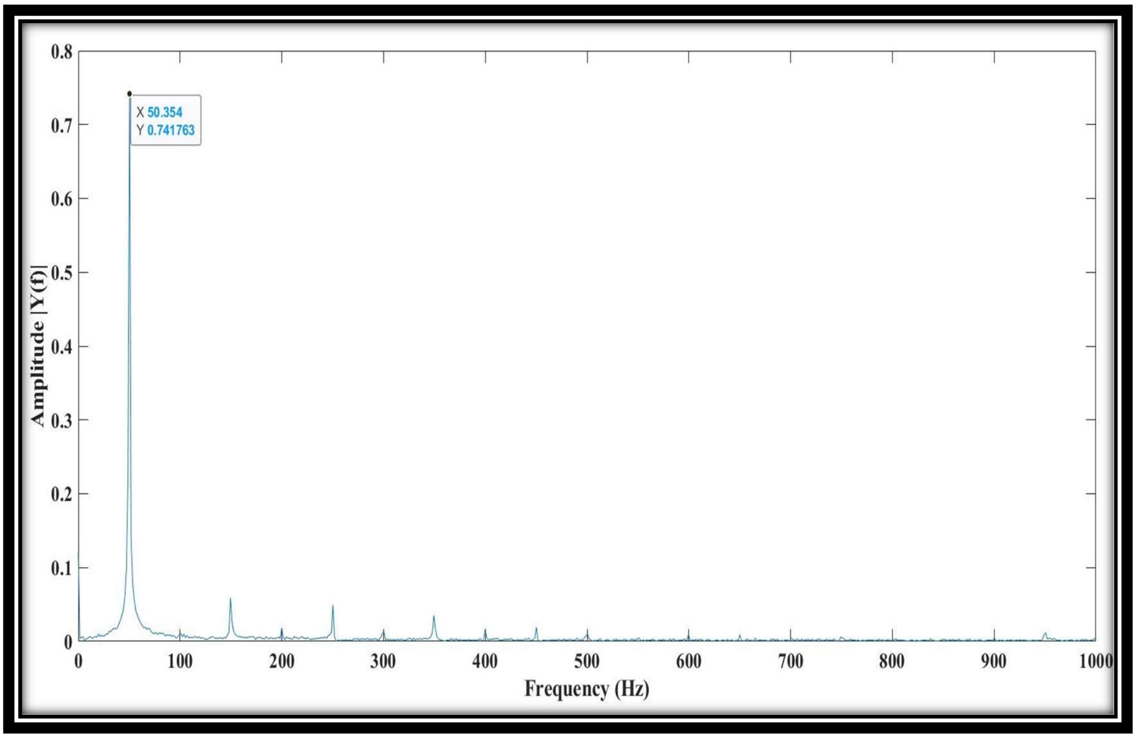


Figure 5.5: Harmonic content of SiR with TiO_2_0.50wt% nano fillers concentration at 2kV

Table 5.3: The Fast Fourier Transform results of the leakage current at various samples.

Samples	Fundamental Harmonic	3th Harmonic	5th Harmonic	7th Harmonic	9th Harmonic
S1	0.846	0.050	0.045	0.048	0.029
S2	0.789	0.070	0.040	0.043	0.028
S3	0.722	0.065	0.035	0.028	0.027
S4	0.712	0.062	0.029	0.027	0.027
S5	0.702	0.059	0.025	0.026	0.026
S6	0.592	0.051	0.021	0.025	0.025
S7	0.472	0.045	0.019	0.024	0.024
S8	0.798	0.079	0.075	0.047	0.028
S9	0.741	0.071	0.049	0.045	0.028
S10	0.721	0.067	0.043	0.029	0.027
S11	0.676	0.061	0.038	0.028	0.027
S12	0.637	0.059	0.032	0.026	0.026
S13	0.507	0.056	0.029	0.026	0.025

From Table5.3, it can be observed that with increasing nanofiller concentration, there is a significant decrease in fundamental harmonic content. The other odd harmonics components are also decreasing in the leakage current. These observations are in perfect tandem with observation from the leakage current plot. The values of 3rd harmonics are less than 20% of the fundamental harmonics, so it can be safely assumed that dry band formation has not yet started taking place [17]. From the decreasing nature of the 3rd, 5th and 7th harmonic content, it can be asserted that the electrical stress is decreasing. 5th harmonic too is decreasing, increase of which is seen as a sign of the development of surface discharge.

Analysis of 3rd harmonic values of the leakage current data are of utmost importance in the investigation of the insulator properties because they give a greater insight into the condition of the insulator Studies on the condition monitoring of insulator has revealed that the leakage current across the insulators is mostly resistive barring the initial low magnitude leakage current which is of capacitive in nature. It is further found that, the increase in the resistive component of the leakage current is proportionate to the 3rd harmonic. Due to these reasons, 3rd harmonic variations have special significance.

5.2.3. Study the effect of filler material on Harmonic present in Leakage Current (Fundamental harmonics)

The fundamental harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Figure 5.6, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of fundamental harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.4. From Figure 5.6 and Table 5.4 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle’s concentration in silicone rubber, leakage current is found to be decreased.

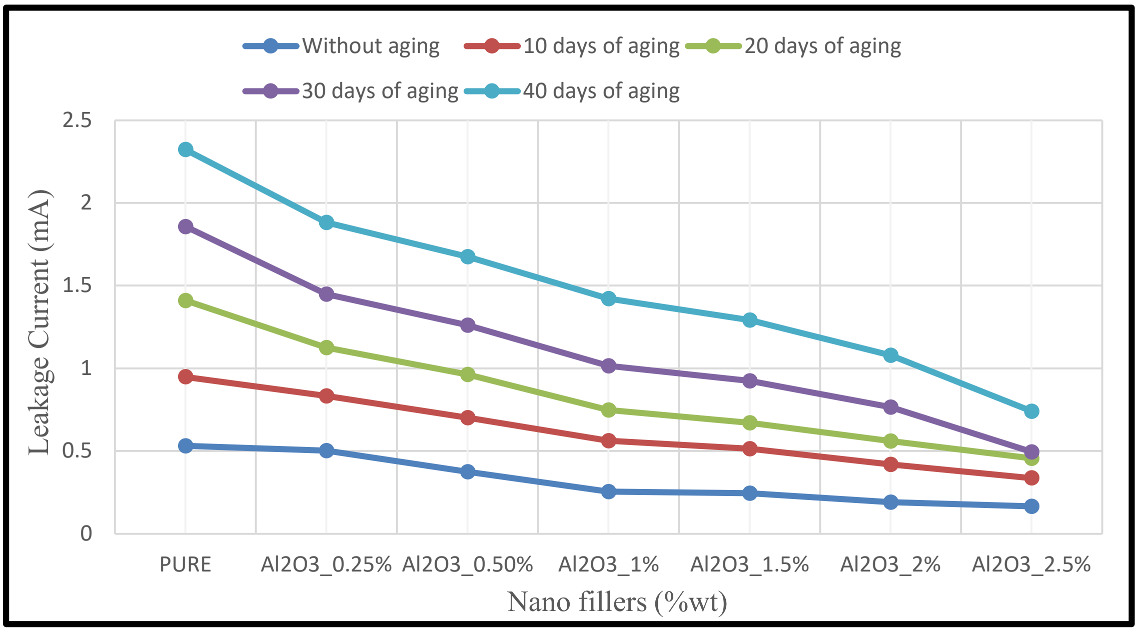


Figure 5.6: Variation in Fundamental harmonic content of leakage current for SiR with Al_2O_3 nano fillers concentration at 10kV.

Table 5.4: Fundamental harmonic content of leakage current for SiR with Al_2O_3.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.531	0.978	1.432	1.856	2.301
Al_2O_3_0.25%	0.501	0.856	1.173	1.452	1.859
Al_2O_3_0.50%	0.374	0.713	1.001	1.256	1.683
Al_2O_3_1%	0.253	0.611	0.754	1.042	1.482
Al_2O_3_1.5%	0.244	0.503	0.645	0.901	1.354
Al_2O_3_2%	0.189	0.405	0.589	0.812	1.102
Al_2O_3_2.5%	0.166	0.298	0.454	0.507	0.753

The fundamental harmonic content of leakage current for silicone rubber with TiO_2 nanofillers at 10 kV have been presented in Figure 5.7, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of fundamental harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.5. From Figure 5.7 and Table 5.5 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased.

