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Electric Field Characteristics of HDPE-NR Biocomposite Under Breakdown Condition

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Abstract: It is critical to develop new insulating materials that can improve the performance of next generation high voltage cables for creating future electrical networks. The high electric field reduces the resistance of solid insulation and produces partial discharge through imperfections in a dielectric, causing the dielectric to age and eventually fail. Thus, this project seeks to analyse the electric field intensity of High Density Polyethylene (HDPE) in breakdown condition when added with 10g, 20g and 30g of different types of bio-filler such as coconut coir fibre, pineapple leaves fibre, and oil palm empty fruit bunch. This can be achieved by creating a two-dimensional (2D) axisymmetric electrostatic model by using the Finite Element Method Magnetics (FEMM) 4.2 software. The results showed that the unfilled HDPE biocomposites have a higher electric field intensity than 10g, 20g, and 30g biocomposite. This indicates that the maximum electric field intensity changes according to the permittivity and voltage of the bio-filler under breakdown conditions. As a result, the maximum electric field intensity was much lower for HDPE added with a 20g of the pineapple leaves fibre. Hence, pineapple leaves fibre was the best composition as it tends to improve the dielectric properties since it has a lower electric field intensity at the top electrode as compared to other compositions.

Keywords: HDPE, electric field, FEMM, biocomposite

1. Introduction

Obviously, the insulator is a material that prevents or slows down the flow of electrical current. Overhead insulator or outdoor insulator have dual functions, particularly for outdoor applications; support conductors mechanically and provide electrical protection to the power system network [1]. Every type of insulating material has a different electric field depending on the different material used and their permittivity values. Electrical insulators made up of glass, ceramic, and porcelain often failed to operate under large electrical fields due to electrical breakdown properties. Thus, it is crucial to develop new alternatives for electrical insulation material due to increased demands for higher voltage levels and to provide better insulation properties.

Polymer biocomposites are the combination of polymer and bio-filler, producing new properties of the matrix. Today, the most frequently used polymer in commercial and industrial products is High-Density Polyethylene (HDPE).

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HDPE is one of basic types under Polyethylene (PE) polymer. It is a thermoplastic polymer; means that it can be melted to a liquid and remolded it to a solid state. It is tough, relatively inexpensive and has excellent process ability. Composite insulators have been proposed as a cost-effective replacement for ceramic and glass insulators. Furthermore, HDPE is frequently utilised in the construction sector for pipe manufacturing and as an insulator in electrical equipment [2][3].

In addition, HDPE has a several drawbacks such as low elasticity and resilience. To recuperate HDPE faintness, mixing HDPE with natural rubber (NR) is the superlative way because NR [4] contains high mechanical strength and elasticity. The drawbacks of NR in application such as unstable to high temperature and non-tolerant to oil based and based on the finding, adding a filler [5] can improved application requirements compared to conventional.

Furthermore, by controlling the weight percentage (wt.%) of filler can resolve the weakness between filler and adhesion matrix. Empty fruit bunch (EFB) fibre offers many benefits which is high specific strength, low cost, renewable, lower density, biodegradable, less abrasive, harmless to human and lead to significant advances in dielectric properties compared to conventional [6]. Moreover, pineapple leaf (PAL) contains excellent potential reinforcement, low energy consumption, good in dielectric constant, low density, has specific strength and stiffness, biodegradable, low cost, high specific properties and nano abrasive [7] while coconut coir (CC) has excellent mechanical and electrical properties performance [8], low cost, light in weight and good in dielectric constant. In this paper, the effect of these three biocomposite fillers were investigated by varying the level of weight percentage, e.g., 10 wt%, 20 wt.% and 30 wt.%, respectively.

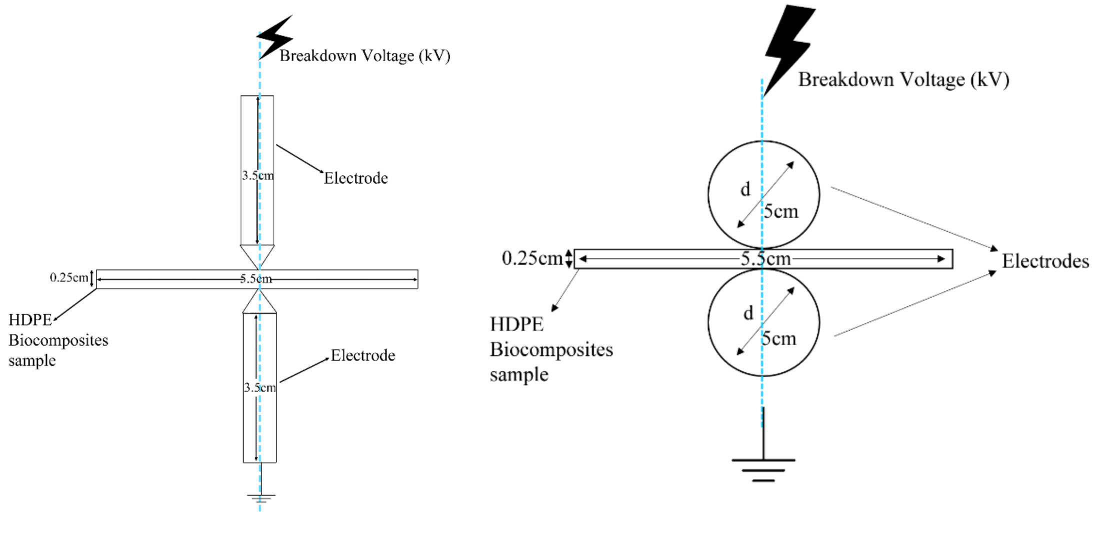
Thus, polymer biocomposites also exhibit breakdown failures, which is the same process that causes pure polymers to malfunction. To ensure the credibility of polymer biocomposites' electrical field strength, it is critical to analyse the electric field intensity of the HDPE-biocomposites insulator using Finite Element Method Magnetics (FEMM) software. The result obtained from the simulation is used to investigate the electrical field characteristic of HDPE-biocomposite under breakdown condition by using FEMM-based software.

