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INFLUENCE OF ELECTRODE SHAPE AND SPACING ON CORONA DISCHARGE PHENOMENA USING A PLASMA GENERATOR

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ABSTRACT

Electrical discharges that happen near high-voltage conductors are known as corona discharges. It will produce light and sound as it ionises the surrounding air. The purpose of this work is to investigate how conductor form and spacing affect the properties of corona discharge produced by a plasma generator. In this study, conductor shapes such as triangle, W-shaped wire, syringe (point), and L-shaped wire (horizontal) were experimented with, as well as the distance between conductors. The outcome demonstrates that conductor spacing affects the corona discharge's plasma intensity, with shorter distances producing stronger electric fields and greater discharge intensities. Furthermore, the dispersion of the plasma is greatly influenced by the conductor's shape, since every conductor shape results in a different pattern of plasma distribution. These findings offer important new information for the development and improvement of systems that make use of corona discharge events.

Keywords: Corona Discharge; Plasma Generator; Conductor Shape; Conductor Spacing; Intensity; Distribution.

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INTRODUCTION

Since technical Since technical polymers are widely used in medical applications—first emerging in the 1940s and 1950s with materials like PMMA and Teflon—biocompatibility, achieved through thorough cleaning and controlled production processes, has become a key objective. Over the past twenty years, advancements have focused on improving the surfaces of these polymers, particularly through medical-grade coatings applied via chemical and physical methods. These coatings help ensure that the polymers are biocompatible, especially in sensitive applications like medical implants. One method for achieving such coatings is the use of low-pressure plasma treatments, which modify the surface of polymers to enhance their properties in biological environments [1]. In recent years, synthetic organic polymer materials have become increasingly important in various technological applications. They offer advantages such as unique physical and chemical properties that make them suitable replacements for metals in certain contexts. However, polymers also have limitations, such as weak adhesive qualities. This weakness can be mitigated through surface treatments like plasma modification, which improves the material's adhesion without altering its bulk properties [2]. Plasma, often referred to as the fourth state of matter, was first identified by Lewi Tonks and Irving Langmuir. It is an ionized gas created when sufficient energy—such as heat or a strong electromagnetic field—is applied to a gas, causing it to conduct electricity. In this study, we focus on generating plasma through corona discharge, a process where electrical fields ionize surrounding air, creating a conductive plasma that can be used for surface treatment. When a gas is exposed to a certain amount of energy, such as heat or a strong electromagnetic field, plasma, which is capable of conducting electricity, is typically created. Due to this energy, the gas's electrons become extremely energetic and smash into atoms to impart their energy to them. The atomic shell is broken by this impact, ionizing the gas particles. Excitation, dissociation, and partial ionization will therefore take place [3]. Plasma can be generated by various means, including mechanical energy, chemical energy, radiation energy, and electromagnetic energy [4]. This study focuses on utilizing electromagnetic energy through the corona discharge phenomenon to generate plasma. A corona discharge is an electrical discharge with comparatively low power that happens at or close to atmospheric pressure. When the voltage supplied to the thin electrode is high enough to ionize the atmosphere surrounding the electron discharge, corona discharge may happen [5]. When a small-diameter wire, needle, or sharp electrode tip is placed in a high electric field, corona discharge happens [6]. Corona discharge, although being a discharge with little energy, generates electrical noise, audible noise, power loss, and surface damage. The corona phenomenon not only leads to power dissipation due to heat and radiation, but also generates acoustic and electrical interference in high-voltage lines [7]. Corona discharge often happens under normal atmospheric pressure, as opposed to low-temperature plasma which necessitates a vacuum. The corona is a flow of charged particles, specifically electrons and ions, that is propelled by an electric field. Corona is the phenomenon that arises when there is a discontinuity in the flow of air or other gases under conditions of elevated pressure [8]. The stress induces the collision of highly charged particles with neutral molecules, resulting in the generation of more ions and the initiation of a chain reaction. Corona typically has a highly damaging impact on high-voltage transmission lines. The reason for this is that corona discharge can result in power losses and weaken insulating materials due to the continuous stress on these materials and the chemical processes induced by corona. Furthermore, due to its elevated frequency, the corona phenomenon frequently disrupts radio telecommunication infrastructure. When dealing with air lines that operate at medium, high, and extremely high voltages, it is crucial to take into account the issue of corona [9]. However, it has been shown that this corona can also be applied in several other domains, particularly in the generation of plasma for plasma treatment technologies, where the creation of electrical discharge is essential for its operation.