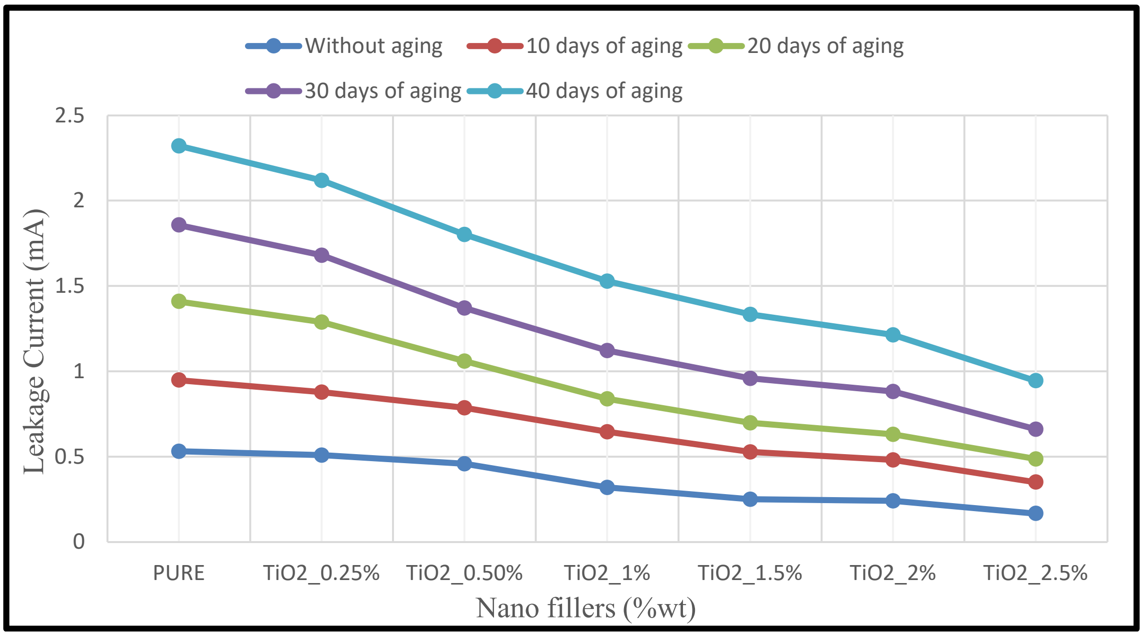


Figure 5.7: Variation in Fundamental harmonic content of leakage current for SiR with TiO_2 nano fillers concentration at 10kV.

Table 5.5: Fundamental harmonic content of leakage current for SiR with TiO_2.

Samples	**Without aging**	**10 days of aging**	**20 days of aging**	**30 days of aging**	**40 days of aging**
PURE	0.531	0.978	1.432	1.856	2.301
TiO_2_0.25%	0.509	0.873	0.743	1.715	2.138
TiO_2_0.50%	0.457	0.795	0.559	1.311	1.815
TiO_2_1%	0.319	0.624	0.895	1.103	1.559
TiO_2_1.5%	0.251	0.512	0.712	0.989	1.357
TiO_2_2%	0.241	0.489	0.556	0.924	1.248
TiO_2_2.5%	0.166	0.325	0.523	0.657	0.978

From Table 5.4 and 5.5, it can be observed that, the alumina nano SiR composite is showing better leakage current response (reduced value of fundamental harmonic content of leakage current) than the titanium dioxide nano SiR composite. For instant, it has been mentioned here that, using TiO_2 nanofillers in SiR, the fundamental harmonic content of leakage current can be reduced up to 57% whereas, using Al_2O_3 nanofillers in SiR, the fundamental harmonic content of leakage current can be reduced up to 67%. This is due to the fact that, Al_2O_3 nanofillers acts like an insulating nano particle and TiO_2 nanofillers acts like semiconductor nano particles.

5.2.4. Study the effect of filler material on Harmonic present in Leakage Current (3rd harmonics)

In 3rd harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Figure 5.8, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 3rd harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.6. From Figure 5.8 and Table 5.6 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased. 3rd harmonics is 10 to 20 times lesser than fundamental harmonics which shown in Figure 5.8 with compare to Figure 5.9.

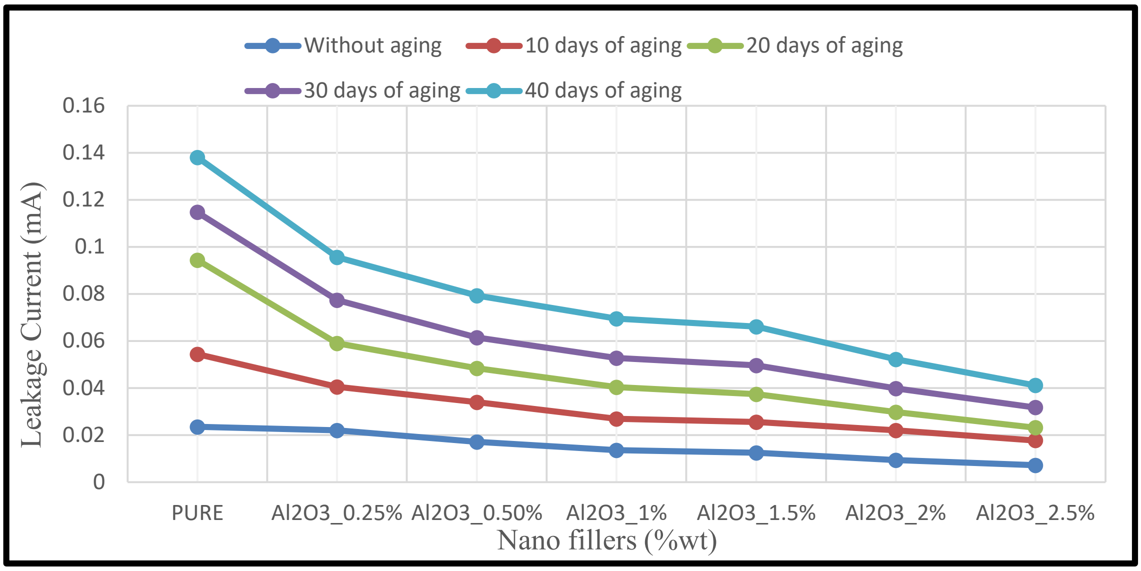


Figure 5.8: Variation in 3rd harmonic content of leakage current for SiR with Al_2O_3 nano fillers concentration at 10kV.

Table 5.6: 3rd harmonic content of leakage current for SiR with Al_2O_3.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.023	0.055	0.095	0.116	0.139
Al_2O_3_0.25%	0.021	0.042	0.059	0.078	0.096
Al_2O_3_0.50%	0.017	0.034	0.049	0.063	0.081
Al_2O_3_1%	0.013	0.028	0.041	0.052	0.072
Al_2O_3_1.5%	0.012	0.025	0.037	0.045	0.068
Al_2O_3_2%	0.009	0.022	0.031	0.039	0.052
Al_2O_3_2.5%	0.007	0.018	0.022	0.031	0.043

In 3rd harmonic content of leakage current for silicone rubber with TiO_2 nanofillers at 10 kV have been presented in Figure 5.9, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 3rd harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.7. From Figure 5.9 and Table 5.7 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased.

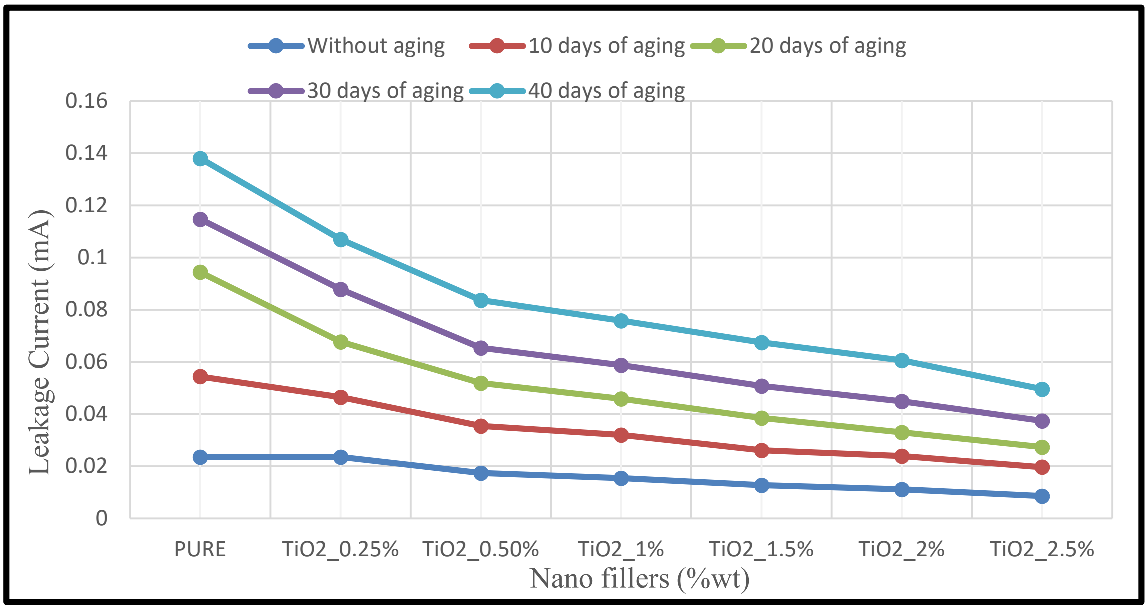


Figure 5.9: Variation in 3rd harmonic content of leakage current for SiR with TiO2 nano fillers concentration at 10kV.

