INTERNATIONAL JOURNAL OF INTEGRATED ENGINEERING
ISSN: 2229-838X e-ISSN: 2600-7916

IJIE

Vol. 17 No. 5 (2025) 327-338
https://publisher.uthm.edu.my/ojs/index.php/ijie

# Electric Field Characteristics of Various Percentages of LLDPE-Natural Rubber Composition Under Moisture Conditions

**Mohamad Azzamuddin Majunit[1], Nor Akmal Mohd Jamail[1]*, Nordiana Azlin Othman[1], Muhammad Saufi Kamarudin[1], Nor Shahida Mohd Jamail[2]**

[1] *Faculty of Electrical and Electronic Engineering Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400, MALAYSIA*

[2] *Prince Sultan University, Riyadh, 12435 SAUDI ARABIA*

*Corresponding Author: norakmal@uthm.edu.my
DOI: https://doi.org/10.30880/ijie.2025.17.05.025

**Article Info**

Received: 26 December 20204
Accepted: 11 July 2025
Available online: 30 August 2025

**Keywords**

Linear Low-Density Polyethylene-Natural Rubber (LLDPE-NR), water absorption, relative permittivity, cylindrical electrodes, electric field intensity

**Abstract**

Enhancing the insulation performance of high-voltage cables is critical for ensuring long-term reliability in modern power systems. One major concern is the degradation of insulation due to sustained exposure to high electric fields, which can lead to flashover events. This study focuses on the electric field behavior of Linear Low-Density Polyethylene (LLDPE) blended with Natural Rubber (NR), examined under both dry and moisture-exposed conditions. Composite samples containing 0% to 30% NR were prepared through mechanical blending and submerged in water for 70 days to evaluate moisture absorption. To support simulation work, the relative permittivity of each sample in both conditions was measured using a Keysight 16514B dielectric test fixture.These permittivity values were incorporated into a COMSOL electrostatic model with cylindrical electrodes to simulate electric field distributions. Among all tested compositions, the sample with 30% natural rubber consistently demonstrated the lowest electric field intensity, even under moist conditions. This enhanced performance is attributed to the influence of natural rubber on the dielectric properties, promoting a more uniform electric field distribution despite higher water uptake. The findings suggest that LLDPE-NR composites with higher NR content hold significant potential for improving insulation in high-voltage cable applications.

## 1. Introduction

Insulation materials are critical components in high-voltage cable systems, where their primary function is to prevent electrical breakdown and ensure safe, reliable operation. A failure in insulation can lead to flashovers, equipment damage, and potential safety hazards. As electrical power networks expand and operating voltages increase, the demand for more robust, durable, and environmentally friendly insulation materials has grown significantly [1], [2]. The effectiveness of an insulating material is largely determined by its dielectric strength and permittivity. Traditional insulators such as porcelain, glass, and ceramics, while mechanically strong, are limited in their capacity to withstand high electric field intensities and are often prone to surface tracking and degradation under environmental stress [3].

In recent years, polymeric composites have emerged as a promising alternative due to their lightweight nature, ease of processing, lower installation costs, and better resistance to environmental pollutants. One such polymer, Linear Low-Density Polyethylene (LLDPE), is widely used in various industrial applications owing to its flexibility and favorable mechanical properties. However, its lower dielectric strength and stiffness limit its application in high-voltage environments [4]. On the other hand, natural rubber (NR), particularly Standard Malaysian Rubber (SMR20), offers attractive electrical insulation characteristics such as high dielectric strength, good elasticity, and resistance to deformation. Its natural origin, renewability, and biodegradability make it an environmentally sustainable material [5], [6].

Natural rubber has historically been used for wire and cable insulation since the early days of the electrical industry [7]. It can recover its shape after deformation and can absorb mechanical shocks, making it suitable for applications requiring flexibility. However, exposure to moisture over time can alter its physical and electrical properties, potentially leading to embrittlement, softening, or loss of insulation performance [8]. Despite this, natural rubber's compatibility with thermoplastics and its ability to improve overall material performance have motivated researchers to explore it as a blending agent in composite systems. LLDPE-NR composites, known as thermoplastic elastomers, combine the processability of thermoplastics with the elasticity of rubbers. These materials are recyclable, which addresses a key limitation of thermosetting insulation materials like cross-linked polyethylene (XLPE), widely used in underground power cables but non-recyclable due to their cross-linked structure [9].

While several studies have evaluated the mechanical, thermal, and water absorption properties of LLDPE-NR composites [10-14], the influence of these materials on electric field behavior—particularly under moisture conditions—remains underexplored. Electric field intensity is a critical factor in insulation design because localized field enhancements can lead to partial discharge, degradation, and eventual breakdown [15-16]. Understanding how the distribution of electric fields is affected by the composition and moisture content of polymer composites is essential to designing better-performing and safer high-voltage insulation systems.

## 1.1 Methodology

This research addresses that gap by investigating the electric field characteristics of LLDPE-NR composites under both dry and moisture-exposed conditions. Composite samples with NR content ranging from 0% to 30% were prepared through mechanical blending, molded into discs of 50 mm diameter and 2.5 mm thickness, and immersed in water for 70 days. The water absorption behavior was monitored by measuring weight changes thrice weekly. To evaluate dielectric properties, the relative permittivity of the samples was measured under both conditions using a Keysight 16451B dielectric test fixture. These values were then incorporated into a COMSOL Multiphysics electrostatic model with cylindrical electrodes to simulate and analyze electric field distributions. The simulation aimed to replicate practical high-voltage cable insulation scenarios, revealing how different NR contents influence the electric field profile and intensity.

