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# Electric Field Characteristics of HDPE-NR Biocomposite under Breakdown Condition using COMSOL

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**Abstract**: For the creation of future electrical networks, it was crucial to creating novel insulating materials that can enhance the performance of high voltage cables of the next generation. The high electric field reduces the resistance of solid insulation and induces partial discharge through dielectric flaws, leading the dielectric to degrade over time and eventually fail. This project aims to analyse the electric field intensity of High-Density Polyethylene (HDPE) in breakdown conditions when added with 10g, 20g, and 30g of various types of bio-filler, including oil palm empty fruit bunch, pineapple leaves fibre and coconut coir fibre. Using the COMSOL Multiphysics software, a two-dimensional (2D) axisymmetric electrostatic model can be generated. According to the results, the unfilled HDPE biocomposites have a higher electric field intensity than the 10g, 20g, and 30g biocomposites, with values of 25.70 MV/m and 32.51 MV/m for a needle to needle and sphere to sphere, respectively. Under breakdown conditions, the maximal electric field strength varies according to the permittivity and voltage of the bio-filler. Therefore, the maximum electric field intensity was dramatically reduced for HDPE containing 20g of pineapple leaves fibre, with values of 2.83 MV/m and 4.39 MV/m for a needle to needle and sphere to sphere, respectively. Consequently, pineapple leaf fibre was the optimal composition, since it tends to improve the dielectric characteristics due to its lower electric field intensity at the top electrode compared to other compositions.

**Keywords**: HDPE, Electric Field, Biocomposite, COMSOL

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## 1. Introduction

Insulators for high voltage (HV) were vital components of electrical power transmission and distribution systems; they prevent excessive current leakage from their supporting points to the ground. To evaluate the activities and performance of insulators, local elements such as contamination, stress, and damaged or broken structures were investigated.

As its name suggests, an insulator was a substance that inhibits or delays the flow of electrical current. In outdoor applications, overhead insulators, sometimes referred to as outdoor insulators, fulfil two functions: mechanically sustaining wires and providing electrical protection for the power system network [1]. The electric field of each type of insulating material varies according to its permittivity values and the substance employed. Due to their electrical breakdown features, porcelain, ceramic, and glass electrical insulators typically failed to work in electric fields of this magnitude. The increased demand for greater voltage levels and superior insulation qualities necessitates the development of novel electrical insulation material solutions.

Polymer biocomposites were composites made up of polymer and bio-filler that have unique matrix properties. High-Density Polyethylene was the most often employed polymer in commercial and industrial applications today (HDPE). HDPE was the most basic kind of polyethene (PE). It can be converted from a liquid to a solid state because it was a thermoplastic polymer. The main reason it was used was that it was robust, reasonably inexpensive, and highly processable. Composite insulators have been offered as low-cost replacements for ceramic and glass insulators. In addition, HDPE was frequently employed in the construction industry for pipe fabrication and as an insulator in electrical equipment [2]-[3].

Consequently, breakdown failures in polymer biocomposites were caused by the same process as failures in pure polymers. To assess the electrical field strength of polymer biocomposites, it was necessary to use the COMSOL software to analyse the electric field intensity of the HDPE-biocomposites insulator. Using COMSOL Multiphysics software, the simulation results were used to investigate the electrical field properties of HDPE-biocomposite under breakdown conditions.

## 2. Methodology

This chapter explains the strategy utilised to achieve the project's goals. The purpose of this study was to determine the electric field density of an HDPE-biocomposite under failure conditions. This study's technique involves examining the link between the electric field intensity and the weight of various biocomposite materials, as well as their permittivity under breakdown conditions. This project was created utilising a technique of numerical computation. COMSOL Multiphysics was utilised to simulate the electric field's intensity.

### 2.1 Research Structure

Figure 1 depicts the flowchart for the comprehensive project planning procedure. This study commences with a review of the pertinent literature to collect pertinent information regarding earlier works on electric field analysis and material properties. Using COMSOL Multiphysics, an axisymmetric model was developed to determine the electric field intensity in different biocomposite weights with breakdown voltage. Repeat the process while modifying the relative permittivity of the sample. If the result does not match the intended result, continue the simulation and study its properties until the desired results were reached. The results were then analysed graphically and summarised in a table. The results were then addressed in terms of the various biocomposites that were utilised to establish the optimal bio-filler mixture for solid insulation.