2. Methodology

This chapter discusses the methodology used to accomplish the project's objectives. The purpose of this project is to identify the electric field density characteristic of HDPE-biocomposite under breakdown condition. The methodology for this research is to analyse the electric field intensity in relation to the weight of different biocomposite materials and their permittivity under breakdown conditions. For this project development, numerical computational technique has been applied. The electric field intensity is simulated using the FEMM 4.2 programme. For experimental setup, the diameter and thickness of mould (circle) is about 55mm and 2.5mm, respectively. The maximum weight for compression moulding process is 130g (maximum weight depends on mould diameter and thickness). The base composition (80g:20g) is fixed while filler composition (10g - 30g).

2.1 Geometry of Electrode Configuration

The electrostatic model was created using the electrode arrangement that was used in the laboratory, as illustrated in Fig. 1. The electrode is sized to correspond to the laboratory's actual electrode needle and sphere, which are 3.5 cm in length and 5 cm in diameter. The sample is put between the electrodes, which measure 0.25 cm in length and 5.5 cm in thickness. Breakdown voltage is used to determine the voltage at the upper needle and sphere electrodes.



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

Fig. 1 - Geometry of electrode configuration

2.2 Software Development

The development of software is important for the investigation of electrical field intensity in relation to various biocomposite materials with breakdown voltage and their allowability. The electrostatic problem is solved in multiple steps using the FEMM 4.2 software simulation. The method for modelling two-dimensional axisymmetric issues in electrostatics is illustrated in Fig. 2 [9].

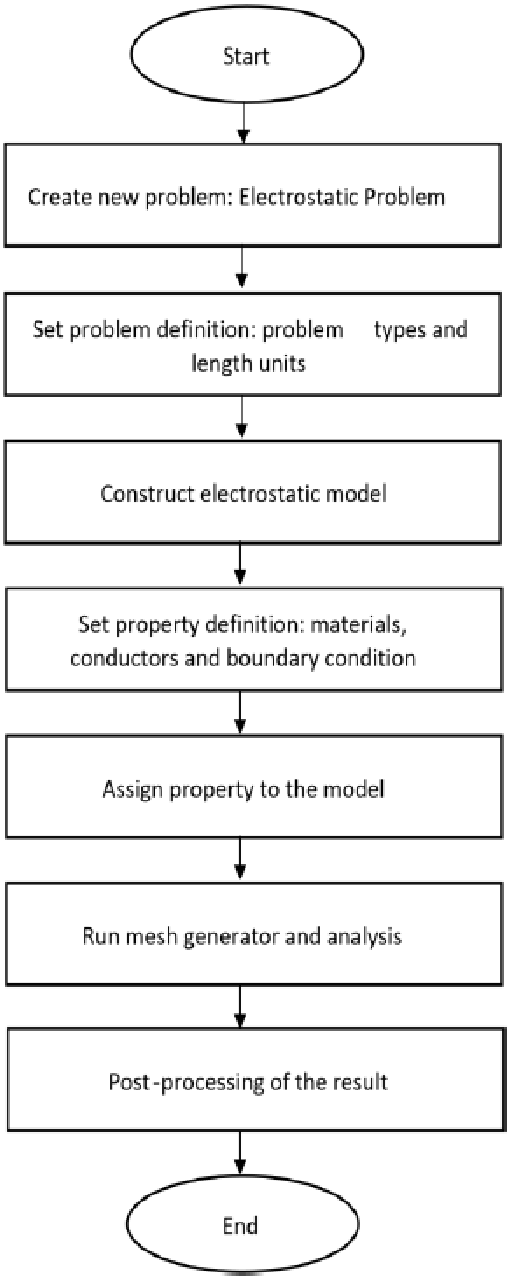
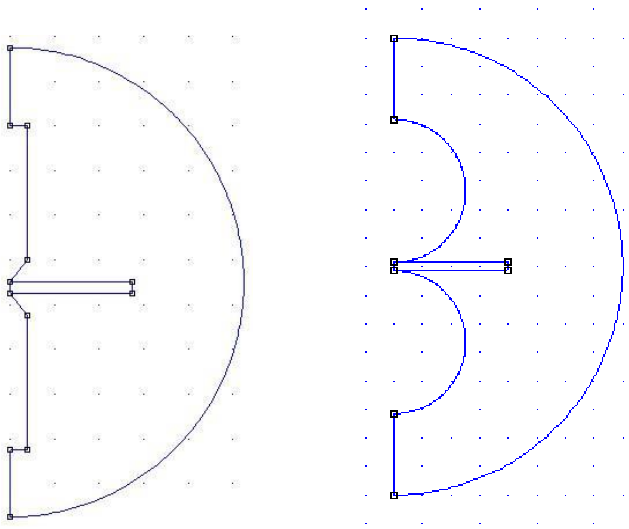


Fig. 2 - Step for designing 2D axisymmetric problems in electrostatics

2.3 Design Model

As illustrated in Fig. 3, the model was developed using the model tools included in the FEMM 4.2 software. According to Fig. 3, there is diameter of one half-circle which represents the outer boundary and two electrodes, is 3.5cm and 0.4cm respectively, were presented vertically, while the sample with a 0.25cm width and 2.75cm length was displayed horizontally.