The main aim of this study is to assess whether increasing the natural rubber content in LLDPE can reduce electric field intensity, even in the presence of moisture. This could provide a dual benefit—enhancing insulation performance while promoting sustainability using biodegradable and recyclable materials. The findings are expected to support the development of eco-friendly alternatives to conventional materials like XLPE, aligning with global initiatives on waste reduction and sustainable materials in power engineering. Research Methodology This chapter discusses the method for conducting research and ensuring its successful completion. Meticulous planning and preparation play essential roles in achieving research objectives. The experiments have been conducted in two different labs - the Polymer laboratory in the Faculty of Mechanical Engineering and the Electronic Physics laboratory in UTHM Pagoh. The simulation for electrical field distribution by using COMSOL Multiphysics has been discussed in detail.

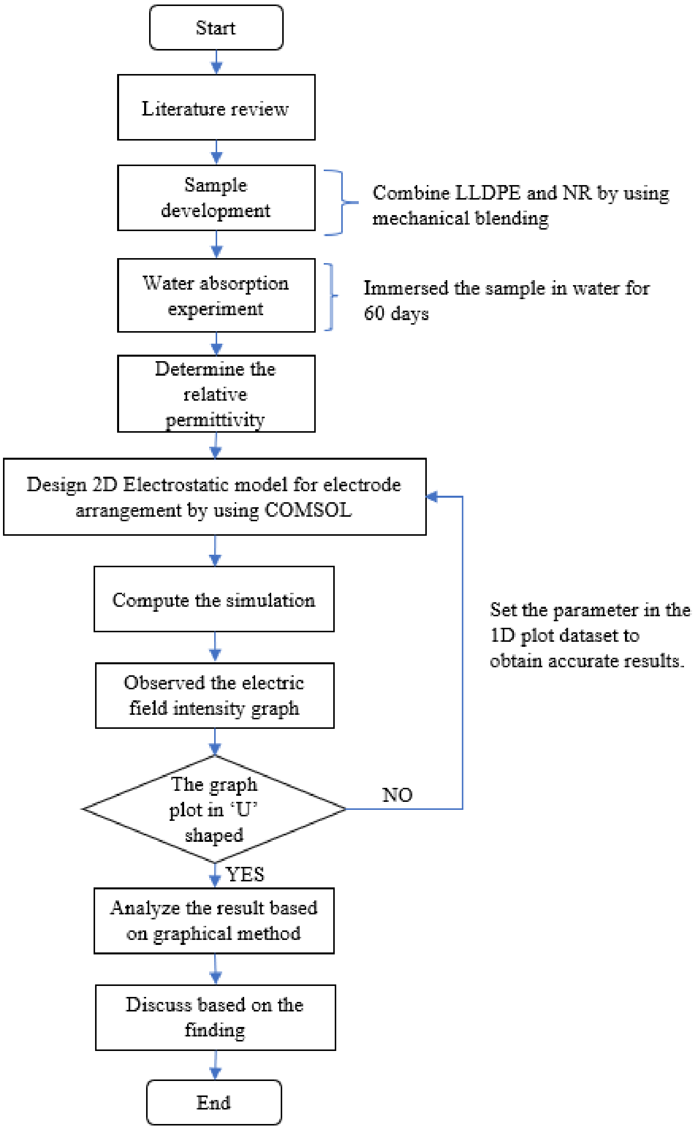



**Fig. 1** *Sample immersed in distilled water in separate containers*

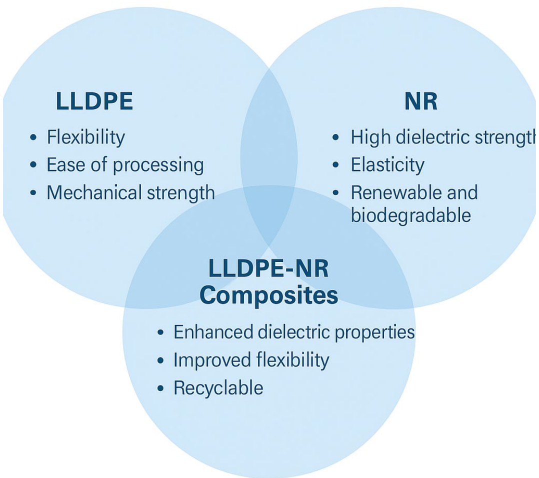



**Fig. 2** *Summary of advantages of LLDPE, NR, and their composites*

By analyzing both experimental and simulated data, this research extends the current knowledge on polymeric insulation by providing insight into how natural rubber content influences dielectric behavior and electric field strength under real-world environmental conditions. It also contributes to the growing body of literature promoting the use of bio-composite materials in electrical engineering applications, with a focus on recyclability, performance, and environmental impact.

## 2.1 Sample Development

This section involves the preparation of a sample that consists of a composition of LLDPE and NR. The percentage of natural rubber in the sample has been varying from 0% to 30%. As a result, there are four different samples with varying ratios. Table 1 shows the exact composition of LLDPE and NR with different proportions. The raw materials used in this study were acquired from Lotte Chemical, Malaysia. The Linear Low-Density Polyethylene (LLDPE) had a density of 0.920 g/cm3, a melting point of 122 Celsius, and a melting index of 1 g/10min. The natural rubber was obtained from Kuala Lumpur Kepong (KLK) Plantation and had a melting point of 150 Celsius, nitrogen content of 0.6%, and dirt content of 0.2%. A mixture of LLDPE and natural rubber has been developed by blending them together using a two-roll mill mixer. This results in a thermoplastic elastomer composition known as LLDPE-NR. The two-roll mill mixer can be found in the polymer laboratory in the Faculty of Mechanical Engineering at UTHM. The sample was mixed for 15 minutes at a speed of 10 rpm and a temperature of 150 Celsius.

