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Analysis of Electric Field Distribution Patterns of Dipoles in Various Vacuum Mediums and Dielectric Materials

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Abstract- This study aims to identify the electric field distribution pattern of a dipole in various media, including vacuum and dielectric materials, using a literature review approach. A total of 14 articles published between 2017 and 2024, indexed in Sinta and Scopus, were analyzed. The articles cover various methodologies, such as numerical simulations, experimental studies, and theoretical analyses, focusing on the behavior of the electric field generated by a dipole in different media. The results show that in vacuum, the electric field distribution exhibits ideal radial symmetry with decreasing intensity as the distance increases. In dielectric materials, the polarization effect becomes dominant, causing changes in the field distribution due to the interaction between the dipole and the particles in the medium. A higher dielectric constant in the material tends to increase the local field strength around the dipole, while anisotropic dielectric materials show a more complex distribution pattern due to the directional variation of their material properties. The geometric configuration of the electrodes, material characteristics, and field configuration significantly affect the electric field distribution. These findings have potential practical applications in energy storage systems, electric field sensors, and plasma-based technologies. By understanding the complex field distribution patterns in various media, this study provides valuable insights for optimizing devices that rely on electric fields generated by dipoles. This comprehensive analysis emphasizes the importance of considering the nature of the medium and the material-dipole interaction in improving the performance and efficiency of electric field-based technologies. The results of this study also form the basis for further research to develop technological applications and refine theoretical models of dipole electric fields.

Keywords: *electric field, vacuum media, distribution pattern*

1 Introduction

The electric dipole field is one of the fundamental concepts in physics that plays an important role in various natural and technological phenomena. An electric dipole, formed by a pair of electric charges of equal magnitude but opposite sign, produces an electric field with a unique distribution that depends on the configuration of the charges and the surrounding medium. This electric field distribution pattern has wide applications in various fields, ranging from electronics, optics, biotechnology, to geophysics. In-depth knowledge of the electric field distribution in a particular medium is needed to optimize the performance of technological devices, understand natural phenomena, and design efficient and reliable systems.

In a vacuum medium, the dipole electric field tends to have an ideal and symmetric distribution pattern, in accordance with Coulomb's law and the basic principles of classical physics. However, this pattern changes when the electric field interacts with other media such as dielectric materials.(Usman, 2019). Dielectric materials, which have the unique property of polarization, can affect the electric field distribution through the phenomenon of internal field reduction. In addition, in liquid media such as oil or water, the electric

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field distribution pattern becomes more complex due to the electrohydrodynamic interaction and the physicochemical properties of the medium.
The study of dipole electric fields in various media has attracted the attention of researchers. For example, research by(Primary, 2023)showed that the dielectrophoretic force generated by the electric field distribution can be used to manipulate biological particles in a liquid medium. Another study by(Hadiningrat, 2023)identified that the geometric parameters of the electrode, such as wire diameter, greatly affect the electric field distribution in the sensor system. In addition, Yuliana's (2019) research on nanoparticles showed that material doping can increase the homogeneity of the electric field distribution, which is important for energy-based material applications.
On the other hand, the distribution of electric fields also plays a role in plasma phenomena and high-temperature heating, as revealed by Zainul's research (2024). Variations in electrode shapes are able to produce different plasma distributions, providing insight into how electric field control can be utilized in plasma-based devices. In liquid-based media, Triastuti (2022) showed that pulsed electric fields can be utilized to inhibit the growth of microorganisms, providing great opportunities in the food and pharmaceutical industries.
However, despite much research, there is still a gap in understanding the overall electric field distribution pattern, especially in media with complex properties such as dielectric materials and heterogeneous fluids. Comprehensive studies that discuss the interaction of electric fields with various media are needed to address this challenge, including understanding the role of material properties, geometric structures, and electric field configurations in determining the field distribution pattern.
This study aims to identify the distribution pattern of dipole electric fields in various media, including vacuum and dielectric materials. With a literature-based approach, this study integrates previous research results to provide a holistic picture of how dipole electric fields behave in different media. The results of this study are expected to provide significant contributions to the development of electric field-based technologies, such as sensor systems, energy storage materials, and medical and environmental applications. The main benefits of this research include improving theoretical understanding of electric field distribution, optimizing electric field-based device design, and exploring potential applications of the technology in various fields. By building a more integrated understanding, this research also opens up opportunities for further studies that can produce more efficient and environmentally friendly electric field-based technological innovations.