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

Fig. 3 - Created model

2.3 Relative Permittivity of Materials

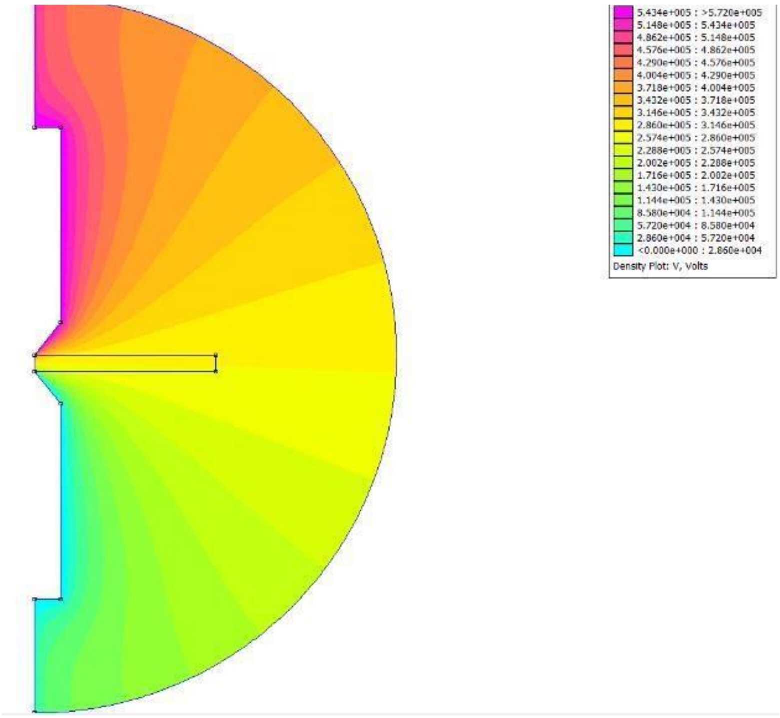
The material property that needs to be considered for the model's electric field is relative permittivity. The relative permittivity of each of the HDPE-NR biocomposites varies. The dielectric constant of solid dielectric materials is determined using the dielectric test fixture. The base matrix was HDPE, which was combined with NR grade SMR CV 10 and the bio-filler. The HDPE-NR biocomposite is composed of 80% HDPE and 20% NR in a ratio of 80:20, as well as varying amounts of bio-filler in the range of 10g, 20g, and 30g. Table 1 summarises the HDPE-NR biocomposites sample, permittivity, and breakdown voltage employed in the simulation.

Table 1 – Permittivity for electric field computation [10-12]

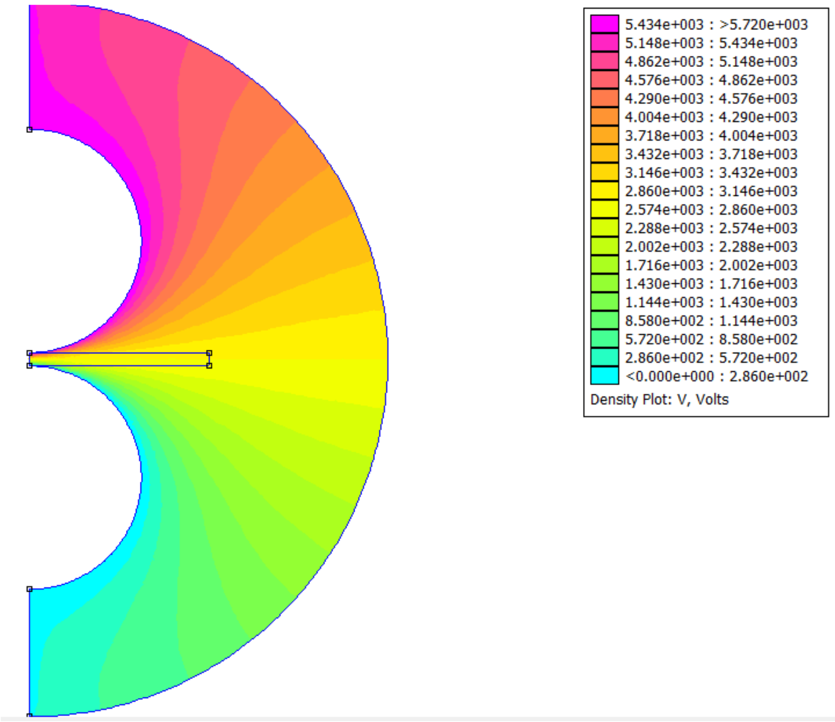
Sample	Bio-filler content (g)	Permittivity value	Breakdown voltage (kV)
Unfilled HDPE	0	2.31	32.74
Unfilled HDPE + NR	0	2.43	5.27
HDPE + NR + EFB	10	2.60	5.72
HDPE + NR + EFB	20	2.82	4.68
HDPE + NR + EFB	30	2.84	11.51
HDPE + NR + PAL	10	2.70	7.60
HDPE + NR + PAL	20	3.04	3.28
HDPE + NR + PAL	30	3.29	4.18
HDPE + NR + CC	10	2.66	8.53
HDPE + NR + CC	20	2.91	4.41
HDPE + NR + CC	30	3.10	8.07

2.5 Post-Processing of the Result

The overall purpose of this process is to obtain the model's voltage distribution and electric field intensity. To view the solution provided by the solver, FEMM 4.2's electrostatics post-processing is employed. Colorful contours and graphs can be used to display the results. Once the post-processor is started, a voltage colour density plot is displayed, as illustrated in Fig. 4. Contours can be defined manually by defining the sample's start and end points.



(a) Needle to needle



(b) Sphere to sphere

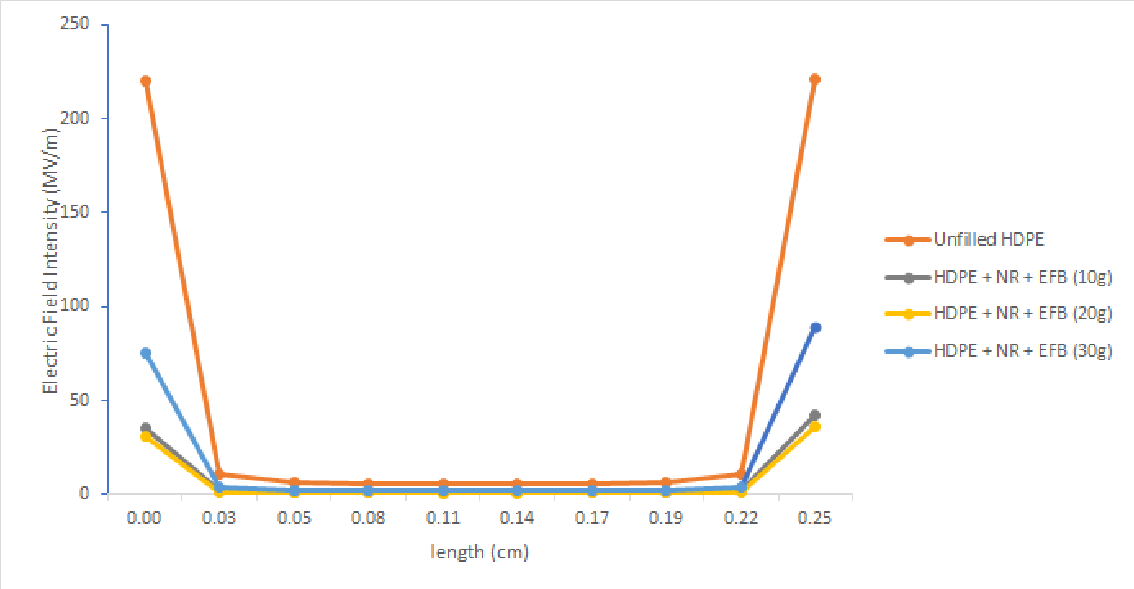
Fig. 4 - Colour density plot of voltage (a) and (b) rendered in the electrostatic post-processor