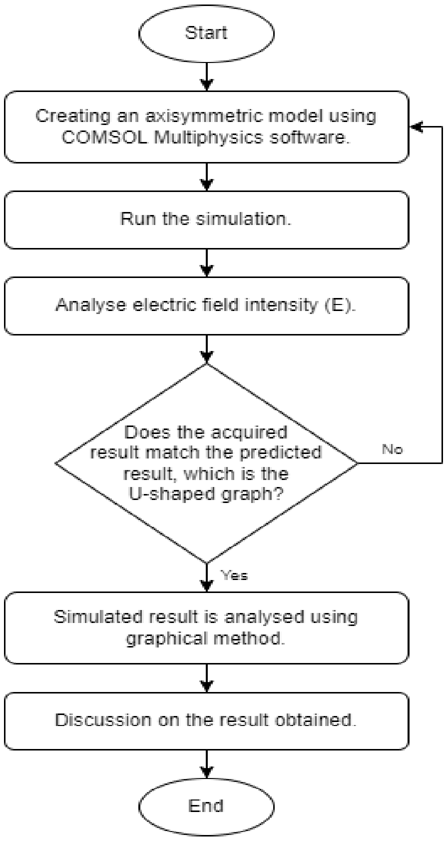
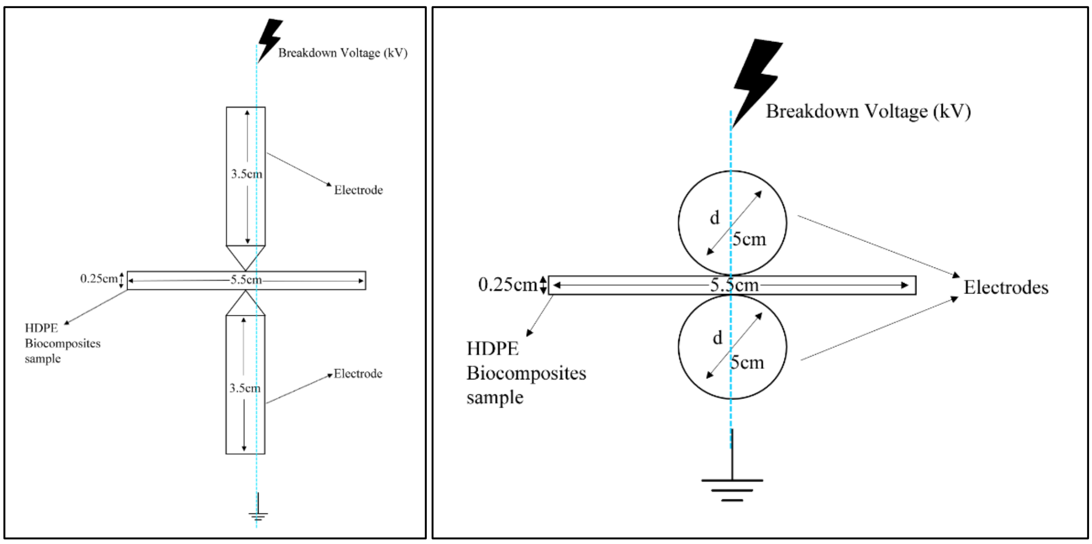



**Figure 1: Research Structure**

2.2 Electrode Configuration Geometry

Using the laboratory electrode setup, the electrostatic model represented in Figure 2 was generated. The electrode has the same proportions as the laboratory's actual needle and sphere electrodes, which were 3,5 cm in length and 5 cm in diameter. The sample was put between electrodes measuring 0.25 cm in length and 5.5 cm in thickness. The voltage at the upper needle and spherical electrodes was determined using breakdown voltage.




(a) Needle to needle (b) Sphere to sphere

**Figure 2: Electrode configuration geometry**

### 2.3 Software Development

For evaluating the relationship between electric field intensity and various biocomposite materials with breakdown voltage and their allowability, it was required to develop software. The electrostatic issue was tackled in several steps using the simulation software COMSOL Multiphysics. Figure 3 depicts the way for modelling two-dimensional axisymmetric issues in electrostatics.