Table 5.7: 3rd harmonic content of leakage current for SiR with TiO_2.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.023	0.055	0.095	0.116	0.139
TiO_2_0.25%	0.022	0.046	0.068	0.079	0.117
TiO_2_0.50%	0.017	0.035	0.052	0.066	0.084
TiO_2_1%	0.015	0.031	0.046	0.059	0.077
TiO_2_1.5%	0.012	0.026	0.039	0.051	0.069
TiO_2_2%	0.011	0.024	0.034	0.045	0.061
TiO_2_2.5%	0.008	0.021	0.027	0.038	0.051

From Table 5.6 and 5.7, it can be observed that, the alumina nano SiR composite is showing better leakage current response (reduced value of 3rd harmonic content of leakage current) than the titanium dioxide nano SiR composite. For instant, it has been mentioned here that, using TiO_2 nanofillers in SiR, the 3rd harmonic content of leakage current can be reduced up to 63% whereas, using Al_2O_3 nanofillers in SiR, the 3rd harmonic content of leakage current can be reduced up to 69%. This is due to the fact that, Al_2O_3 nanofillers acts like an insulating nano particle and TiO_2 nanofillers acts like semiconductor nano particles.

5.2.5. Study the effect of filler material on Harmonic present in Leakage Current (5th harmonics)

In 5th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Figure 5.10, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 5th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.8. From Figure 5.10 and Table 5.8 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased.

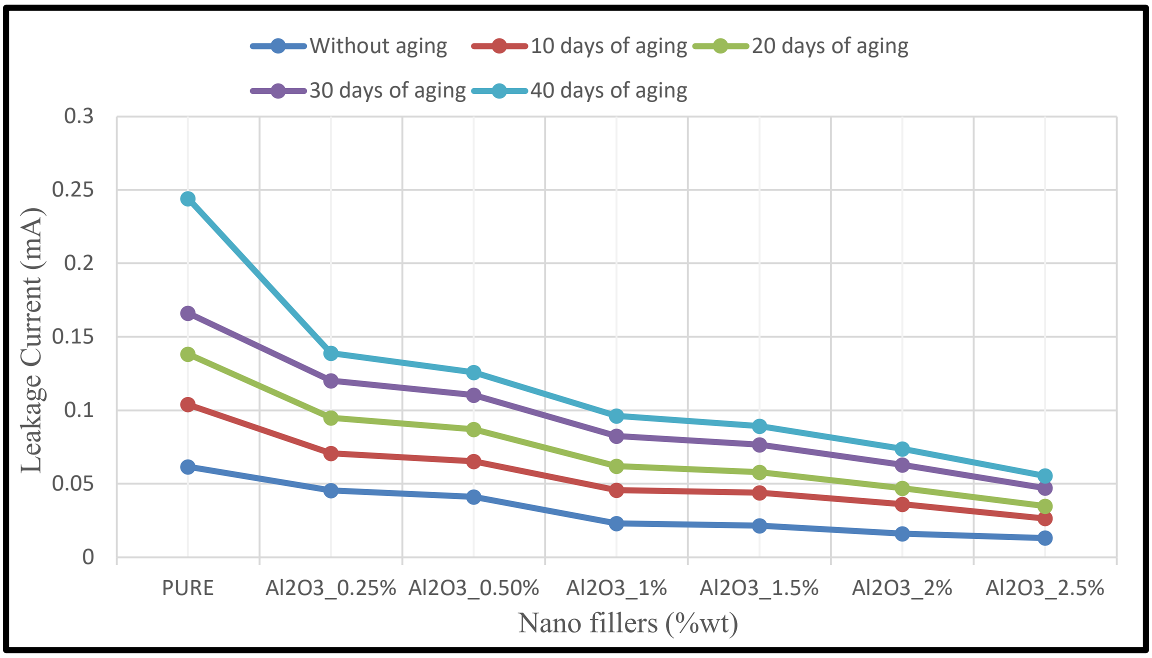


Figure 5.10: Variation in 5th harmonic content of leakage current for SiR with Al_2O_3 nano fillers concentration at 10kV.

Table 5.8: 5th harmonic content of leakage current for SiR with Al_2O_3.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.061	0.115	0.141	0.165	0.245
Al_2O_3_0.25%	0.045	0.064	0.093	0.131	0.141
Al_2O_3_0.50%	0.041	0.061	0.089	0.121	0.125
Al_2O_3_1%	0.023	0.049	0.064	0.082	0.101
Al_2O_3_1.5%	0.021	0.041	0.058	0.075	0.094
Al_2O_3_2%	0.016	0.035	0.049	0.063	0.071
Al_2O_3_2.5%	0.013	0.025	0.035	0.049	0.059

In 5th harmonic content of leakage current for silicone rubber with TiO_2 nanofillers at 10 kV have been presented in Figure 5.11, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 5th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.8. From Figure 5.11 and Table 5.9 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particles concentration in silicone rubber, leakage current is found to be decreased.

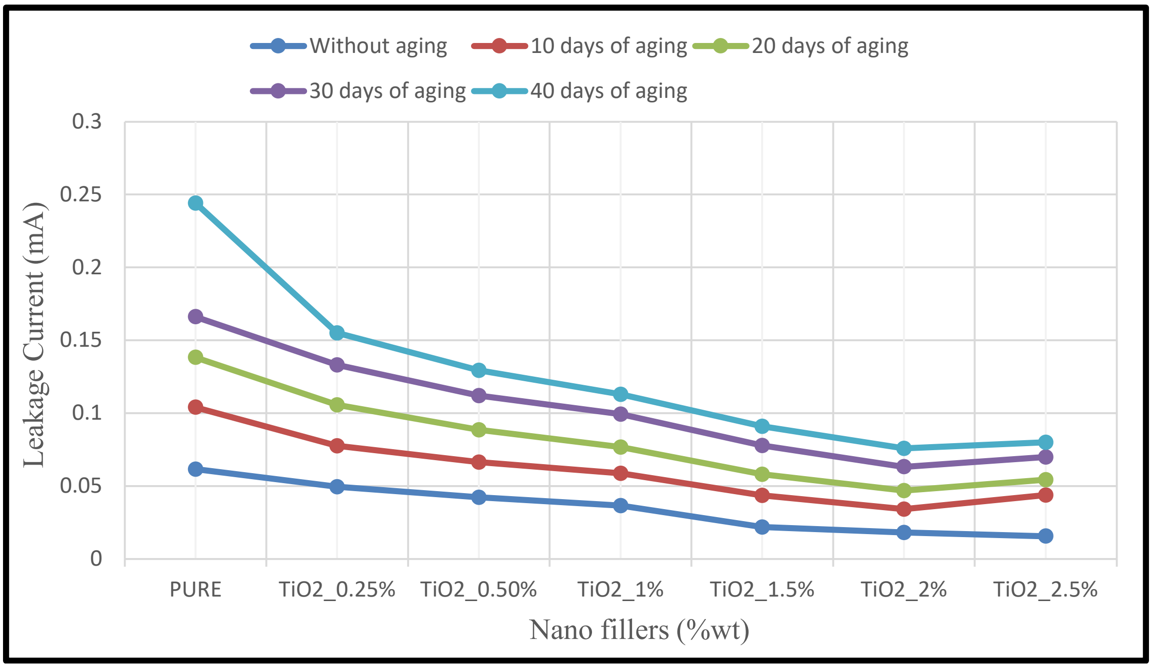


Figure 5.11: Variation in 5th harmonic content of leakage current for SiR with TiO_2 nano fillers concentration at 10kV.

Table 5.9: 5th harmonic content of leakage current for SiR with TiO_2.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.061	0.115	0.141	0.165	0.245
TiO_2_0.25%	0.049	0.078	0.119	0.136	0.159
TiO_2_0.50%	0.042	0.069	0.092	0.115	0.132
TiO_2_1%	0.036	0.058	0.079	0.105	0.118
TiO_2_1.5%	0.021	0.047	0.061	0.079	0.095
TiO_2_2%	0.018	0.039	0.048	0.067	0.079
TiO_2_2.5%	0.015	0.041	0.052	0.071	0.083

From Table 5.8 and 5.9, it can be observed that, the alumina nano SiR composite is showing better leakage current response (reduced value of 5th harmonic content of leakage current) than the titanium dioxide nano SiR composite. For instant, it has been mentioned here that, using TiO_2 nanofillers in SiR, the 5th harmonic content of leakage current can be reduced up to 66% whereas, using Al_2O_3 nanofillers in SiR, the 5th harmonic content of leakage current can be reduced up to 75%. This is due to the fact that, Al_2O_3 nanofillers acts like an insulating nano particle and TiO_2 nanofillers acts like semiconductor nano particles.

5.2.6. Study the effect of filler material on Harmonic present in Leakage Current (7th harmonics)

In 7th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Figure 5.12, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 5th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.10. From Figure 5.12 and Table 5.10 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased.