3. Results

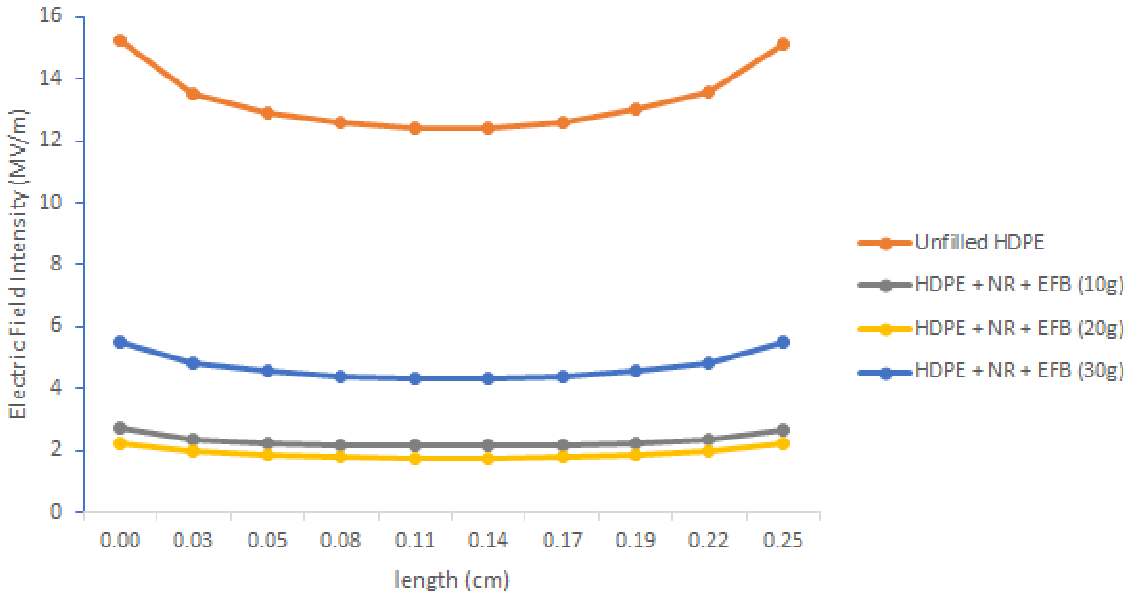
The results of the electric field intensity of HDPE-NR biocomposites are discussed in this chapter. The results are obtained by using the FEMM software to simulate the electrostatic model. Microsoft Excel was used to tabulate and analyse all of the data collected. The sample's voltage and electric field distribution have been discussed. In addition, this chapter considers the comparison of electric field intensity for various weight of biocomposite with breakdown voltage. Following that, this chapter discusses which uses for bio-filler as solid insulation are appropriate.

3.1 HDPE Polymer Matrix with EFB Bio-filler

The graph in Fig. 5 compares the electric field intensity for HDPE with various weights of empty oil palm fruit bunches. Before the sample reaches its end point, the electric field is measured from the sample layer nearest to the positive conductor. As shown in the graph, the electric field intensity is greatest at the sample's surface, which is closest to the top needle and sphere electrodes. As distance from the conductor surface increases, the electric field decreases. The result also shows that 20g EFB has a lower electric field while 30g EFB has a higher electric field.