**Table 1** *Composition of LLDPE and NR with different proportions*

| An example of a column heading | LLDPE (%) | Natural Rubber (%) |
|---|---|---|
| Sample 1 | 100 | 0 |
| Sample 2 | 90 | 10 |
| Sample 3 | 80 | 20 |
| Sample 4 | 70 | 30 |

## 2.2 Water Absorption Test

The samples with different percentages of LLDPE and natural rubber have been immersed in distilled water and placed in separate containers. Distilled water was used to avoid any impurities or contamination that could affect the experiment. All the samples were placed at the same room temperature so that the temperature would not affect the experiment. Fig 1 shows the sample immersed in the distilled water in a separate container at room temperature.

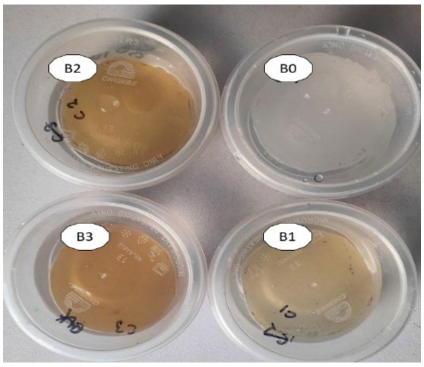



**Fig. 1** *Sample immersed in distilled water in separate containers*

There are various methods for evaluating the water absorption of solid materials. The simplest and quickest method involves measuring the increase in mass of the specimens by weighing them. Initially, the mass (M0) of each specimen is recorded before it is immersed in water. Over a 92-day period of water immersion, the increase in mass (ΔM) of the specimens is periodically monitored. The moisture content (M) present within the specimens is then determined by calculating the difference between the initial mass (Mo) and the gained moisture (ΔM). Equation (1) shows the formula to calculate the percentage of water absorption.

$$M = \frac{\Delta M}{Mo} x\,100 = \frac{M - Mo}{Mo} x\,100 \quad (1)$$

## 2.3 Relative Permittivity Test

This section describes the process and steps required to perform a relative permittivity test on a sample using a Dielectric test fixture 16451B. Before conducting the relative permittivity test, the thickness of the sample must be measured using a digital calliper. The sample is then placed between two electrodes, and it is important to ensure that there are no air gaps between the sample and the electrodes to obtain accurate results. Fig 2 shows the placement of the sample electrode between the two electrodes using the dielectric test fixture 1645B.

**Fig. 2** *The sample was placed between two electrodes on the dielectric test fixture*

## 2.4 Electrode Arrangement Geometry

Fig 3 illustrates the configuration of a cylindrical aluminum electrode, designed in accordance with the IEC 60243:1 standard using AutoCAD software. The sample, with a diameter of 50mm and a width of 2.5mm, is positioned between two electrodes. Each cylindrical electrode has a diameter of 25mm and a height of 25mm. The top electrode is supplied with a high voltage of 11kV, while the bottom electrode serves as the ground.

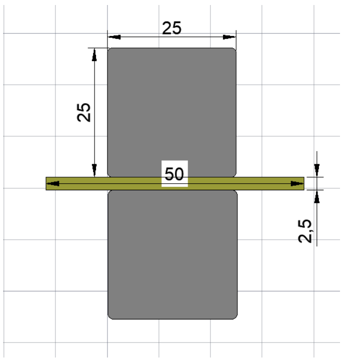
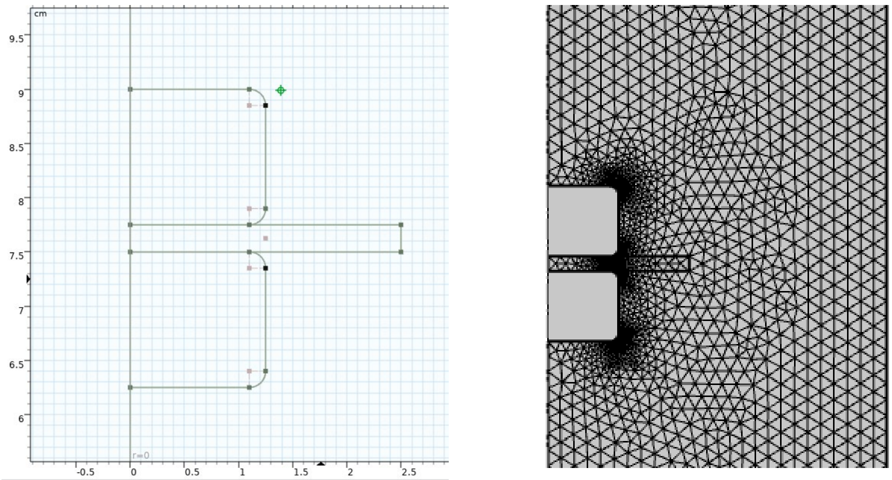



**Fig. 3** *Electrode configuration for cylindrical-cylindrical aluminium electrode*

## 2.5 Development of Electrostatic Model by Using COMSOL 6.3 Multiphysics

In Fig 4(a), the final design of the electrode configuration created using COMSOL 6.3 is displayed. The pressure chamber rectangle has dimensions of 7 cm width and 17.5 cm length, accommodating the cylinder-cylinder aluminium electrode. The cylinder is 25 mm in height and has a diameter of 25 mm. Additionally, the sample has a diameter of 50 mm and a width of 2.5 mm. In Fig 4 (b), the mesh for the cylinder-cylinder electrode is shown using a finer mesh. A finer mesh, consisting of more and smaller elements, can more accurately represent the geometry and field distribution.