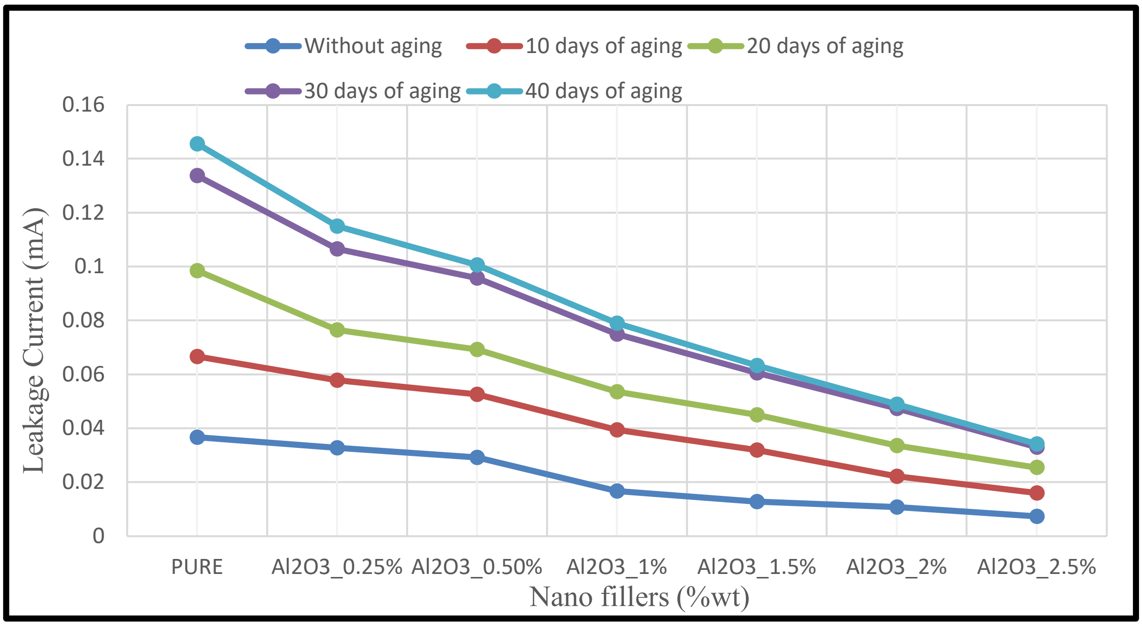


Figure 5.12: Variation in 7th harmonic content of leakage current for SiR with Al_2O_3 nano fillers concentration at 10kV.

Table 5.10: 7th harmonic content of leakage current for SiR with Al_2O_3.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.037	0.066	0.098	0.134	0.144
Al_2O_3_0.25%	0.032	0.056	0.076	0.111	0.116
Al_2O_3_0.50%	0.029	0.052	0.071	0.096	0.102
Al_2O_3_1%	0.016	0.041	0.054	0.075	0.081
Al_2O_3_1.5%	0.012	0.032	0.045	0.061	0.064
Al_2O_3_2%	0.01	0.023	0.034	0.047	0.048
Al_2O_3_2.5%	0.007	0.016	0.026	0.031	0.034

In 7th harmonic content of leakage current for silicone rubber with TiO_2 nanofillers at 10 kV have been presented in Figure 5.13, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 7th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.10. From Figure 5.13 and Table 5.10 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased.

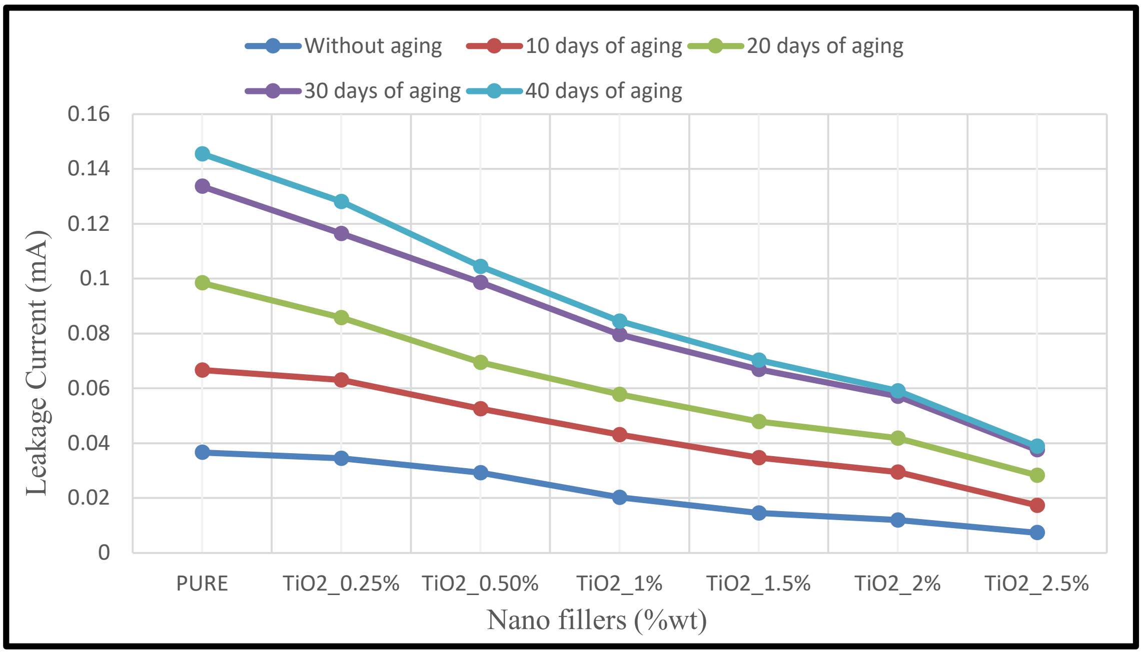


Figure 5.13: Variation in 7th harmonic content of leakage current for SiR with TiO_2 nano fillers concentration at 10kV.

Table 5.11: 7th harmonic content of leakage current for SiR with TiO_2.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.037	0.066	0.098	0.134	0.144
TiO_2_0.25%	0.034	0.064	0.086	0.117	0.128
TiO_2_0.50%	0.029	0.053	0.069	0.101	0.105
TiO_2_1%	0.021	0.044	0.058	0.081	0.085
TiO_2_1.5%	0.014	0.035	0.048	0.068	0.072
TiO_2_2%	0.012	0.031	0.042	0.056	0.061
TiO_2_2.5%	0.007	0.018	0.029	0.039	0.041

From Table 5.10 and 5.11, it can be observed that, the alumina nano SiR composite is showing better leakage current response (reduced value of 7th harmonic content of leakage current) than the titanium dioxide nano SiR composite. For instant, it has been mentioned here that, using TiO_2 nanofillers in SiR, the 7th harmonic content of leakage current can be reduced up to 71% whereas, using Al_2O_3 nanofillers in SiR, the 7th harmonic content of leakage current can be reduced up to 76%. This is due to the fact that, Al_2O_3 nanofillers acts like an insulating nano particle and TiO_2 nanofillers acts like semiconductor nano particles.

5.2.7. Study the effect of filler material on Harmonic present in Leakage Current (9th harmonics)

In 9th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Figure 5.14, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 9th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.12. From Figure 5.14 and Table 5.12 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased.

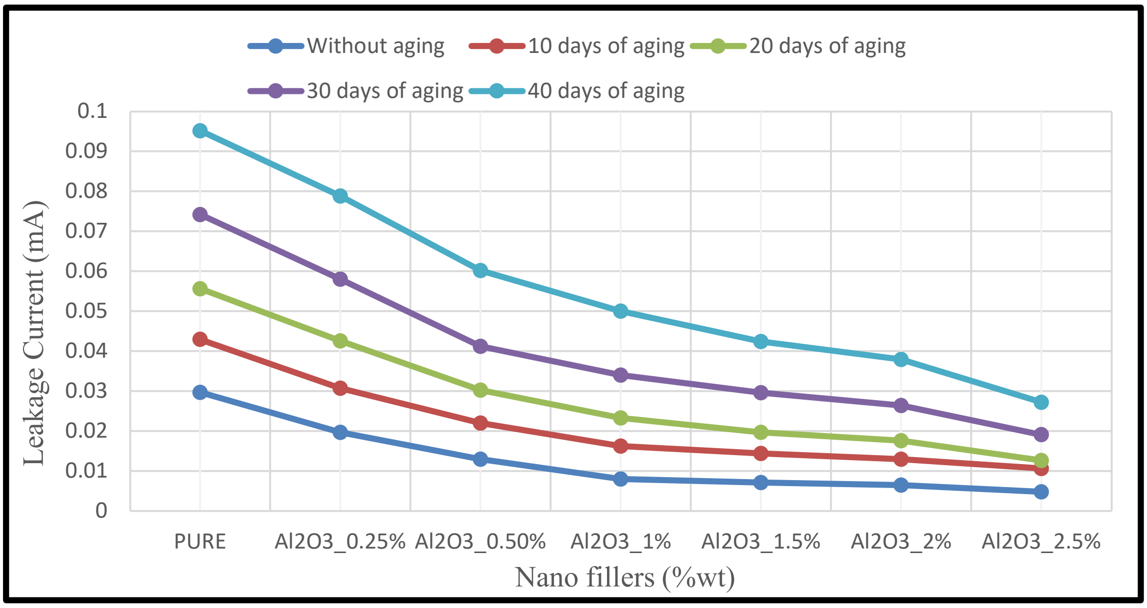


Figure 5.14: Variation in 9th harmonic content of leakage current for SiR with Al_2O_3 nano fillers concentration at 10kV.