(a) Graph needle to needle

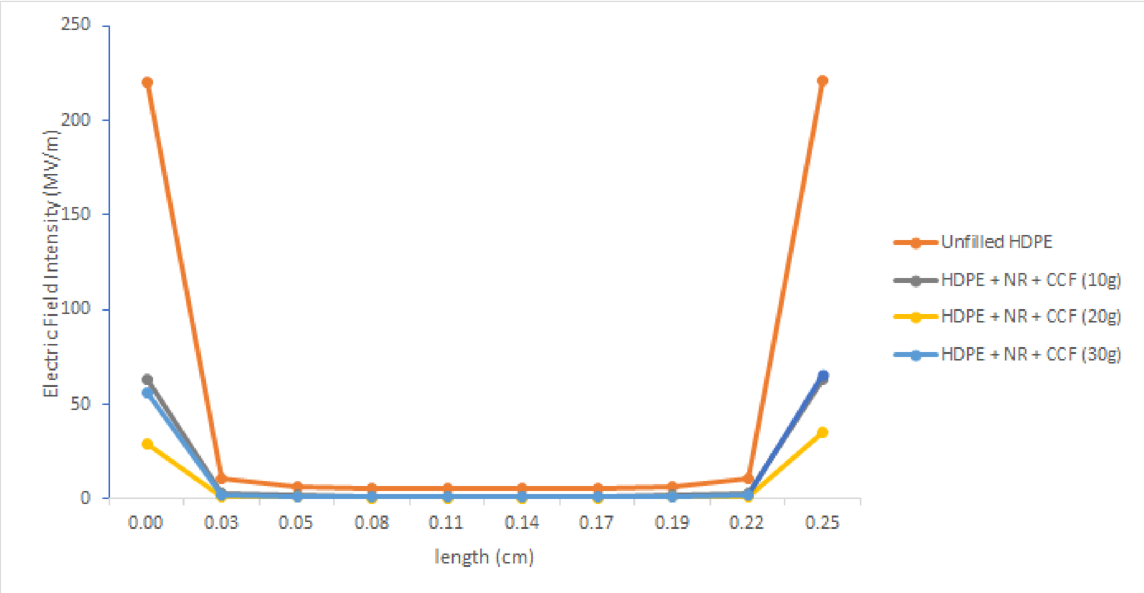


(b) Graph sphere to sphere

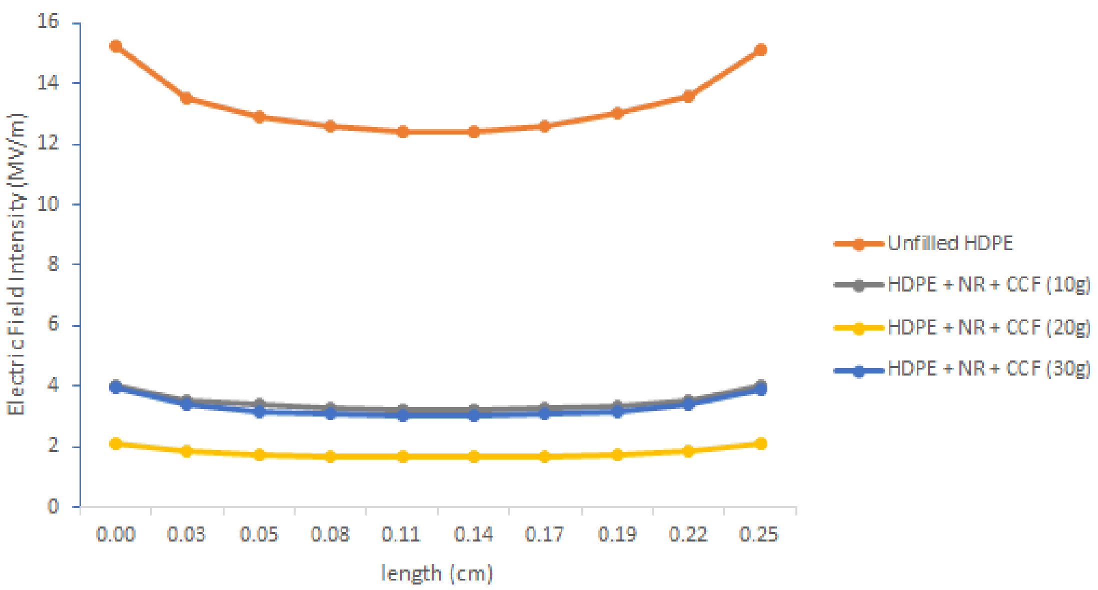
Fig. 5 - Electric field intensity for HDPE with 10g, 20g, and 30g of oil palm empty fruit bunch with unfilled HDPE as reference

3.2 HDPE Polymer Matrix with CCF Bio-filler

The graph in Fig. 6 compares the electric field intensity for HDPE with various weights of coconut coir fibre. The electric field is measured from the sample layer closest to the positive conductor before it reaches the sample's end point. As shown in the graph, the electric field intensity is greatest at the sample's surface, which is closest to the top needle and sphere electrodes. As distance from the conductor surface increases, the electric field decreases. Additionally, the result indicates that 20g of CCF has a lower electric field than 30g of CCF. According to the graph, the electric field intensity is highest at the sample's surface, closest to the top electrode.



(a) Graph needle to needle

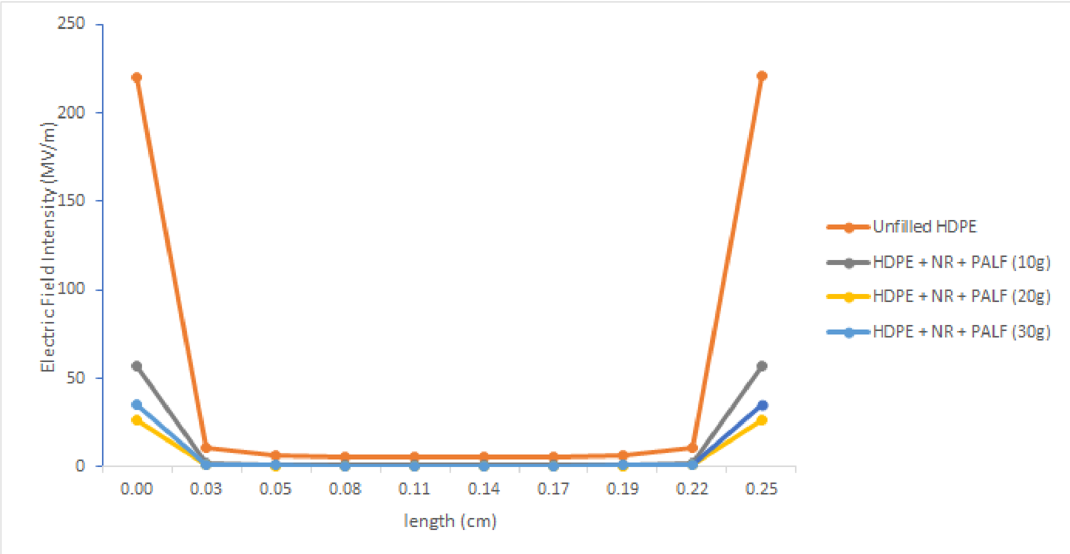


(b) Graph sphere to sphere

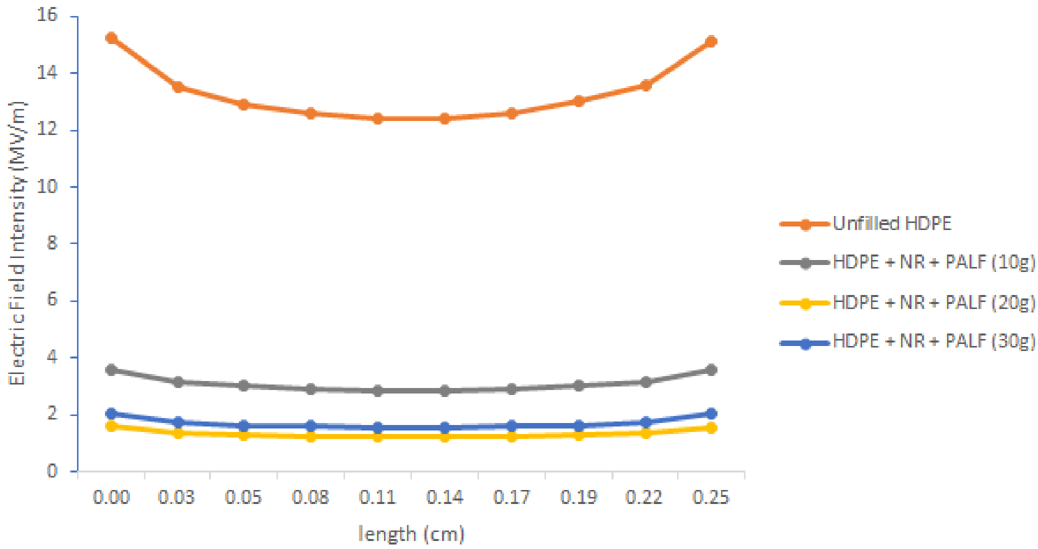
Fig. 6 - Electric field intensity for HDPE with 10g, 20g, and 30g of coconut coir fibre with unfilled HDPE as a reference

3.2 HDPE Polymer Matrix with PALF Bio-filler

Fig. 7 illustrates the comparison of the electric field intensity for HDPE and various weights of pineapple leaves fibre. The electric field is measured from the layer of the sample closest to the positive conductor to the sample's end point. The graph indicates that the electric field intensity is highest at the sample's surface, which is closest to the top sphere electrode. Additionally, the result indicates that 30g of PALF has a lower electric field than 10g of PALF.