**(a)** **(b)**

**Fig. 4** *Design electrode (a) Geometry model; (b) Mesh model*

## 3. Result and Discussion

This section discusses the development of solid insulation using Linear Low-density Polyethylene (LLDPE) and natural rubber. The percentage of natural rubber has been varying from 0% to 30% of the LLDPE-based composite. Observation and comparison have been made for each sample, with composition ratios of 100:0, 90:10, 80:20, and 70:30. The percentage of water absorption, relative permittivity, and electrical field intensity have been discussed in detail. The sample, with a diameter of 50mm and a thickness of 2.5mm,

### 3.1 Physical Characteristics of LLDPE-NR Blend

Mechanical blending can affect the physical characteristics and appearance of an LLDPE-NR composition. According to Fig 5, the sample becomes darker as the proportion of natural rubber increases from 100:0 to 70:30. This darkening is due to the higher amount of natural rubber in the sample. A pure LLDPE sample at a 100:0 ratio is white, reflecting the original colour of LLDPE. The sample, with a diameter of 50mm and a thickness of 2.5mm, was created according to the specifications outlined in Table 2.

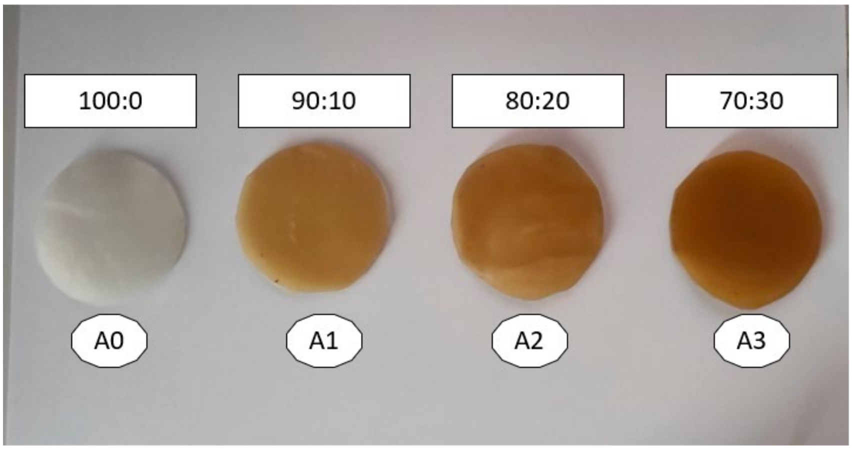



**Fig. 5** *Electrode configuration for cylindrical-cylindrical aluminium electrode*

Int. Journal of Integrated Engineering Vol. 17 No. 5 (2025) p. 327-338

**Table 2** *Composition of LLDPE and NR with different proportions*

| Condition | LLDPE (%) | Natural Rubber (%) | Designation |
|---|---|---|---|
| Normal | 100 | 0 | A0 |
| | 90 | 10 | A1 |
| | 80 | 20 | A2 |
| | 70 | 30 | A3 |
| Moisture | 100 | 0 | B0 |
| | 90 | 10 | B1 |
| | 80 | 20 | B2 |
| | 70 | 30 | B3 |

## 3.2 Percentage of Water Absorption

The graph in Figure 6 illustrates the water absorption percentage over a period of 70 days. It demonstrates that the B1 sample reached saturation in 50 days, followed by the B2 sample at 57 days and B3 at 65 days. The results indicate that the B3 sample took longer to reach saturation which about 0.55 % than the B1 and B2 samples. Therefore, it can be concluded that an increasing percentage of natural rubber can prolong the duration of saturation for the sample.