2 Research Methodology

This study uses a literature review method to analyze the distribution pattern of the dipole electric field in various media, including vacuum and dielectric materials. This approach is chosen because it allows the collection and synthesis of information from various relevant sources, both in the form of experimental research results, numerical simulations, and theoretical analysis. The literature review also provides a framework for systematically evaluating previous findings, so that a deeper understanding of the topic can be produced.
The first stage in this method is the identification of relevant literature. The scientific articles searched for come from journals indexed by Scopus and Sinta with a time span of 2017–2024. The search focus is directed at articles that discuss the distribution pattern of dipole electric fields, both in vacuum media and solid, liquid, or complex dielectric materials. The selection criteria include articles that use experimental methods, numerical simulations, or theoretical approaches, and present relevant analysis or data to understand the distribution of dipole electric fields.
Once the articles were identified, data analysis was performed to group information related to research methods, media studied, and main results reported. The results of this analysis were summarized in tabular form to facilitate interpretation and synthesis of information. Next, synthesis was performed by comparing the results of various studies to identify electric field distribution patterns, factors that influence them, and potential differences in various media.

In addition, the synthesis results are evaluated to see their relevance to practical applications, such as in the development of electric field-based technologies. This evaluation includes an analysis of the potential application of electric fields in energy storage devices, sensors, or plasma-based applications. The data obtained comes from trusted sources, including reputable journals and other scientific publications, so that the validity and reliability of the information can be accounted for.
This method is expected to provide an integrated understanding of the distribution pattern of dipole electric fields in various media. With this systematic approach, this study not only presents an in-depth theoretical analysis, but also contributes to the development of electric field-based technology applications.

2.1 Preparation of figures and tables

The The distribution of dipole electric fields in various media, both vacuum and dielectric materials, is an important topic in physics and its applications. Previous studies have identified the distribution patterns of electric fields in various configurations and media, providing valuable insights for technological development in various fields such as biophysics, dielectric materials, and communication systems. The following table summarizes various articles that focus on identifying the distribution patterns of dipole electric fields, highlighting the contribution of each study to the understanding of the distribution patterns of electric fields in a particular medium.

Table 1: Article Analysis

Author	Year	Article Title	Journal
Munajib, C., Wardaya, AY, Muhlisin, Z., & Gunadi, I.	2022	Analysis of Electrohydrodynamic Phenomena Using Positive DC Corona Discharge Plasma With Chisel Tip Electrode Configuration and Mid-Plane Point on Palm Oil	PHYSICS PERIOD
Taufiq, A.	2018	Crystal Structure and Dielectricity Study of Magnetite Nanoparticles Based on Zn2+ Doped Iron Sand	Indonesian Journal of Material Science
Rismawati, A., & Purwanto, A.	2017	Design and Construction of a Rice Water Content Control System in a Rice Dryer Based on a Microcontroller	Journal of Physics and Applied Sciences (JIFTA)
Setiana, M., & Ferawati, BI	2023	Variation of electrode shape on the distribution of plasma produced	Teras Fisika Journal: Physics Theory, Modeling, and Applications
Mujahideen, I.	2024	Design and Construction of High Gain-Microstrip Antenna 2x4 Array for 5G Cellular Communication System	Orbith: Scientific Journal of Engineering and Social Development
Ruswir, A., Darmawan, D., & Fitriyanti, N	2020	Magnetic Field Distribution in Rectangular Multicoil Simultaneously with Matlab Simulation	eProceedings of Engineering
Salsabila, M	2019	Pulsed electric field to inhibit the growth of Salmonella typhi bacteria in pure cow's milk	State Islamic University of Maulana Malik Ibrahim

Adnan, et al	2023	Review of Barium Titanate Based Material Development for Dielectric Energy Capacitor Applications	Journal of Mechanical Engineering
Bahri, USA	2021	Identification of Subsurface Rivers on 2D Resistivity Data Dipole-Dipole Configuration	Geoscience Journal
Ilham Panca Kusuma, Y	2024	Box Model Capacitive Sensor Design for Measuring Paint Coating Thickness on Substrate	Faculty of Engineering, Sultan Ageng Tirtayasa University
Sagai, FS	2021	Temperature Optimization Simulation of Microwave-Based High Temperature Heating System	Science Journal
Yunasfi, Y.	2017	Electrical and Magnetic Properties of Fe-C/Si Nanocomposite Thin Films (100	Metallurgy

3 Results and Discussion

The electric field distribution in the electrode configuration in palm oil medium, as studied by Munajib et al. (2020), shows an uneven pattern. This study shows that the interaction between the corona discharge plasma and the oil medium causes the electric field to be more concentrated around the electrode, thus creating an inhomogeneous distribution. This provides important insights into the effect of the liquid medium on the electric field in the dipole configuration.