Table 5.12: 9th harmonic content of leakage current for SiR with Al_2O_3.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.029	0.043	0.056	0.074	0.095
Al_2O_3_0.25%	0.019	0.031	0.043	0.058	0.079
Al_2O_3_0.50%	0.012	0.022	0.031	0.042	0.061
Al_2O_3_1%	0.007	0.016	0.023	0.034	0.051
Al_2O_3_1.5%	0.007	0.014	0.019	0.029	0.043
Al_2O_3_2%	0.006	0.013	0.018	0.026	0.038
Al_2O_3_2.5%	0.004	0.011	0.013	0.019	0.027

In 9th harmonic content of leakage current for silicone rubber with TiO_2 nanofillers at 10 kV have been presented in Figure 5.15, taking without aging and with several days of aging (10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging). The corresponding values of 9th harmonic content of leakage current for silicone rubber with Al_2O_3 nanofillers at 10 kV have been presented in Table 5.12. From Figure 5.15 and Table 5.12 it can be observed that leakage current follows an increasing pattern with increase in aging periods (in days) while with the increase in the nano particle's concentration in silicone rubber, leakage current is found to be decreased.

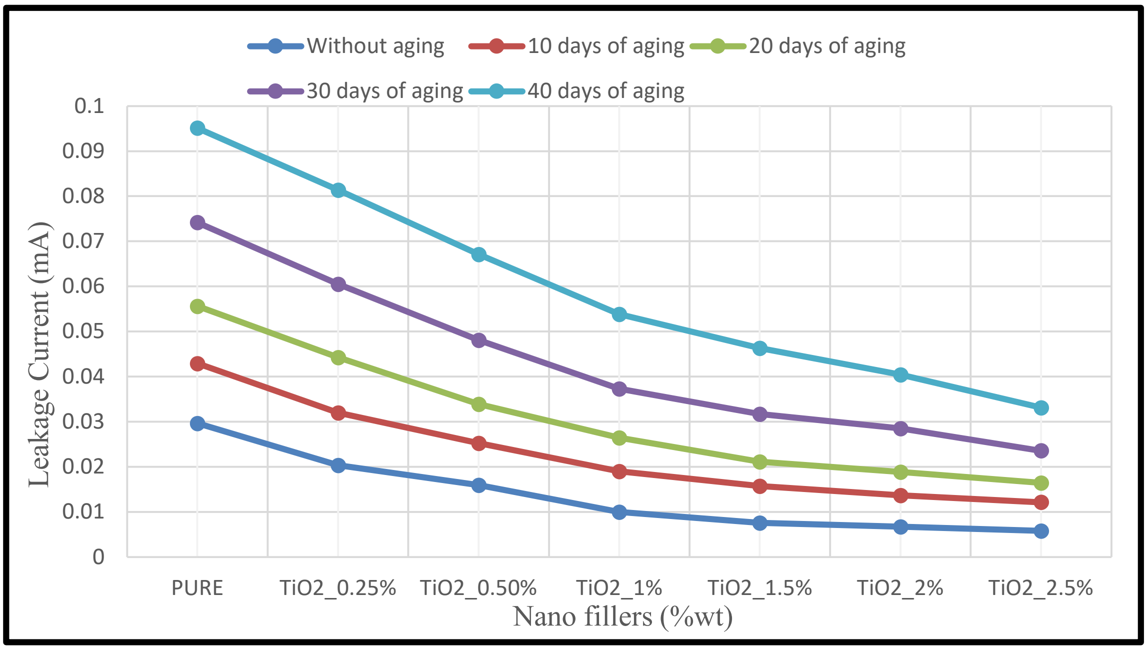


Figure 5.15: Variation in 9th harmonic content of leakage current for SiR with TiO_2 nano fillers concentration at 10kV.

From Table 5.12 and 5.13, it can be observed that, the alumina nano SiR composite is showing better leakage current response (reduced value of 9th harmonic content of leakage current) than the titanium dioxide nano SiR composite. For instant, it has been mentioned here that, using TiO_2 nanofillers in SiR, the 9th harmonic content of leakage current can be reduced up to 65% whereas, using Al_2O_3 nanofillers in SiR, the 9th harmonic content of leakage current can be reduced up to 71%. This is due to the fact that, Al_2O_3 nanofillers acts like an insulating nano particle and TiO_2 nanofillers acts like semiconductor nano particles.

Table 5.13: 9th harmonic content of leakage current for SiR with TiO_2.

Samples	Without aging	10 days of aging	20 days of aging	30 days of aging	40 days of aging
PURE	0.029	0.043	0.056	0.074	0.095
TiO_2_0.25%	0.021	0.032	0.044	0.061	0.082
TiO_2_0.50%	0.015	0.025	0.034	0.048	0.067
TiO_2_1%	0.009	0.019	0.026	0.038	0.054
TiO_2_1.5%	0.007	0.016	0.021	0.032	0.046
TiO_2_2%	0.006	0.014	0.019	0.028	0.041
TiO_2_2.5%	0.005	0.013	0.017	0.024	0.033

It can be observed that, after adding the nanofiller composite to silicone rubber it enhances the properties of nanofillers, which can see in all above graph of leakage current. Nanofillers always added to the silicone rubber (SiR) base to improve their electrical and mechanical properties. As soon as, to the nanofillers properties of Al_2O_3 & TiO_2, find that both of them increases the properties of SiR, but slightly different form each other: TiO_2-(Titanium dioxide) helps the SiR properties with thermal strength and relative permittivity and Al_2O_3- (Aluminum oxide) helps the SiR properties by electrical resistivity, mechanical strength and compressive strength. By this properties nanofillers helps to reduces the cost of composite insulators.

The leakage current increase with the increase in humidity. The higher humidity levels distortion at wave crest increases that means more and more electrical discharge have started to occur. In may experiments, it can be finding the 10kV have more leakage current with compare to the 2kV, 4kV, 6kV and 8kV voltages. When samples get aged, then presence of humidity and then leakage current start to flow. When comparing all five harmonics, then to know that the growth of fundamental components is the prime reason for increase of leakage current with humidity. FFT (Fast Fourier Transform) analysis is done to obtain the characteristics of leakage current in frequency domain. In this experiment, have been got different frequency components like fundamental harmonics, 3rd harmonics, 5th harmonics, 7th harmonics and 9th harmonics. It can be observed that the leakage current in ageing condition contains 5rd harmonics higher than all other harmonics. The significance of 3rd, 7th and other higher-order harmonic components increases while the insulator maintains its pure state. This indicates that distinct harmonic components alter in different ways as one's age increases. Consequently, the complete development trend of leakage current can be greatly responded to the 3rd, 5th, and 7th harmonic components. On the data gathered from pure polymer insulators under various humidity settings, FFT analysis has been used. The data makes it evident that, in the case of a pure insulator, the 3rd harmonic component's magnitude is smaller than that of the 5th, 7th and 9th order harmonics. Numerous studies have already been conducted on the relationship between the third and fifth harmonic ratios of leakage current at various angles. In order to track the insulator's level of contamination, it was examined from the ratio of 3rd harmonics to the 9th harmonic leakage current at various humidity levels.

It can be observed in 3rd harmonics that, by referring to the FFT analysis of a signal related to insulators, such as Partial Discharge (PD) signals in insulation materials and dielectric properties of insulators. The dominance of the 3rd harmonic could be attributed to non-linear behaviour of insulation materials under stress or voltage and corona discharge or surface discharges, which can generate harmonic frequencies.

It can be observed in 5th harmonics that the dominance of the 5th harmonic in insulators is not a common phenomenon and might be specific to the particular material, measurement setup, or application. Example such as Partial Discharge (PD) signals in insulation materials, PD activity can generate harmonic frequencies, Dielectric resonance, Measurement setup in the measurement setup, including the sensor, cable, and instrumentation, can introduce resonances or filtering effects that emphasize the 5th harmonic, Surface discharges or corona activity on the insulator's surface can generate harmonic frequencies, including the 5th harmonic.

Harmonic with humidity for pure insulator, show the behaviour of harmonic components are decreasing with the increase of humidity. This indicates that for a pure insulator, the third harmonic component of leakage current does not increase noticeably with humidity. Once more, the size of the seventh harmonic component is larger than the third harmonic component for a pure insulator. When humidity rises, with the 7th harmonic component increases more than the 3rd harmonic component.

Harmonic with humidity for aging insulator, show the behaviour of harmonic increases non-linearly with humidity for an aged insulator. The third harmonic component greatly increases in this old state. The third harmonic component's magnitude in this aged state is significantly larger than the fifth, seventh, ninth, and other higher order harmonic components' magnitudes. The preceding two figures make it evident that the primary determinant of the insulator's aging severity is the 3rd to 9th harmonic ratio.

5.3. Hydrophobicity Estimates

Hydrophobicity can be regarded as the ability to repel water which is considered as a crucial characteristic of polymeric insulators, and silicone rubber insulators. It should be mentioned that, the insulator with more hydrophobicity has been considered as better insulator to be used. An experimental set-up was developed in the laboratory to measure hydrophobicity of the insulator with a goniometer. Further, the change in hydrophobicity with nano filler content have been studied in this work. Three samples were obtained for each percentage of filler concentration, and each sample's contact angle was measured five times under controlled conditions. The samples were then analysed using the average of these data.

5.3.1. Contact Angle of SiR Samples for different nano fillers Concentration (without Aging)

In the Figure 5.16 shown that variation of raw (unaged) state contact angle for SiR samples with different concentration of nano fillers.