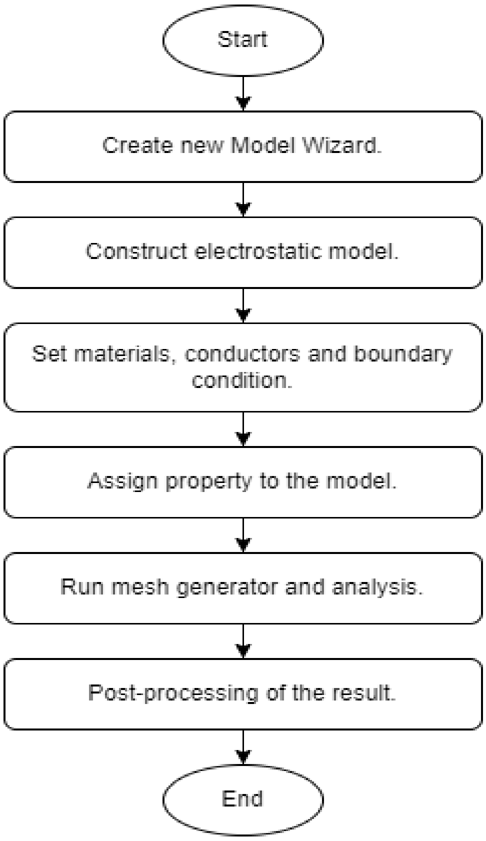
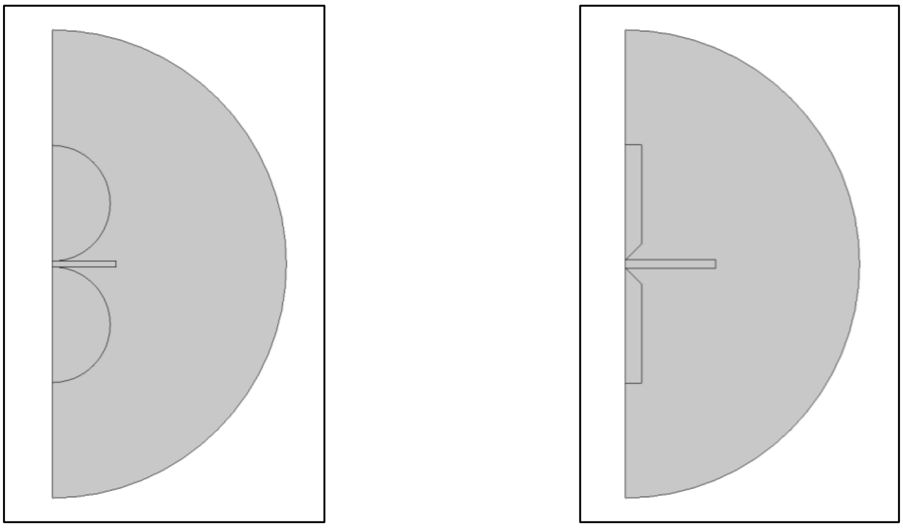



**Figure 3: Step for developing 2D axisymmetric electrostatic issues**

### 2.4 Model of Design

As shown in Figure 4, the model was developed using the model creation tools of the COMSOL software. According to Figure 4, the diameter of one half-circle representing sphere to sphere and needle to the needle was 20.25cm and 14.25cm, respectively, and was displayed vertically, whereas the sample with dimensions of 0.25cm in width and 2.75cm in length was displayed horizontally.