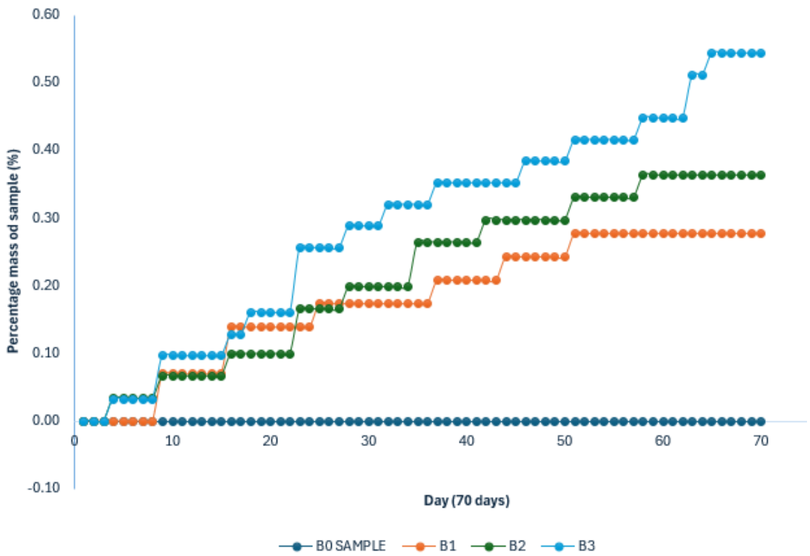



**Fig. 6** *Electrode configuration for cylindrical-cylindrical aluminium electrode*

## 3.3 Relative Permittivity of the Sample

Table 3 shows the relative permittivity of the samples under normal and moisture conditions. The table shows that the relative permittivity of the samples decreases from the A0 sample to the A3 sample under normal conditions. This decrease can be attributed to the increasing percentage of natural rubber, which alters the properties of the LLDPE base, resulting in lower relative permittivity. However, under moisture conditions, an increase in relative permittivity is observed for all samples compared to their normal state. This suggests that water absorption can modify the properties of the sample, leading to a higher relative permittivity.

**Table 3** *Composition of LLDPE and NR with different proportions*

| Condition | LLDPE (%) | Natural Rubber (%) | Designation | Relative Permittivity |
|---|---|---|---|---|
| Normal | 100 | 0 | A0 | 2.3114 |
| | 90 | 10 | A1 | 2.2013 |
| | 80 | 20 | A2 | 2.1584 |

| | | | | |
|---|---|---|---|---|
| | 70 | 30 | A3 | 2.1065 |
| Moisture | 100 | 0 | B0 | 2.3317 |
| | 90 | 10 | B1 | 2.3894 |
| | 80 | 20 | B2 | 2.4891 |
| | 70 | 30 | B3 | 2.4921 |

## 3.4 Voltage and Electric Field Distribution

Figure 7 displays the voltage distribution and includes a legend for the voltage density plot in a rod-rod electrode configuration. The voltage density plot uses a rainbow colour map to show the voltage distribution across the model. A voltage of 11 kV is applied to the top electrode, while the bottom electrode acts as the ground electrode. A sample with varying composition percentages under normal and moisture conditions is placed between the rod electrodes.

The top electrode is represented by a dark red colour, indicating a high voltage and strong electric field intensity. This dark red colour spreads across the surface area, transitioning to yellow, which signifies a medium voltage and electric field intensity. On the other hand, the bottom electrode is shown in blue, symbolising a ground with the lowest voltage. The colour map indicates the presence of the sample with a white area between the electrodes. This white colour is caused by the voltage and electric field distribution not being able to penetrate the sample positioned between the electrodes.

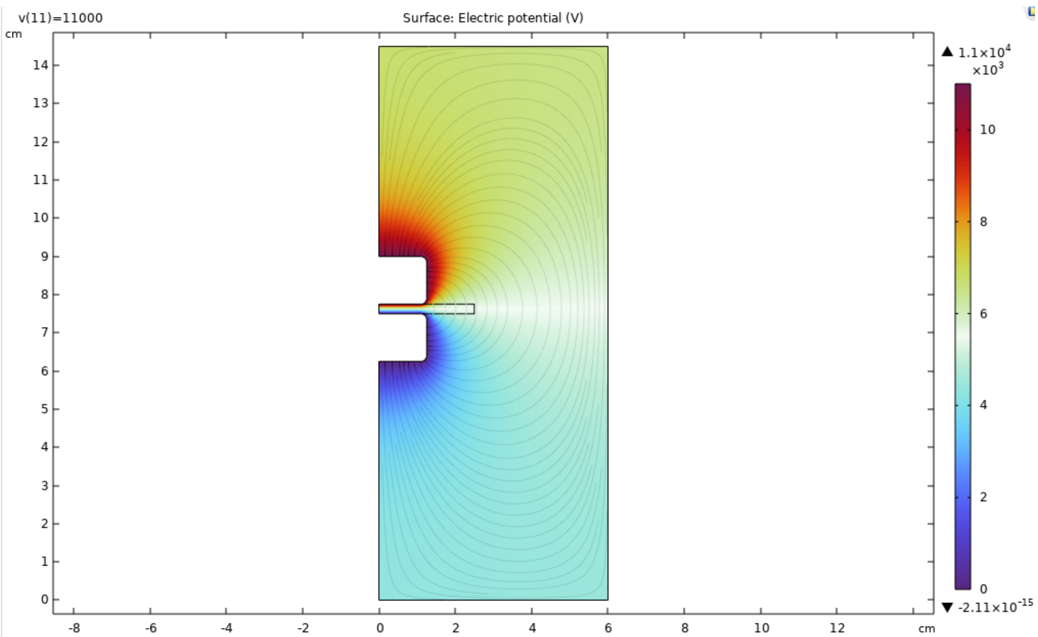



**Fig. 7** *Electrode configuration for cylindrical-cylindrical aluminium electrode*

Figure 8 shows a parabolic curve representing the maximum and minimum electric field intensities between the cylinder-cylinder aluminium electrodes. The highest electric field intensity is observed at the surfaces of the top and bottom electrodes, while the lowest electric field intensity is found at the centre of the dielectric sample. This analysis indicates that the electric field intensity increases closer to the surfaces of the top and bottom electrodes. As the distance lengthens, the electric field becomes more distributed, resulting in a decrease in electric field intensity in the middle of the electrodes and an increase again when closer to the bottom electrode. Consequently, the graph takes on a 'U' shape.