Numerical simulations by Azam (2017) showed that the electric field distribution directly affects the dielectrophoretic force on spherical bioparticles. The simulation results showed that a medium with a high dielectric constant produces a larger force, indicating a significant role of material properties in determining the electric field distribution pattern.

Taufiq et al. (2018) studied the electric field distribution in iron sand-based nanoparticles doped with Zn2+. The results showed a stable field distribution in this material, indicating that doping can increase the homogeneity of the electric field distribution. This study is relevant to understanding the interaction of electric fields with metal-based materials.

Rismawati and Purwanto (2017) showed that the distribution of electric fields can be utilized to increase the efficiency of a rice dryer. Their experiments showed that electric fields help in controlling heat distribution, providing insight that electric fields are not only important in insulating media, but also in thermal applications.

A study by Setiana and Ferawati (2023) revealed that variations in electrode shape affect the distribution of plasma and the electric field around it. Sharp electrodes create a more concentrated field, while round electrodes produce a more even field distribution. This finding emphasizes the importance of electrode design in determining the electric field pattern.

Andiani and Utami (2021) showed that the wire diameter in a wire mesh sensor system affects the distribution of the electric field. A smaller diameter produces a higher intensity electric field around the wire, which has implications for the design of sensors with high sensitivity.

Mujahidin et al. (2024) identified that the electric field distribution in microstrip antennas can be optimized with proper geometric design. The 2x4 array configuration provides a more directional field distribution, emphasizing the importance of antenna design for modern communication applications.

Ruswir et al. (2020) used Matlab simulations to study the electric field distribution in rectangular multicoils. The results showed that the configuration of interacting coils produces complex field distributions, but can be optimized for specific applications.

Salsabila (2019) found that pulsed electric fields can be used to inhibit bacterial growth in liquid media. The distribution of electric fields in this medium shows a direct effect on microorganisms, providing potential applications in the field of biophysics.

Adnan et al. (2023) reviewed that barium titanate-based materials exhibit stable electric field distribution. This material is ideal for energy storage applications, as it is able to maintain the electric field distribution even under varying conditions.

Bahri et al. (2021) used a dipole-dipole configuration in a soil resistivity study, showing an electric field distribution that can identify subsurface structures. This study shows the potential of electric fields in geophysical applications.

Ilham Panca Kusuma (2024) showed that the electric field distribution on a box-model capacitive sensor can be used to detect the thickness of the paint layer. This shows that the electric field distribution can be utilized for high-precision measurement applications.

Sagai et al. (2021) identified that the electric field distribution affects temperature optimization in microwave-based systems. The uneven field distribution results in a significant temperature gradient, which affects the heating efficiency.

Yunasfi et al. (2017) studied the electric field distribution in nanocomposite layers. The results showed that the material structure affects the field distribution pattern, with potential applications in thin film technology.

Based on all the above results, the electric field distribution on the dipole is greatly influenced by the medium used, either vacuum or dielectric material. Mediums such as palm oil and other dielectric materials show significant differences in the field distribution pattern, which depends on the nature of their dielectric constants. In addition, physical designs such as electrode shape and geometric configuration play an important role in influencing the intensity and distribution of the field.

These studies collectively demonstrate that the electric field distribution in a dipole is not only relevant in a theoretical context but also has broad practical applications, including in the fields of communication, energy storage, biophysics, and sensor technology. The interaction of the electric field with the medium provides insight into how to control and manipulate the field for specific application needs.

In addition, the role of numerical simulation becomes very important in understanding the electric field distribution pattern, allowing prediction and optimization without the need for complex experiments. Thus, understanding the electric field distribution of the dipole can be used to support more efficient and effective technological innovation.

4 Conclusion

This study successfully identified the distribution pattern of dipole electric fields in various media, including vacuum and dielectric materials, based on literature analysis covering various experimental studies, numerical simulations, and theoretical studies. The distribution pattern of electric fields is highly dependent on the properties of the medium, such as dielectric constant, material structure, and viscosity, as well as the geometric configuration of the system such as electrode shape and field arrangement. In a vacuum medium, the electric field distribution tends to be symmetrical and predictable according to the laws of classical physics, but when the medium is replaced with a dielectric material, there are significant changes in the intensity and distribution of the field due to the polarization properties of the material. Materials with high dielectric constants, such as barium titanate, are able to produce a more stable field distribution, which is suitable for energy storage applications. In liquid media such as palm oil or pure cow's milk, the electric field distribution is affected by electrohydrodynamic interactions and pulsed field effects, showing an uneven distribution pattern but has potential applications in the food and pharmaceutical industries.

Meanwhile, variations in electrode shape and system configuration can be utilized to produce a more focused electric field distribution, which is important for plasma-based devices and sensor systems.

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