(a) Sphere to sphere (b) Needle to needle

**Figure 4: Created model**

2.5 Material’s Relative Permittivity

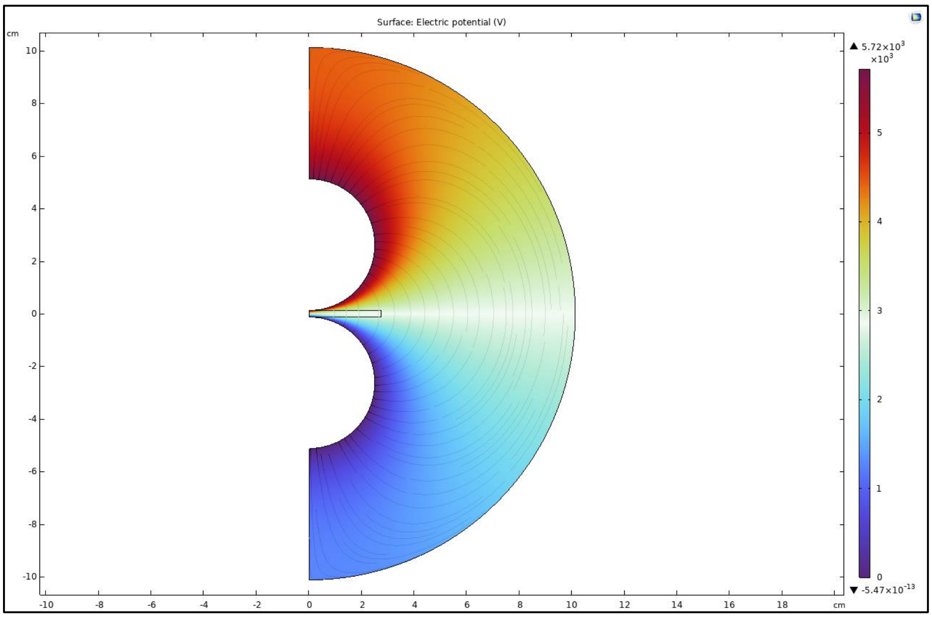
When calculating the electric field of a model, the material’s relative permittivity must be accounted for. The relative permittivity of each HDPE-NR biocomposites was distinct from the others. This instrument measures the dielectric constant of dielectric solids. Incorporated into the HDPE matrix were NR-grade SMR CV 10 and bio-filler. The HDPE-NR biocomposite consists of 80 percent HDPE and 20 percent NR in a ratio of 80:20, together with 10g, 20g, and 30g of bio-filler. Table 1 summarises the HDPE-NR biocomposites sample, permittivity, and breakdown voltage utilised in the simulation.

**Table 1: Permittivity for electric field computation**

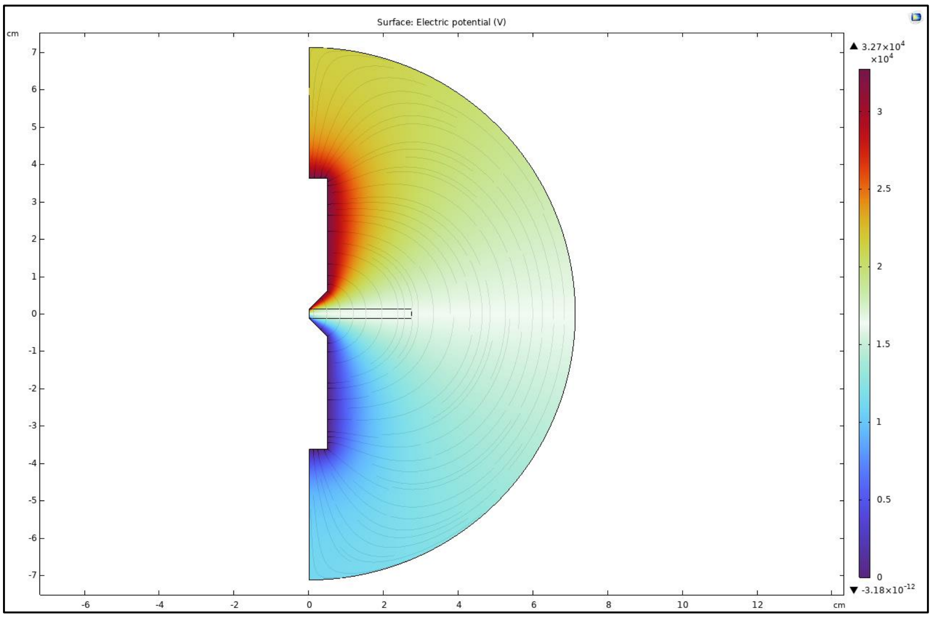
| Sample | Bio-filler content (g) | Permittivity Value | Breakdown Voltage (kV) |
|---|---|---|---|
| Unfilled HDPE | 0 | 2.31 | 32.74 |
| Unfilled HDPE + NR | 0 | 2.43 | 5.27 |
| HDPE + NR + Empty Fruit Bunch | 10 | 2.60 | 5.72 |
| HDPE + NR + Empty Fruit Bunch | 20 | 2.82 | 4.68 |
| HDPE + NR + Empty Fruit Bunch | 30 | 2.84 | 11.51 |
| HDPE + NR + Coconut Coir Fibre | 10 | 2.70 | 7.60 |
| HDPE + NR + Coconut Coir Fibre | 20 | 3.04 | 3.28 |
| HDPE + NR + Coconut Coir Fibre | 30 | 3.29 | 4.18 |
| HDPE + NR + Pineapple Leaves Fibre | 10 | 2.66 | 8.53 |
| HDPE + NR + Pineapple Leaves Fibre | 20 | 2.91 | 4.41 |
| HDPE + NR + Pineapple Leaves Fibre | 30 | 3.10 | 8.07 |