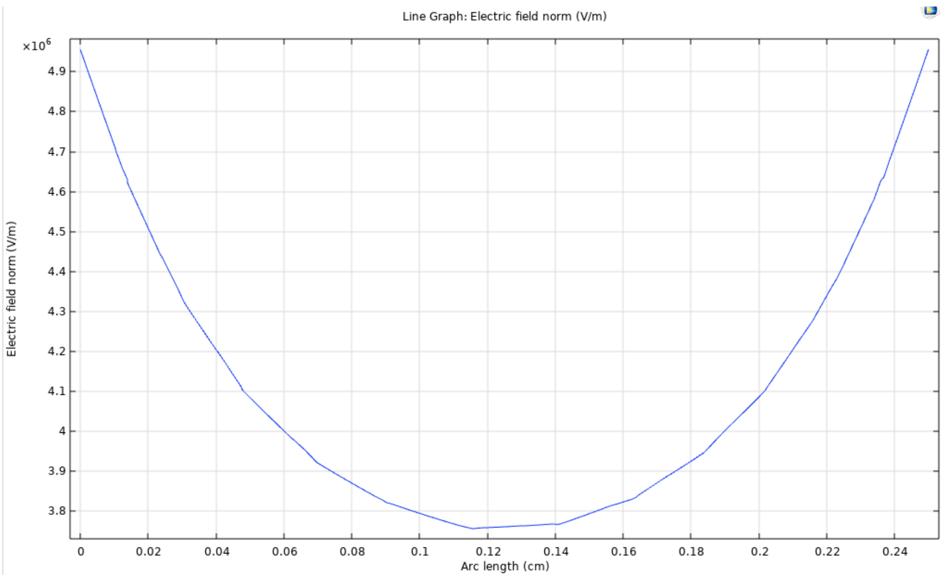



**Fig. 8** *The graph for electric field intensity versus length*

## 3.5 Electric Field Distribution Simulation Result

Table 4 illustrates the maximum and minimum electric field intensities for different percentages of the LLDPE-Natural rubber composite under two conditions: normal and moisture. The relative permittivity of the sample varied for each experiment. The data revealed that as the percentage of natural rubber increased from 0% to 30%, the relative permittivity decreased, and simultaneously, the maximum electric field intensity also decreased. The A0 sample, which is unfilled LLDPE, showed the highest maximum electric field intensity among all the samples. In contrast, the A3 sample exhibited the lowest electric field intensity compared to the A0, A1, and A2 samples.

**Table 4** *Composition of LLDPE and NR with different proportions*

| Condition | LLDPE (%) | Natural Rubber (%) | Designation | Relative Permittivity | Minimum Electric Field, Emin (MV/m) | Maximum Electric Field, Emax (MV/m) |
|---|---|---|---|---|---|---|
| Normal | 100 | 0 | A0 | 2.3114 | 3.7698 | 4.9673 |
| | 90 | 10 | A1 | 2.2013 | 3.7849 | 4.9616 |
| | 80 | 20 | A2 | 2.1584 | 3.7921 | 4.9596 |
| | 70 | 30 | A3 | 2.1065 | 3.8019 | 4.9570 |
| Moisture | 100 | 0 | B0 | 2.3317 | 3.7668 | 4.9674 |
| | 90 | 10 | B1 | 2.3894 | 3.7542 | 4.9695 |
| | 80 | 20 | B2 | 2.4891 | 3.7389 | 4.9732 |
| | 70 | 30 | B3 | 2.4921 | 3.7362 | 4.9837 |

## 3.6 Discussion and Analysis

The experimental data gathered for the LLDPE-NR composite samples highlight how varying the natural rubber (NR) content—ranging from 0% to 30%—influences several key characteristics, namely: physical appearance, water absorption, relative permittivity, and electric field intensity.

One of the most apparent observations was the change in the composite's physical appearance. As the NR content increased, the colour of the sample progressively darkened. This darkening is attributed to modifications in the physical and chemical properties of the material during the blending process. Specifically, the introduction of NR alters the distribution and size of rubber domains within the LLDPE matrix, resulting in a visibly darker composite [7].

Water absorption tests further confirm the influence of NR content on the composite's performance. As the proportion of NR increased from 0% to 30%, the water absorption rate also increased. This behavior is due to NR's lower hydrophobicity compared to LLDPE, making it more susceptible to moisture uptake. The A0 sample, which contains 100% LLDPE and no NR, exhibited the lowest water absorption among all tested samples, reinforcing its superior moisture-resistant properties [7]. These findings suggest that although NR can improve certain mechanical properties, it compromises the composite's resistance to water ingress.

In terms of dielectric behavior, the results from the relative permittivity tests demonstrate a consistent trend: increasing the NR content leads to a decrease in the composite's relative permittivity. This finding aligns with existing literature, as NR has a lower dielectric constant than LLDPE. Based on the conventional rule of mixtures for composite materials, the overall relative permittivity of a blended system is expected to fall between that of its constituents [8]. Thus, increasing the proportion of NR effectively reduces the composite's relative permittivity, which may be beneficial for insulation applications where low permittivity is desired.

Furthermore, relative permittivity was found to be higher in moisture conditions compared to normal dry conditions. This increase is primarily due to the presence of water molecules within the solid insulation, which are polar in nature. These molecules possess a dipole moment that aligns with the applied electric field, leading to an increase in the overall dielectric constant of the material [9]. The ability of water to influence the dielectric behavior underscores the importance of maintaining dry conditions in high-voltage insulation applications.