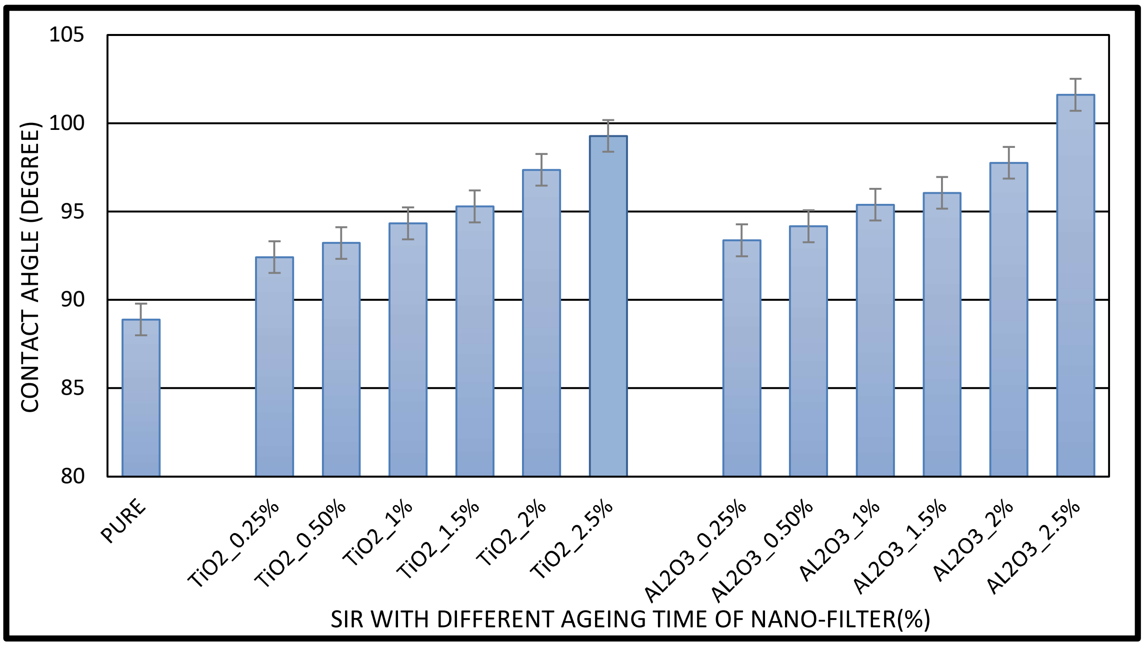


Figure 5.16: Variation in contact angle with the increase of nano fillers concentration.

It can be observed from the Figure 5.16 that, an increase in the filler content leads to a rise in the contact angle, which in turn enhances the hydrophobicity of the samples. Given that materials with contact angles larger than 90^0 are known to be hydrophobic, it is possible to infer from the Figure 5.16 that, the silicone rubber insulator containing 2.5%, 2%, 1.5% and 1% nanofillers is becoming more hydrophobic, which is a beneficial result of the experiment. The purpose of this experiment was to look into how nanofillers affected silicone rubber insulators' hydrophobicity. According to the findings, adding 1.5%, 2%, 2.5% nanofillers increased the material's hydrophobicity, which is a desired effect. This result is in line with the notion that materials are often hydrophobic when their contact angle is larger than 90^0. These findings imply that adding nanofillers to silicone rubber insulators may be a viable way to improve their efficiency in applications where hydrophobicity is crucial. Subsequent investigations may examine the ideal concentration of nanofillers to attain the highest level of hydrophobicity, along with additional possible advantages or disadvantages of this methodology. All things considered do this work offers insightful information on the possible uses of nanofillers to enhance the characteristics of silicone rubber insulators. Silicone rubber's low-surface-energy base polymer, poly dimethyl siloxane (PDMS), is thought to be the cause of this. As was previously mentioned, low-surface-energy materials have excellent hydrophobicity, or a very high contact angle with water droplets [42]. The surface area of alumina and titanium dioxide nanofillers is substantially higher than, the bulk counterparts. The higher surface area-to-volume ratio of the nanofillers increase its reactivity and improved catalytic capabilities. In the investigation of hydrophobicity, it has been found that aluminium oxide is more hydrophobic than titanium dioxide in nature. Alumina nanofillers can modify surfaces by coatings with other materials or functionalization with different chemical groups. These changes have the potential to change the surface chemistry and enable specific interactions with other materials.

5.3.2. Contact Angle of SiR Samples for different nano filers Concentration (10 days of aging)

In the Figure 5.17, the variation of aging state measure in contact angle for SiR samples with different concentration of nano fillers with 10 days of aging, an increase in the filler content leads to a rise in the contact angle, which in turn enhances the hydrophobicity of the samples. In the observation of contact angle measurements for silicone rubber (SiR) samples, it is quantified by the contact angle formed between a water droplet and the surface of the material. A higher contact angle indicates greater hydrophobicity, meaning the surface is more effective at repelling water. According to the experiment, a lower contact angle signifies that the surface is more wettable and less hydrophobic. Given that materials with contact angles larger than 90^0 are known to be hydrophobic and contact angles smaller than 90^0 are known to be hydrophilic, it is possible to infer from the Figure 5.17 that, the silicone rubber insulator containing 2.5%, 2%, 1.5%, 1%, 0.50% and 0.25% nanofillers is becoming more hydrophobic, which is a beneficial result of the experiment. Specifically, SiR samples with alumina exhibited higher contact angles compared to those with titanium dioxide, indicating superior water repellency. This suggests that alumina is more effective at improving the hydrophobic properties of SiR compared to titanium dioxide.

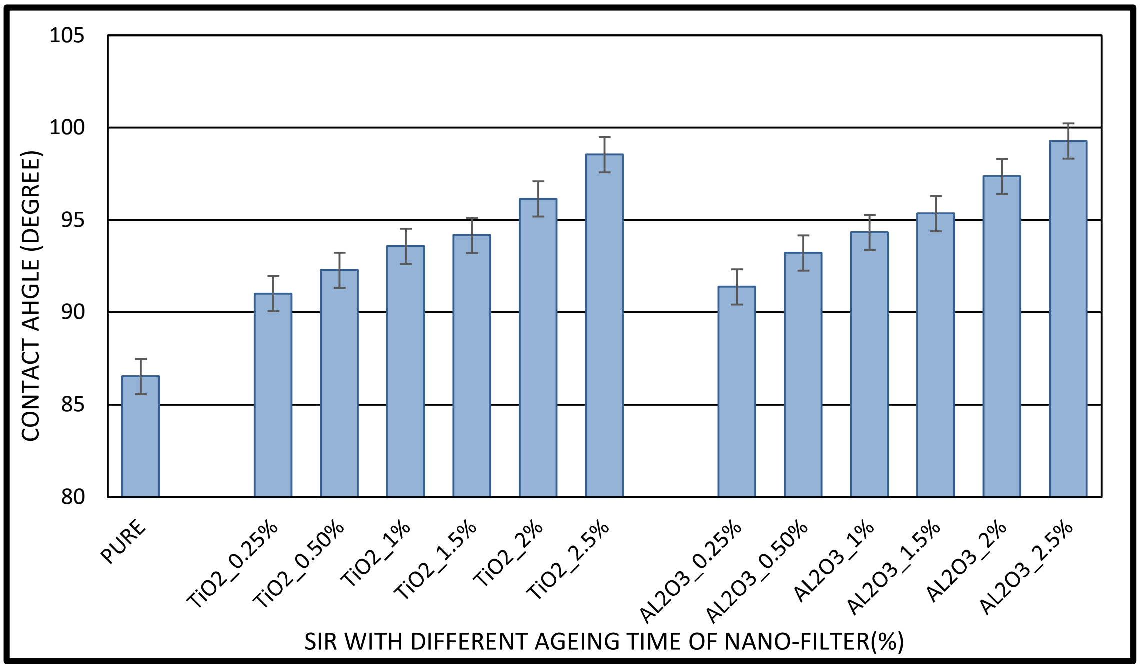


Figure 5.17: Variation in contact angle with the increase of nano fillers concentration (10 days of aging).

5.3.3. Contact Angle of SiR Samples for different nano filers Concentration (20 days of aging)

In the Figure 5.18, the variation of aging state measure in contact angle for SiR samples with different concentration of nano fillers with 20 days of aging, an increase in the filler content leads to a rise in the contact angle, which in turn enhances the hydrophobicity of the samples. In the observation of contact angle measurements for silicone rubber (SiR) samples, it is quantified by the contact angle formed between a water droplet and the surface of the material. A higher contact angle indicates greater hydrophobicity, meaning the surface is more effective at repelling water. According to the experiment, a lower contact angle signifies that the surface is more wettable and less hydrophobic. Given that materials with contact angles larger than 90^0 are known to be hydrophobic and contact angles smaller than 90^0 are known to be hydrophilic, it is possible to infer from the Figure 5.18 that, the silicone rubber insulator containing 2.5%, 2%, 1.5% and 1% nanofillers is becoming more hydrophobic, which is a beneficial result of the experiment. Specifically, SiR samples with alumina exhibited higher contact angles compared to those with titanium dioxide, indicating superior water repellency. This suggests that alumina is more effective at improving the hydrophobic properties of SiR compared to titanium dioxide.