2.6 Post-Processing of The Result

This approach aims to determine the model's voltage distribution and electric field intensity. COMSOL's electrostatics post-processing software was utilised to examine the solution generated by the solver. Colourful contours and graphs might be utilised to depict the results. Once the post-processor was activated, a voltage colour density plot was displayed, as shown in Figure 5. Manually creating contours requires giving the start and end locations of the sample.




(a) Sphere to sphere




(b) Needle to needle

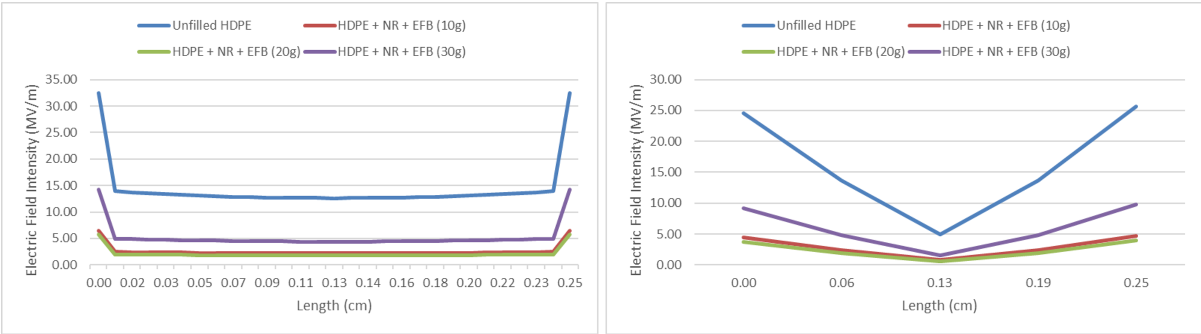
**Figure 5: Electrostatic post-processor-rendered colour density plot of voltage (a) Sphere to sphere and (b) Needle to needle**

## 3. Results and Discussion

The results of the electric field intensity of HDPE-NR biocomposites were discussed in this chapter. To obtain the results, the electrostatic model was simulated using the COMSOL Multiphysics software. Using Microsoft Excel, we calculated and analysed the collected data. The sample's voltage and electric field dispersion have been discussed. This section also compares the breakdown voltage to the electric field intensity for various biocomposites of varying densities. This section will address the appropriate applications of bio-fillers as insulation materials.

### 3.1 HDPE Polymer Matrix with Empty Fruit Bunch (EFB) Bio-filler

Figure 6 compares the electric field intensity of HDPE to that of various weights of empty oil palm fruit bunches. Prior to completing the sample, the electric field was measured from the layer of the sample that was closest to the positive conductor. The electric field intensity was greatest near the sample's surface, which was closest to the needle and spherical electrodes, as indicated by the graph. As the distance from the surface of the conductor rises, the electric field lessens. The data also reveals that 20g EFB has a smaller electric field than 30g EFB.

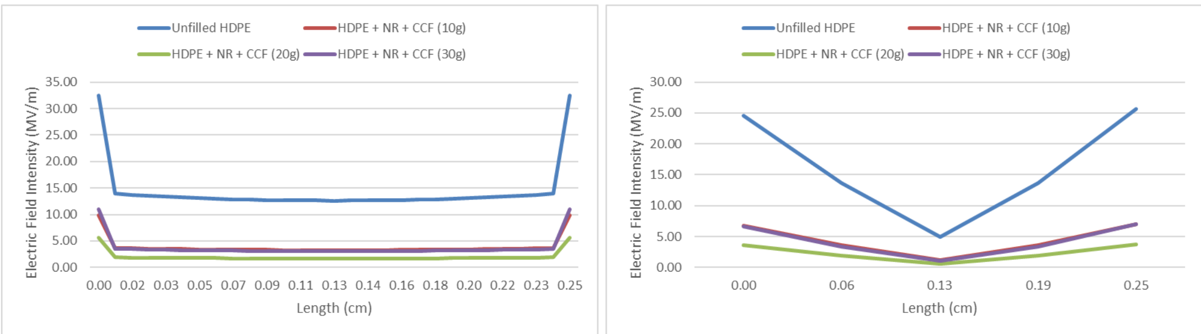



(a) Sphere to sphere (b) Needle to needle

**Figure 6: Electric field intensity for HDPE with 10g, 20g, and 30g of empty oil palm fruit bunch and HDPE without filler**