The electric field intensity distribution, plotted as a function of length between two electrodes, exhibits a typical parabolic or "U-shaped" curve. This pattern indicates that the electric field is strongest near the electrode surfaces and weakest at the center of the dielectric. This phenomenon arises from the movement of charges in the material under an applied field—positive charges migrate toward the cathode, and negative charges move toward the anode. As a result, charge accumulation near the electrodes intensifies the electric field at the boundaries while reducing it toward the center [10].

Simulation results further support the experimental findings. As shown in Table 4.4, increasing the NR content in the composite results in a decrease in the maximum electric field intensity. This inverse relationship is a direct consequence of the material's relative permittivity: lower permittivity materials generate lower electric field intensities under the same applied voltage. Moreover, materials with lower relative permittivity typically exhibit higher breakdown voltages, meaning they can withstand stronger electric fields before dielectric failure occurs [11]. This relationship suggests that adding NR to LLDPE can improve the insulation's overall reliability by enhancing its breakdown strength, despite its slight drawbacks in water resistance.

In conclusion, the introduction of natural rubber into LLDPE significantly alters both the physical and dielectric properties of the composite. While the addition of NR decreases water resistance and relative permittivity, it also reduces electric field intensity and improves breakdown voltage—making the LLDPE-NR composite a potentially valuable material for high-voltage insulation applications, depending on the specific requirements of the system.

## 4. Conclusion

This study investigated the potential of an LLDPE-NR composite as an electrical insulation material for high-voltage applications. The composite was developed by blending linear low-density polyethylene (LLDPE) with varying proportions of natural rubber (NR), ranging from 0% to 30%, using a Two-Roll Mill mixer. The mixing process was carried out at the Polymer Laboratory of UTHM, and it successfully produced homogeneous samples with good physical stability, demonstrating the practicality of incorporating natural rubber into LLDPE for insulation purposes.

Following the fabrication, water absorption tests were conducted by immersing the samples in water for a 70-day period. The results showed a clear trend: as the natural rubber content increased, so did the percentage of water absorbed. The B0 sample, consisting of 100% LLDPE, exhibited the lowest water absorption and thus the best hydrophobic performance. On the other hand, the B3 sample, with 30% NR, showed the highest water absorption, highlighting the hydrophilic nature of natural rubber. This indicates that while the addition of NR can provide certain benefits, it may compromise moisture resistance, which is an important consideration for insulation exposed to humid or wet environments.

Electrical properties were evaluated by measuring the relative permittivity of each sample using a Keysight 16451B dielectric test fixture. The results revealed that increasing the NR content led to a reduction in relative permittivity. The sample with 30% NR demonstrated the lowest permittivity value among all tested compositions. This finding suggests that natural rubber can enhance the dielectric performance of LLDPE by reducing its overall polarizability, which is beneficial for high-voltage insulation applications. In particular, lower relative permittivity contributes to better insulation performance by reducing capacitive losses and enhancing electric field control.
The electric field characteristics of each composite were then analyzed using COMSOL Multiphysics, where the measured relative permittivity values were used as input parameters. The simulation results indicated that the sample with 30% NR exhibited the lowest maximum electric field intensity. This reduction in electric field stress implies an increase in breakdown voltage capability, as materials with lower permittivity are generally better at withstanding high voltage stress without failing. Therefore, the composite with 30% NR shows the most promise in terms of electrical performance.

However, while the 30% NR sample demonstrated superior electrical characteristics, it also showed the highest water absorption. This introduces a trade-off between electrical performance and moisture resistance. Increased water content within the insulation material can lead to a rise in relative permittivity and, consequently, in electric field intensity under wet conditions, potentially leading to premature insulation breakdown. Thus, although the electrical advantages of higher NR content are evident, the increase in moisture sensitivity must be taken into account depending on the intended application.

In conclusion, this study has shown that the incorporation of natural rubber into LLDPE can effectively improve the electrical performance of the composite, particularly by lowering relative permittivity and reducing electric field intensity. The best performance in terms of dielectric properties was observed in the sample with 30% natural rubber. However, this composition also resulted in higher water absorption, suggesting that it may be more suitable for dry or controlled environments. These findings provide a valuable basis for further development of polymer-based insulation materials, and future work may focus on optimizing the balance between electrical performance and environmental durability, potentially through surface treatments or the use of hydrophobic additives.

## Acknowledgement

The authors would like to thank Universiti Tun Hussein Onn Malaysia (UTHM) for the financial support. This research was supported by Universiti Tun Hussein Onn Malaysia (UTHM) through TIER 1 vot Q909. The authors also gratefully acknowledge Kvolt Focus Group Team and Polymer Laboratory UTHM for technical support.

## Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of the paper.

## Author Contribution

*The authors confirm their contribution to the paper as follows:* ***study conception and design:*** *Mohamad Azzamuddin Majunit, Nor Akmal Mohd Jamail;* ***data collection:*** *Mohamad Azzamuddin Majunit;* ***analysis and interpretation of results:*** *Mohamad Azzamuddin Majunit, Nor Akmal Mohd Jamail, Nordiana Azlin Othman, Muhammad Saufi Kamarudin;* ***draft manuscript preparation:*** *Mohamad Azzamuddin Majunit, Nor Akmal Mohd Jamail, Nor Shahida Mohd Jamail;. All authors reviewed the results and approved the final version of the manuscript.*