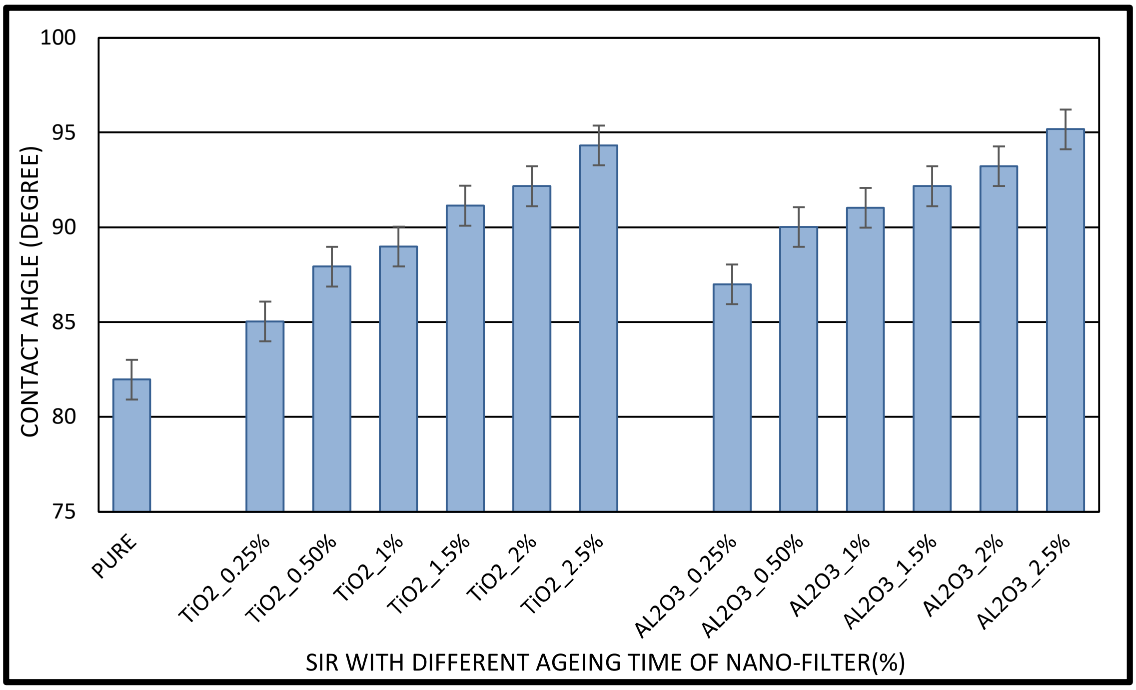


Figure 5.18: Variation in contact angle with the increase of nano fillers concentration (20 days of aging).

5.3.4. Contact Angle of SiR Samples for different nano filers Concentration (30 days of aging)

In the Figure 5.19, the variation of aging state measure in contact angle for SiR samples with different concentration of nano fillers with 30 days of aging, an increase in the filler content leads to a rise in the contact angle, which in turn enhances the hydrophobicity of the samples. In the observation of contact angle measurements for silicone rubber (SiR) samples, it is quantified by the contact angle formed between a water droplet and the surface of the material. A higher contact angle indicates greater hydrophobicity, meaning the surface is more effective at repelling water. According to the experiment, a lower contact angle signifies that the surface is more wettable and less hydrophobic. Given that materials with contact angles larger than 90^0 are known to be hydrophobic and contact angles smaller than 90^0 are known to be hydrophilic, it is possible to infer from the Figure 5.19 that, the silicone rubber insulator containing 2.5%, 2% and 1.5% nanofillers is becoming more hydrophobic, which is a beneficial result of the experiment. Specifically, SiR samples with alumina exhibited higher contact angles compared to those with titanium dioxide, indicating superior water repellency. This suggests that alumina is more effective at improving the hydrophobic properties of SiR compared to titanium dioxide.

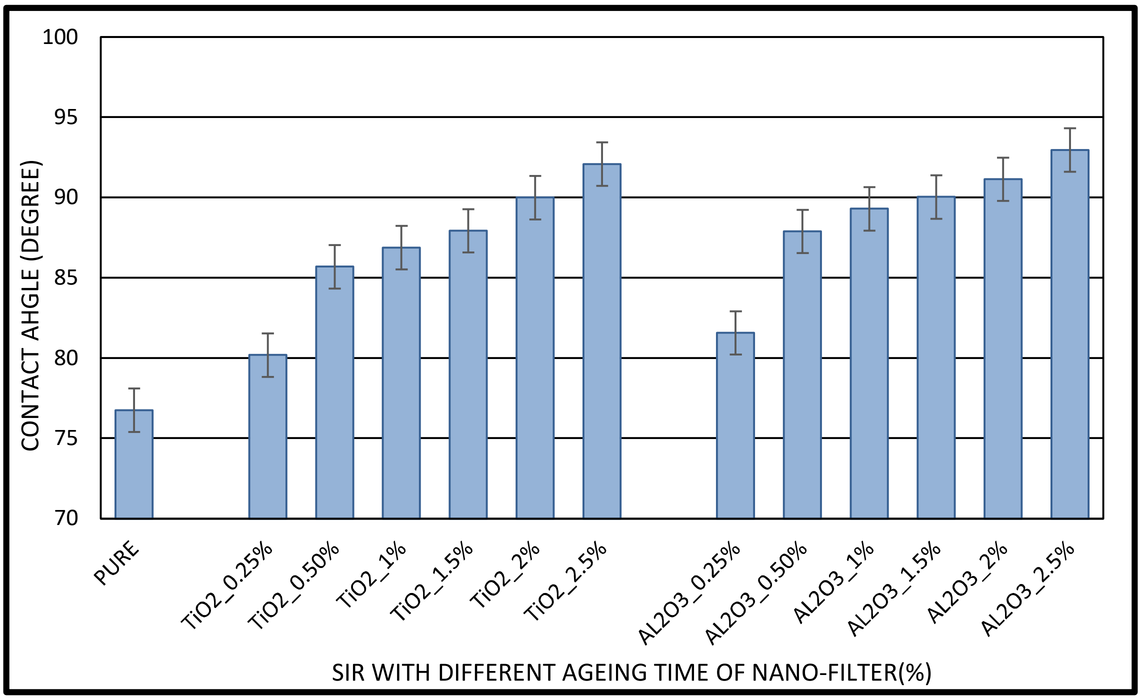


Figure 5.19: Variation in contact angle with the increase of nano fillers concentration (30 days of aging).

5.3.5. Contact Angle of SiR Samples for different nano filers Concentration (40 days of aging)

In the Figure 5.20, the variation of aging state measure in contact angle for SiR samples with different concentration of nano fillers with 40 days of aging, an increase in the filler content leads to a rise in the contact angle, which in turn enhances the hydrophobicity of the samples. In the observation of contact angle measurements for silicone rubber (SiR) samples, it is quantified by the contact angle formed between a water droplet and the surface of the material. A higher contact angle indicates greater hydrophobicity, meaning the surface is more effective at repelling water. According to the experiment, a lower contact angle signifies that the surface is more wettable and less hydrophobic. Given that materials with contact angles larger than 90^0 are known to be hydrophobic and contact angles smaller than 90^0 are known to be hydrophilic, it is possible to infer from the Figure 5.20 that, the silicone rubber insulator containing 2.5% and 2% nanofillers is becoming hydrophilic, which is a beneficial result of the experiment. Specifically, SiR samples with alumina exhibited higher contact angles compared to those with titanium dioxide, indicating superior water repellency. This suggests that alumina is more effective at improving the hydrophobic properties of SiR compared to titanium dioxide.

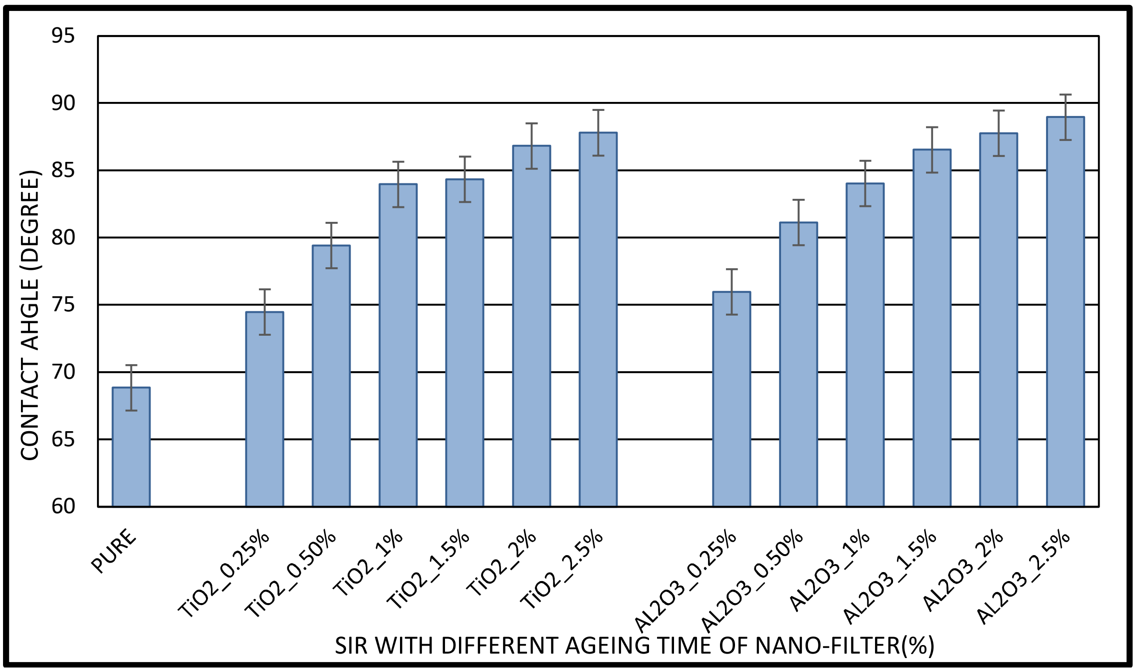


Figure 5.20: Variation in contact angle with the increase of nano fillers concentration (40 days of aging).