### 3.2 HDPE Polymer Matrix with Coconut Coir Fibre (CCF) Bio-filler

Figure 7 compares the electric field intensity of HDPE and various coconut coir fibre weights. Prior to concluding the sample, the electric field was measured from the sample layer closest to the positive conductor. As indicated by the graph, the electric field intensity was greatest near the surface of the sample, which was closest to the needle and spherical electrodes. As the distance from the surface of the conductor rises, the electric field lessens. Moreover, according to the data, 20g of CCF has a weaker electric field than 30g of CCF. The sample surface nearest to the top electrode has the strongest electric field strength, as seen by the graph.

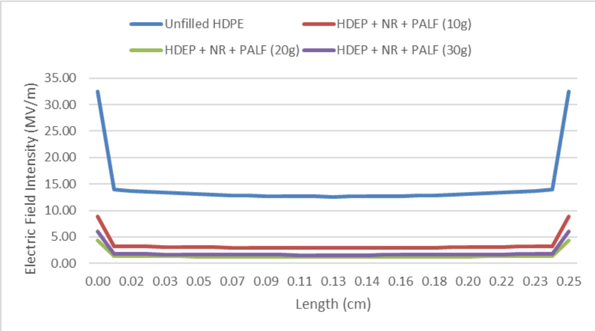



(a) Sphere to sphere (b) Needle to needle

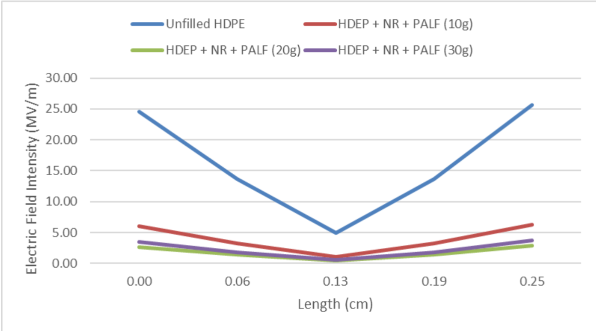
**Figure 7: Intensity of the electric field for HDPE with 10g, 20g, and 30g of coconut coir fibre relative to HDPE without filler**

3.3 HDPE Polymer Matrix with Pineapple Leaves Fibre (PALF) Bio-filler

The electric field intensity of HDPE and pineapple leaf fibres of various weights was depicted in Figure 8. From the layer of the sample nearest to the positive conductor until the end of the sample, the electric field was measured. The sample surface closest to the top sphere electrode has the strongest electric field strength, as shown in the graph. According to statistics, the electric field of 30g of PALF was less than that of 10g of PALF.




(a) Sphere to sphere



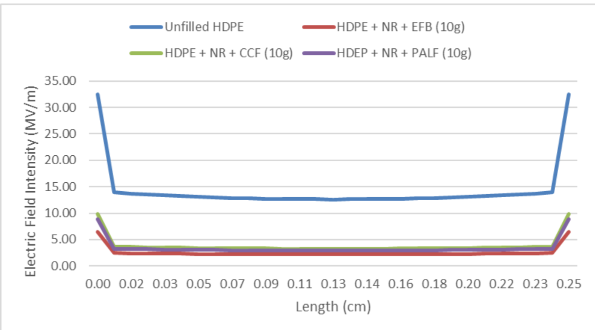

(b) Needle to needle

**Figure 8: Intensity of the electric field for HDPE with 10g, 20g, and 30g of pineapple leaf fibre, relative to HDPE without filler**