(a) Graph needle to needle



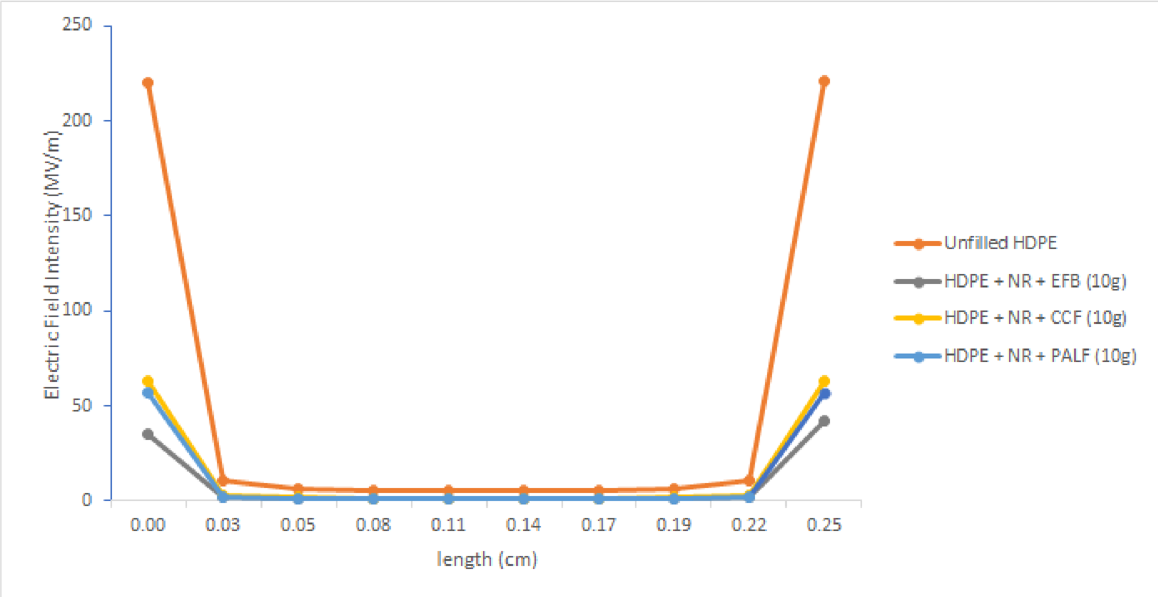
(b) Graph sphere to sphere

Fig. 7 - Electric field intensity for HDPE with 10g, 20g, and 30g of pineapple leaves fibre with unfilled HDPE as a reference

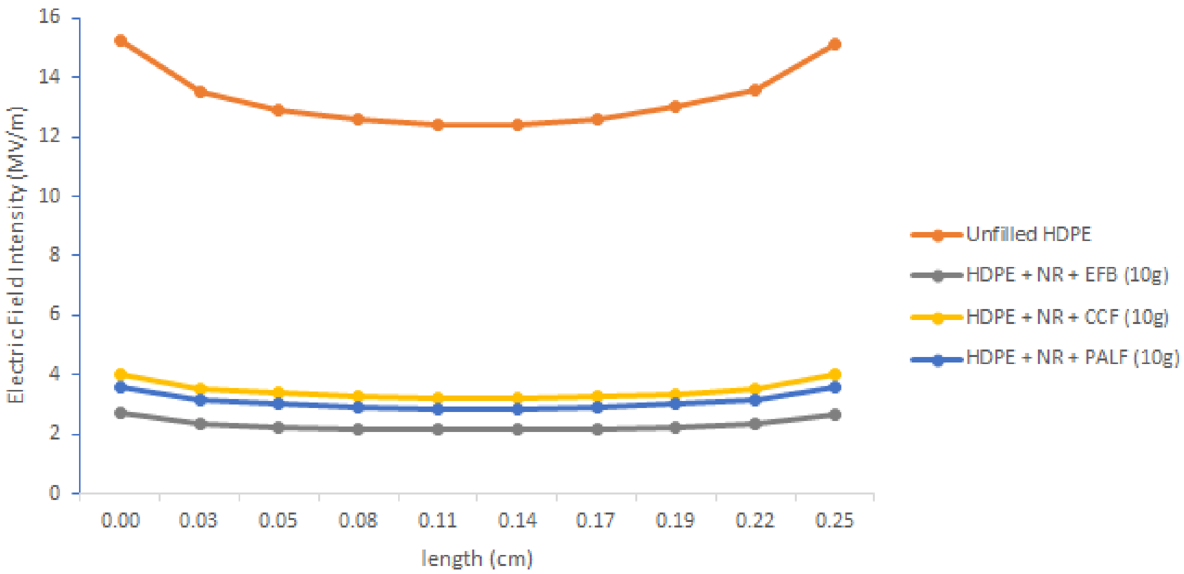
3.3 Comparison Between Different Bio-filler

For the purpose of this discussion, the electric field intensity of HDPE was compared to that of 10g, 20g, and 30g of biocomposites in order to find the best composition of coconut coir fibre, pineapple leaves fibre, and oil palm empty fruit bunch bio-filler as solid insulation. The graph showing the variation in electric field intensity throughout the thickness of the sample is given in Fig. 8 to Fig.10.