Various elements influence the corona discharge phenomena. Several factors that can affect electrical conductivity include air conditions, conductor spacing, electrical voltage, and the geometry and dimensions of the conductors [10]. This study primarily aims to investigate the impact of conductor spacing and conductor shape variations on the plasma generated by the corona discharge phenomenon. Plasma is a quasineutral combination of electrons, radicals, positive ions, and negative ions. Plasma is a distinct phase that exhibits unique features compared to regular gases due to the presence of both positively and negatively charged ions. Plasma is commonly defined as a gas that has been ionized [11]. Plasma technology has seen recent advancements that have rendered it acceptable for use in large-scale industrial applications. Plasma treatment can alter the chemical bonds on the material's surface, resulting in the formation of new polar groups such as -COOH, -O-OH, -OH, as well as nitrogen-containing groups. It has the ability to enhance the hydrophilic characteristics, surface energy, and roughness of polymer materials. Partial etching or surface deterioration via plasma irradiation can potentially alter the topography of the polymer surface [12]. The experiment's findings demonstrated that plasma treatment had the capacity to modify and enhance the surface properties of the specific polymer under investigation. Plasma treatment can induce structural alterations, such as surface modification or the application of a thin layer onto the polymer's surface, while controlling the chemical composition and physical topography of the surface. Specifically, the techniques of surface modification and plasma deposition can add novel functional groups, regulate surface roughness, create cross-linkages, initiate graft polymerization, and put a thin coating onto the polymer's surface [13]. Corona discharge is the release of an electron from the surface of a conducting wire or conductor caused by an electric field or high voltage gradient. When the electric field surrounding a high-voltage conductor surpasses the dielectric strength of the air, it results in the discharge of an electric charge into the surrounding air [14]. Ionization happens when electrons traverse an electric field gradient. This phenomenon occurs due to the collision of air molecules, resulting in the generation of unbound positive ions and electrons. Ionization persists, resulting in a surge of electrons [15].

This research is important because it addresses the need to develop improved electrode designs for plasma surface treatment technologies. These technologies are widely used in industries such as biomedical engineering, electronics, and materials science, where precise surface modifications are required for enhancing material properties like adhesion, durability, and biocompatibility. By offering new insights into the relationship between electrode shape and spacing on corona discharge phenomena, this study provides valuable information that can optimize plasma treatments for a variety of applications, including the coating of medical devices, the fabrication of electronic components, and the enhancement of polymer surfaces. The purpose of this study is to closely monitor and analyze the impact of electrode spacing on the intensity of plasma generated by the corona discharge phenomenon. Additionally, it examines how the shape of the electrode influences the resulting plasma distribution. The findings are expected to contribute to the development of more efficient and effective plasma surface treatment systems, ultimately improving processes in industries where surface engineering is critical.

METHOD

This study his study examines two independent variables: the distance between the electrodes and the shape of the electrode. The initial study investigates the impact of electrode spacing on the intensity of plasma generated by the corona discharge phenomenon, quantified by measuring the diameter of the resulting plasma using a digital microscope AM4517MZT. The electrodes used in this experiment consist of a stainless steel plate as the ground electrode and a 1.2 mm diameter wire as the high-voltage electrode. The power supply is a high-voltage DC generator capable of producing a voltage of up to 30 kV with a frequency of 50 Hz. The voltage was adjusted for each experiment based on the specific distance between the electrodes. Plasma discharge was generated by applying this high voltage across the electrodes. The second part of the study investigates the impact of electrode shape on the plasma distribution. The electrode shapes tested include point-shaped (syringe), horizontal (L-shaped wire), triangular (triangular wire), and W-shaped (W-shaped wire). For stability, a stative was used to hold the electrodes in a fixed position during the experiment.