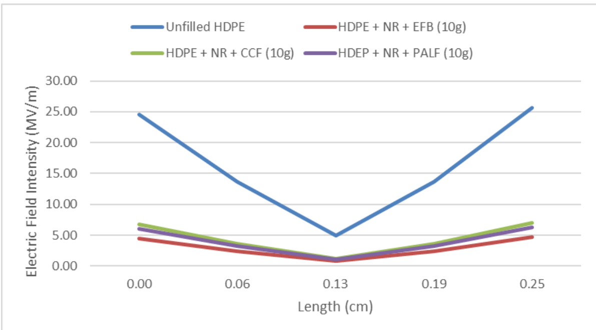
3.4 Comparison Between Different Bio-filler

The electric field intensity of HDPE was compared with that of 10g, 20g, and 30g of biocomposites to determine the optimal mixture of oil palm empty fruit bunch fibre, pineapple leaf fibre, and coconut coir fibre bio-filler for solid insulation. Figures 9 to 11 display the graph illustrating the fluctuation in electric field intensity across the sample's thickness.

The electric field intensity for an HDPE sample containing 10g of biocomposites was shown in Figure 9. According to the findings, the sample surface nearest to the top electrode has the most powerful electric field. The intensity of the electric field decreases as the distance from the conductor's surface increases. The HDPE sample without filling had the highest electric field intensity when compared to the other HDPE samples. CCF bio-filler has the highest electric field among 10g of biocomposites when the sample length was less than 0.05 cm from the surface, whereas EFB bio-filler has the lowest electric field. For lengths ranging from 0.05 cm to 0.17 cm, CCF bio-fillers continue to have the highest electric field intensity, whereas EFB bio-fillers have the lowest electric field intensity.



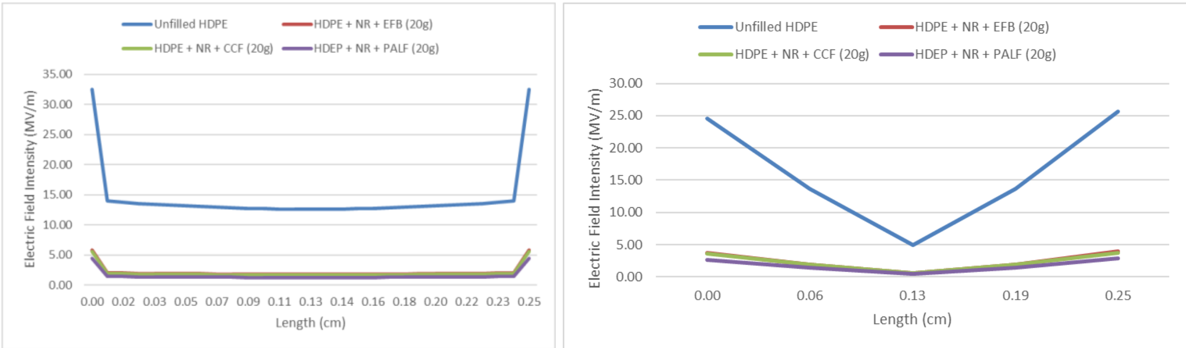

(a) Sphere to sphere




(b) Needle to needle

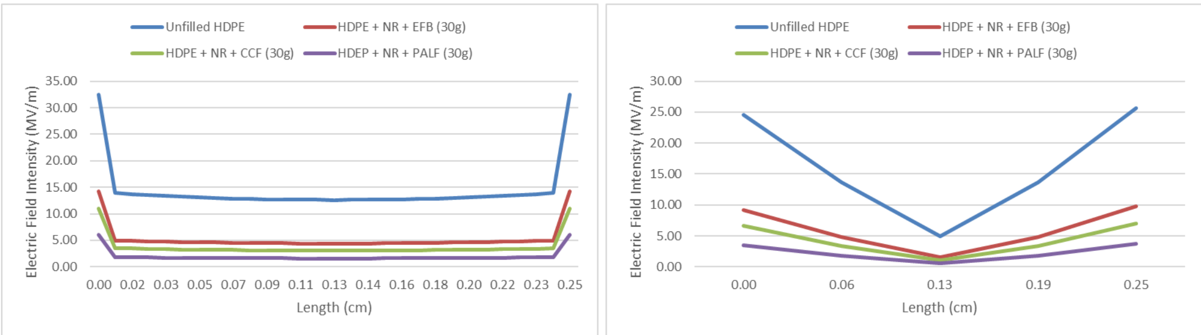
**Figure 9: Intensity comparison of the electric field for HDPE and 10g of biocomposites**