The electric field intensity for sample HDPE containing 10g of biocomposites was illustrated in Fig. 9. According to the analysis, the sample's surface nearest to the top electrode shows the maximum electric field intensity. The intensity of the electric field decreases with increasing distance from the conductor surface. For reference, the unfilled HDPE sample had the highest electric field intensity of the other HDPE samples. As observed, when the sample length is less than 0.05 cm from the surface, CCF bio-filler shows the highest electric field, whereas EFB bio-filler shows the lowest electric field among 10g of biocomposites. The results reveal the same result for lengths ranging from 0.05 cm to 0.17 cm, which is that CCF bio-fillers continue to show a higher electric field intensity, while EFB bio-fillers show the lowest electric field intensity.



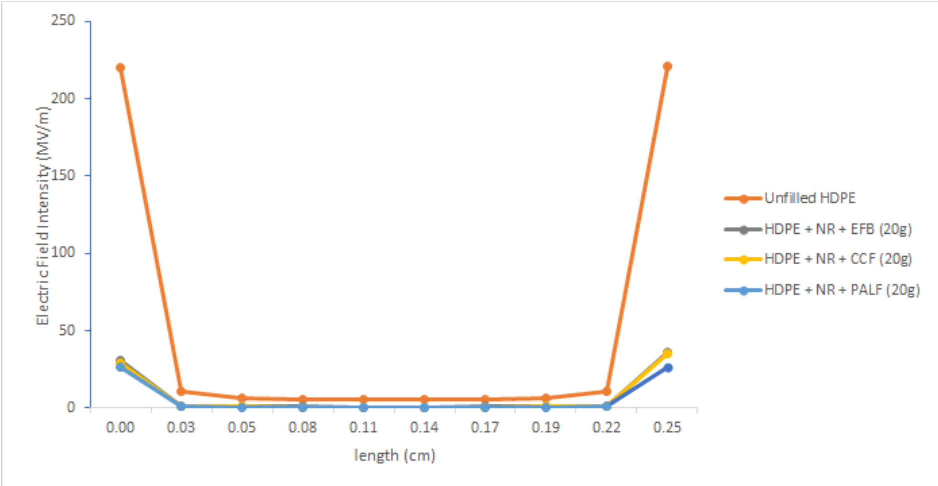
(a) Graph needle to needle



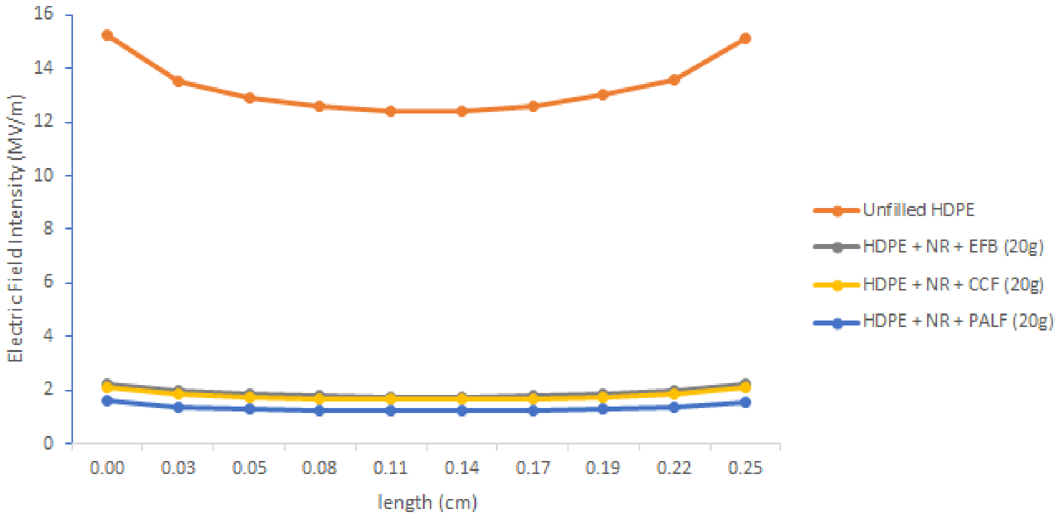
(b) Graph sphere to sphere

Fig. 8 - Comparison of electric field intensity for sample HDPE with 10g of biocomposites

The electric field intensity for sample HDPE was shown in Fig. 9 and Fig. 10 when 20g and 30g of biocomposites were applied, respectively. The electric field intensity showed the same behaviour and trend as HDPE with a 10g of biocomposite in both situations. The sample's surface nearest to the top electrode shows the highest electric field intensity. The electric field intensity decreases with increasing distance from the conductor surface. As is the case in all situations, 30g of EFB biofiller shows the highest maximum electric field intensity, followed by CCF biofiller, while PALF biofiller shows the lowest maximum electric field intensity of all biocomposites. This is due to the fact that PALF biocomposites have a lower breakdown voltage than EFB and CCF biocomposites. This indicates that the maximum electric field intensity varied according to the permittivity and breakdown voltages of the bicomposites.