## References

[1] J. Li, Y. Wei, Z. Huang, F. Wang, X. Yan, and Z. Wu, "Electrohydrodynamic behavior of water droplets on a horizontal super hydrophobic surface and its self-cleaning application," Appl Surf Sci, vol. 403, pp. 133–140, 2017, doi: https://doi.org/10.1016/j.apsusc.2017.01.141

[2] E. Mboungou, C. Mavon, J. . -m. Friedt, C. Bergeon, and M. Fromm, "Impact of Water Content on the Electrical Behavior of Epoxy Insulators," IEEE Transactions on Dielectrics and Electrical Insulation, vol. 15, no. 2, pp. 311–318, 2008, doi: 10.1109/TDEI.2008.4483447

[3] W. Zhao, W. H. Siew, and M. J. Given, "The electrical performance of thermoplastic polymers when used as insulation in cables," in 2013 48th International Universities' Power Engineering Conference (UPEC), 2013, pp. 1–4. doi: 10.1109/UPEC.2013.6714868.

[4] N. Jamail, M. A. M. Piah, N. A. Muhammad, and Q. E. Kamarudin, "PDC analysis of LLDPE-NR nanocomposite for effect of moisture absorption," International Journal of Electrical and Computer Engineering, vol. 7, pp. 3133–3139, Dec. 2017, doi: 10.11591/ijece.v7i6.pp3133-3139.

[5] F. D. Zailan, R. S. Chen, S. Ahmad, D. Shahdan, A. M. Ali, and M. I. F. M. Ruf, "Adunan polimer polietilena linear berketumpatan rendah, getah asli dan polianilina: Sifat regangan dan kestabilan terma," The Malaysian Journal of Analytical Sciences, vol. 22, pp. 999–1006, 2018, [Online]. Available: https://api.semanticscholar.org/CorpusID:264271383

[6] Z. Wanxi, Z. Chunxiao, and L. Hongji, "Research on LLDPE-inorganic nanocomposites," in 2008 2nd IEEE International Nanoelectronics Conference, 2008, pp. 255–260. doi: 10.1109/INEC.2008.4585481.

[7] E. Mastalygina, I. Varyan, N. Kolesnikova, M. I. C. Gonzalez, and A. Popov, "Effect of natural rubber in polyethylene composites on morphology, mechanical properties and biodegradability," Polymers (Basel), vol. 12, no. 2, Feb. 2020, doi: 10.3390/polym12020437.

[8] I. M. Alwaan, A. Hassan, and M. A. M. Piah, "Effect of Natural Rubber/Epoxidized Natural Rubber (90/10) on Dielectric Properties and Crystallization of Metallocene Linear Low Density Polyethylene," Polymers and Polymer Composites, vol. 23, no. 7, pp. 495–502, Sep. 2015, doi: 10.1177/096739111502300708.

[9] F. Pratomosiwi, N. Pattanadech, B. Wieser, M. Muhr, G. Pukel, and M. Stossl, “Dielectric properties measurements of oil immersed pressboard,” in 2012 IEEE International Conference on Condition Monitoring and Diagnosis, IEEE, Sep. 2012, pp. 60–63. doi: 10.1109/CMD.2012.6416199.

[10] N. A. M. Jamail et al., “Effect of Nanofillers on the Polarization and Depolarization Current Characteristics of New LLDPE-NR Compound for High Voltage Application,” Advances in Materials Science and Engineering, vol. 2014, pp. 1–7, 2014, doi: 10.1155/2014/416420.

[11] R. Liao, F. Zhang, Y. Yuan, L. Yang, T. Liu, and C. Tang, “Preparation and Electrical Properties of Insulation Paper Composed of SiO2 Hollow Spheres,” Energies (Basel), vol. 5, no. 8, pp. 2943–2951, Aug. 2012, doi: 10.3390/en5082943.

[12] N. A. Muhamad, A. A. Suleiman, and M. F. Ishak, “Optimal percentage natural rubber blends with Low Density Polyethylene (LDPE) for breakdown voltage (BDV) improvement,” in The 2nd IEEE Conference on Power Engineering and Renewable Energy (ICPERE) 2014, 2014, pp. 61–65. doi: 10.1109/ICPERE.2014.7067244

[13] D. W. Nurhajati, U. R. Lestari, and I. Setyorini, "Effect of $Bi_2O_3$ on the properties of linear low-density polyethylene (LLDPE)/natural rubber compound (NRC) composites," *Journal of Physics: Conference Series*, vol. 1442, no. 1, pp. 012058, 2020. doi: 10.1088/1742-6596/1442/1/012058

[14] A. H. Ritonga, N. Jamarun, S. Arief, H. Aziz, D. A. Tanjung, and B. Isfa, “Improvement of mechanical, thermal, and morphological properties of organo-precipitated calcium carbonate filled LLDPE/cyclic natural rubber composites,” *Indones. J. Chem.*, vol. 22, no. 1, pp. 233–241, 2022, doi: 10.22146/ijc.68888.

[15] G. Gardan and G. C. Montanari, “Partial Discharge Inception Modelling of Materials and Systems: Contribution of Electrodes to Electric Field Profile Calculation,” Applied Sciences, vol. 14, no. 1, 201, Dec. 2023, doi:10.3390/app14010201.

[16] M. Choudhary, M. Shafiq, I. Kiitam, I. Pälu, W. Hassan, and P. P. Singh, “Investigation of partial discharge characteristics in XLPE cable insulation under increasing electrical stress,” *Engineering Failure Analysis*, vol. 158, 108006, Jan. 2024, doi: 10.1016/j.engfailanal.2024.108006.