Table 5.14: The change in contact angle in both without aging and with aging.

Samples	Without aging	10 days of aging	20 days of aging	30days of aging	40 days of aging
S1	88.89	86.53	81.97	76.75	68.84
S2	92.42	91.01	85.03	80.19	74.47
S3	93.22	92.28	87.93	85.69	79.41
S4	94.33	93.58	88.98	86.88	83.97
S5	95.29	94.17	91.14	87.93	84.34
S6	97.36	96.14	92.17	90	86.82
S7	99.28	98.54	94.32	92.08	87.8
S8	93.37	91.38	86.99	81.57	75.96
S9	94.17	93.22	90.01	87.89	81.13
S10	95.39	94.33	91.03	89.3	84.02
S11	96.06	95.35	92.17	90.04	86.53
S12	97.76	97.36	93.22	91.14	87.76
S13	101.61	99.28	95.17	92.96	88.96

In the experiment, shown that even after aging, there is less of a decline in contact angle. The hydrophobicity of the 1.5% nano filler silicone rubber insulator has not diminished even after aging, suggesting that nanoparticle-mixing with SiR insulator can be employed as an external insulator. In order to keep water from permeating the surface and causing electrical breakdown and equipment damage, the insulator's hydrophobicity is essential. Promising outcomes have been observed in the silicone rubber insulator's ability to retain its hydrophobicity even after aging when nanoparticles are added. It can be observed that, the Al_2O_3 is better than TiO_2 in properties of hydrophobic state. This may contribute to the creation of outdoor insulators that are more dependable and long-lasting. To maximize the effectiveness, more study is required to improve the size and concentration of the nanoparticles. It should also be tested in a variety of environmental settings to make sure it works in a variety of situations. In summary, this study emphasizes the possible advantages of adding nanoparticles to SiR insulators in order to enhance their longevity and performance. for electrical apparatus This may result in enhanced functionality and equipment durability in challenging conditions. Since less material would be required to produce the same level of insulation, the use of nanoparticles in insulators may also result in lower material costs and utilization. To properly comprehend the long-term impacts of employing nanoparticles in insulators and to maximize their use for various applications, more research is necessary. The results collectively imply that adding nanoparticles to insulators holds great promise for raising efficiency and cutting expenses in electrical equipment.

CHAPTER-6

CONCLUSIONS AND FUTURE WORK

Chapter-6

6.1. Conclusions

In the lab, samples of temperature-vulcanized (TV) silicone rubber (SiR) with varying alumina and titanium dioxide nanofiller concentrations were manufactured with success. The acronym for temperature-vulcanized is [TV]. The produced samples were employed to assess the shifts in hydrophobicity and variations in the leakage current (LC) waveform brought about by different alumina and titanium dioxide nanofiller quantities.

The most significant conclusion drawn from the investigation into the leakage current waveform for samples of SiR containing different amounts of alumina and titanium dioxide filler, that the size of the leakage current decreases as filler concentration increases. The measurement of the leakage current's RMS value, which demonstrated a linearly declining nature with increasing filler content, provided more support for this. To perform further analysis, a Fourier transform was applied to the combined LC data, and the results indicated that the odd harmonies (the fundamentals 3, 5, 7 and 9) exhibited declining tendencies. This suggests that, in addition to decreasing LC magnitude, an increase in filler content also suppresses the formation of dry bands. It was discovered that when the voltage level grew in magnitude, the average value of the 3" to fundamental component ratio decreased. This is a very encouraging sign that the ability to suppress leakage current increases as the voltage magnitude increases. An additional noteworthy observation is that the voltage's magnitude affected the capacity to reduce leakage current. The LC study's results enable one to conclude that alumina filler serves as both a reinforcing filler and a suppressor of the LC current, with more LC suppression occurring at higher filler concentrations. The fact that the filler concentration was raised suggests this. It's also vital to remember that alumina filler's particular qualities have made it more and more popular for use in a variety of sectors. Alumina filler is renowned for its large surface area and chemical stability, in addition to its capacity for reinforcement and LC suppression. Because of this, it is a useful ingredient in the manufacture of paints, rubber, and polymers drawing oxides into the bulk and away from the surface. The hydrophobicity recovery was tested in unaged conditions, 10 days of aging, 20 days of aging, 30 days of aging and 40 days of aging and the results indicated that the percentage of recovery increased as the filler content increased. When the different between in hydrophobic has been found that alumina is enhancing the nanofillers is better than titanium dioxide. The primary cause of the increased hydrophobicity recovery is the reorientation of the methyl groups toward the insulator's surface and the oxidized groups away from it. The oxidized groups are drawn towards the bulk by the alumina fillers' development of intermolecular forces. Thus, in general, it can be concluded that adding alumina nanofillers to room-temperature vulcanized silicone rubber inhibits the development of LC and increases its dynamic hydrophobicity. The concentration of alumina filler used in these applications must be carefully considered, though, since using too much might have unfavourable effects, including increased viscosity and lower flexibility. The study's overall findings emphasize the versatility of alumina filler and its possible advantages when used at the right concentrations.

Even though the initial hydrophobicity measurements or the raw hydrophobicity measured after many hours of sample preparation showed that the increasing filler concentration resulted in a decrease in the contact angle measured, the hydrophobicity estimates of SiR samples also showed positive results on the addition of Alumina and titanium dioxide nanofiller. The high surface energy of alumina, an inorganic filler, allows for surface wetting, which explains why. By contaminating the samples with a mild degree of pollution in compliance with IEC 60507 criteria and assessing the hydrophobicity transfer after many hours, the samples' dynamic hydrophobic properties were also examined. It was found that the percentage of hydrophobicity transmitted to the aging surface increased with the amount of filler used. This was found because new chains of low molecular weight (LMW) compounds were created, and the amount of filler was increased by using more alumina filler titanium dioxide filler. The hydrophobicity transfer to the aging surface was thus markedly increased with the help of nanofiller adding to it. This discovery holds significant ramifications for the creation of fresh approaches to the elimination and repair of aging. It might be feasible to improve the efficacy and efficiency of the remediation methods now in use by employing alumina filler to create new chains of LMW chemicals. This study also emphasizes how crucial it is to comprehend how filler materials might improve hydrophobicity transfer and other crucial characteristics. In order to fully investigate the possibilities of alumina filler and other materials in this situation and to determine any potential disadvantages or restrictions related to their application, more research is required. In the end, these initiatives may result in notable progress in the capacity to combat environmental pollution and safeguard the general public's health.

6.2. Future Work

In this work, the attention was focused on the impact that Alumina and titanium dioxide nanofiller had on RTV SiR. Although the nanofiller demonstrated a good augmentation of leakage current suppression and hydrophobic qualities, more research is required to determine whether or not it is suitable for use in a variety of environmental situations. Consideration may be given to carrying out more study on the subjects that are mentioned below:

1. It is possible to execute the tracking and erosion test, which is a crucial evaluation of the effectiveness of outdoor insulators, and further investigate the impact of alumina filler on the resistance to tracking and erosion.
2. Future studies may concentrate on the impact that a temperature variation has on the sample's dynamic hydrophobic properties and the potential impact of different filler concentrations.
3. An examination of the relationship between different amounts of alumina filler and titanium dioxide as well as the impacts of aluminium trihydrate (a filler that is commonly used for qualities that hinder tracking) on LC suppression and increases in the hydrophobic property.
4. The purpose of this study was to investigate the possible advantages of using different filler concentrations in subsequent studies. In particular, how different concentrations of alumina filler interacted with aluminium trihydrate. Alumina filler has been demonstrated to improve LC suppression and increase hydrophobicity, whereas aluminium trihydrate filler is a popular filler that is well-known for its capacity to inhibit tracking. By observing at the interactions between the two nanofillers, a novel approach can be introduced to enhance the performance of the fillers across a range of applications.
5. According to this work, using different filler concentrations may have major benefits over using conventional methods, especially when it comes to enhancing hydrophobic qualities and minimizing tracking. Although more research is required to completely comprehend the potential advantages of these various filler concentrations, this work offers a good foundation for such studies.

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