Figures 10 and 11 illustrate the electric field intensity of the HDPE sample when 20g and 30g of biocomposites, respectively, were applied. Regarding the electric field intensity, 10g of biocomposite displayed the same behaviour and trend as HDPE in both instances. The electric field was strongest on the sample surface nearest to the top electrode. The electric field's intensity decreases with distance from the conductor's surface. Under all conditions, 30g of maximum electric field intensity was greatest for EFB bio-filler, followed by CCF bio-filler and PALF bio-filler, which demonstrates the lowest maximal electric field strength among all biocomposites. This was the case because PALF biocomposites have a lower breakdown voltage than EFB and CCF biocomposites. This indicates that the maximum electric field intensity was dependent on the permittivity and breakdown voltages of the biocomposites.




(a) Sphere to sphere (b) Needle to needle

**Figure 10: Intensity comparison of the electric field for HDPE and 20g of biocomposites**




(a) Sphere to sphere (b) Needle to needle

**Figure 11: Intensity comparison of the electric field for HDPE and 30g of biocomposites**

### 3.5 Discussion

Observable from the collected data was the difference in electric field intensity between different biocomposite weights and breakdown voltage on the resulting HDPE-NR biocomposites. With parabolic curves, the electric field diminishes with increasing distance from the conductor surface in all HDPE-NR biocomposite samples. It appears that the top electrode has a greater electric field intensity than the bottom electrode. The electric field intensity was greatest near the surface of each sample, closest to the top electrode, according to the data. The electric field was stronger at the top electrode because it receives the highest voltage. When a sample was exposed to an electric field, electrons and positive ions migrate to electrodes with opposing polarities, with positive charge migrating toward the cathode and negative charge travelling toward the anode. As a result, there was a build-up of the field at both electrodes and a proportionate reduction in insulation thickness in the middle [4].

Adding bio-filler to a polymer matrix changes the intensity of the electric field, as opposed to a polymer matrix without filler. The simulation was used to investigate the impacts of different biocomposites' weights and permittivity on the breakdown voltage of the final HDPE-NR biocomposites. According to simulation results, the electric field intensity of empty HDPE biocomposites was greater than that of 10g, 20g, and 30g biocomposites, with values of 25.70 MV/m and 32.51 MV/m for needle to needle and sphere to sphere, respectively. This means that the permittivity and breakdown voltage of the filler defines the maximal electric field intensity.

The electrical breakdown was influenced by the material's electric field intensity and occurs in a high-field zone, resulting in a reduced breakdown strength. The electrode in PALF bio-top filler has a lower electrical field intensity than other formulations, with values of 2.83 MV/m and 4.39 MV/m for the needle to needle and sphere to sphere, respectively, which improves its dielectric properties.

## 4. Conclusion

Using simulation with the COMSOL Multiphysics programme, all of this project's objectives were accomplished. The fundamental objective of this research was to build an electrostatic model of biocomposite HDPE-NR. With Finite Element Magnetics, an axisymmetric electrostatic model with two electrodes, and one HDPE-NR biocomposite sample, a version of the COMSOL Multiphysics programme was successfully developed. The simulation may examine the breakdown voltage, electric field distribution, and electric field intensity for various biocomposite densities. Compared to unfilled HDPE, the inclusion of bio-filler into HDPE has a significant effect on the electric field intensity. Using the COMSOL Multiphysics software, the electrical field properties of HDPE-biocomposite under breakdown conditions were investigated. The electric field intensity of empty HDPE biocomposites was greater than that of 10g, 20g, and 30g biocomposites, with values of 25.70 MV/m and 32.51 MV/m for needle to needle and sphere to sphere, respectively, according to simulation results. According to the permittivity and voltage of the bio-filler, the maximum electric field strength under breakdown conditions varies. The third objective was to determine the ideal combination of coconut coir fibre, pineapple leaf fibre, and empty fruit bunch bio-filler for solid insulation. The results demonstrated a correlation between the electric field strength, permittivity value, and breakdown voltage. In comparison to other compositions, PALF bio-filler was the best in this regard, with values of 2.83 MV/m and 4.39 MV/m for the needle to needle and sphere to sphere, respectively, since its reduced electric field intensity at the top electrode tends to improve dielectric properties.

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