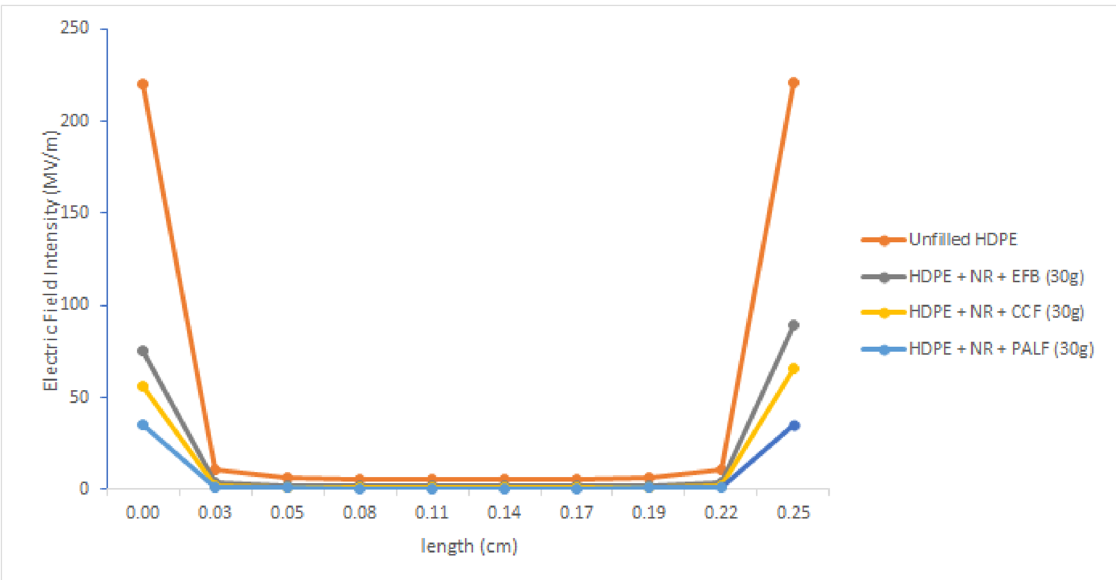


(a) Graph needle to needle

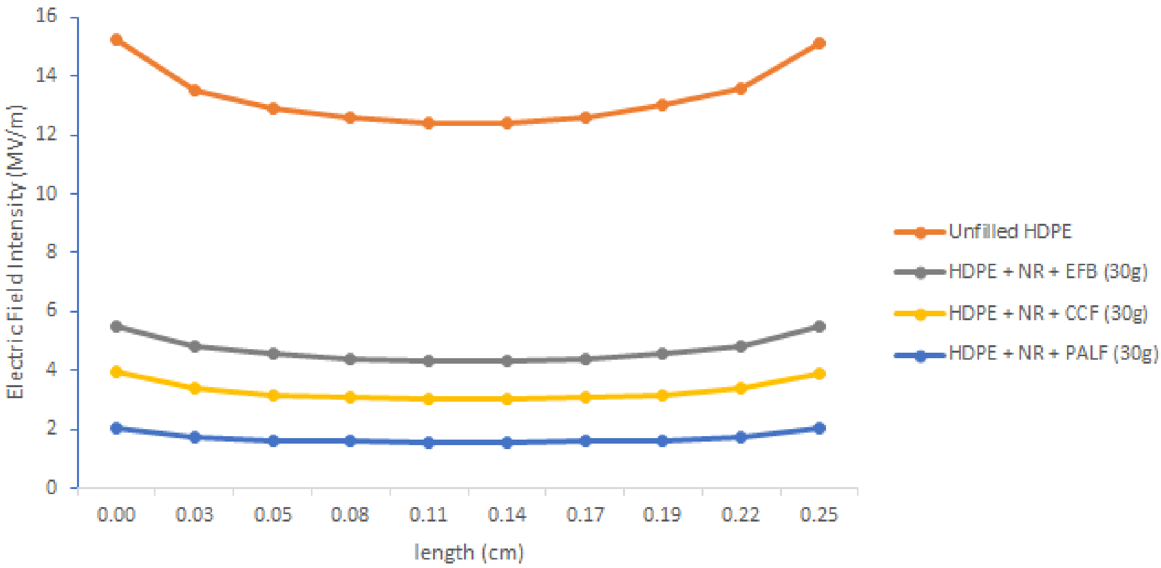


(b) Graph sphere to sphere

Fig. 9 - Comparison of electric field intensity for sample HDPE with 20g of biocomposites



(a) Graph needle to needle



(b) Graph sphere to sphere

Fig. 10 - Comparison of electric field intensity for sample HDPE with 30g of biocomposites

3.4 Discussion

The difference in electric field intensity between different weights of biocomposite with breakdown voltage on the resulting HDPE-NR biocomposites may be observed from the results obtained. All of the HDPE-NR biocomposite samples have parabolic curves, with the electric field decreasing with increasing distance from the conductor surface. When compared to the bottom electrode, the top electrode appears to have a higher electric field intensity. According to the analysis, all samples have the highest electric field intensity at their surface, closest to the top electrode. This is because a high voltage is given to the top electrode, which results in the highest electric field. When an electric field is given to a sample, electrons and positive ions migrate toward the electrode with the opposite polarity, with positive charge moving toward the cathode and negative charge toward the anode. The result is an accumulation of the field at both electrodes and a corresponding decrease in the insulation thickness in the central region. [13].

When compared to an unfilled polymer matrix, the presence of bio-filler in a polymer matrix has an effect on the intensity of the electric field. The effects of different biocomposites' weights and permittivity on the breakdown voltage of the resulting HDPE-NR biocomposites were investigated using simulation. According to the simulation results, unfilled HDPE biocomposites show a higher electric field intensity than 10g, 20g, and 30g biocomposites. This means that the maximum electric field intensity varies according to the permittivity and breakdown voltage of the bio-filler.

Reseracher [14] the formation of agglomeration of water molecules has shown that caused the presence of bio-filler-matrix interface. The creation of agglomerations increases due to the complexities of obtaining a homogeneous filler dispersion at high filler content as the filler content increases. According to researcher [15], agglomeration of fillers in the composite sample tends to increase the movement of charges that can cause higher conductivity. Thus, the sample containing 20g of biocomposites was the best sample since it had the lowest maximum electric field and conductivity values in comparison to the other samples in the same group.

The electric field intensity of sample HDPE was compared to the electric field intensity of 20g of biocomposites in order to determine the optimal composition of coconut coir fibre, pineapple leaves fibre, and oil palm empty fruit bunch bio-filler as solid insulation. The simulation results clearly illustrate that when PALF bio-filler is combined with HDPE, the maximum electric field intensity is the lowest when compared to CCF and EFB bio-filler.

Furthermore, electrical breakdown is dependent on the material's electric field intensity and happens in a high field region, resulting in a reduced breakdown strength. As a result, PALF bio-filler was the best composition because the top electrode has lower electrical field intensity than other compositions, which enhances dielectric characteristics.

4. Conclusion

The breakdown voltage, the distribution of the electric field and the electric field intensity for different biocomposite weights can be analysed by the simulation using FEMM software version 4.2. In general, the inclusion of bio-filler in HDPE significantly affects the electric field intensity compared to unfilled HDPE. According to the simulation results, unfilled HDPE biocomposites have a higher electric field intensity than 10g, 20g, and 30g biocomposite. This indicates that the maximum electric field intensity changes according to the permittivity and voltage of the bio-filler under breakdown conditions. The results established a relationship between the electric field intensity and the permittivity value and voltage in the breakdown condition. In this regard, PALF bio-filler was the best composition since it tends to improve the dielectric characteristics due to its lower electric field intensity at the top electrode than other compositions.

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