The breakdown voltage was measured using a high-voltage probe with a division ratio of 1000:1, which is suitable for high-voltage applications and ensures accurate measurement within the safe operational range. The probe was connected to a digital oscilloscope Rigol DS4014, allowing the voltage waveform to be recorded and analyzed during the experiment.

The breakdown voltage was defined as the point at which visible corona discharge was detected between the electrodes, indicating the ionization of the surrounding air. The measurements were taken for each configuration of electrode spacing, and the voltage at which the breakdown occurred was carefully recorded to provide accurate data for comparison with theoretical models, such as the Paschen curve. This setup ensured that all voltage readings were reliable and consistent across the various distances tested.

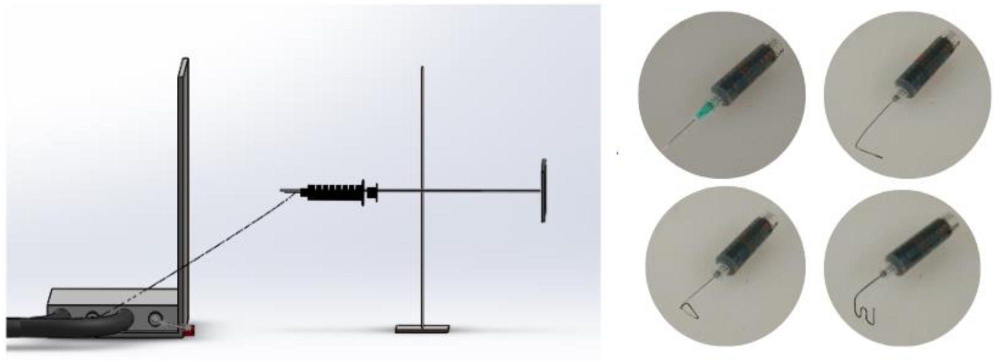


Figure 1. Design Tool Plasma High Voltage

This study employs a plasma generator apparatus consisting of a power supply, two conductors. The first conductor is a stainless steel plate, while the second conductor utilises syringes and wires with varying shapes. Additionally, a stative is employed to ensure the stability of the second conductor. The process of plasma production through the corona discharge phenomena utilising a plasma generator machine is illustrated in the flow diagram below.

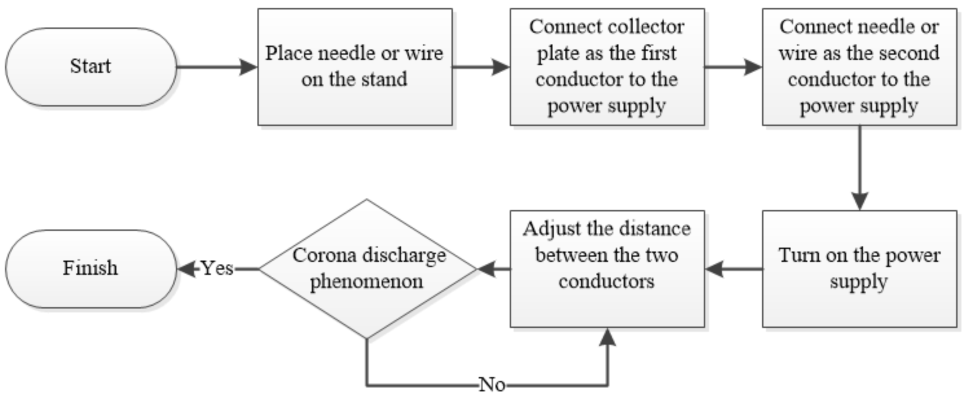


Figure 2. The experiment's flow diagram for plasma formation

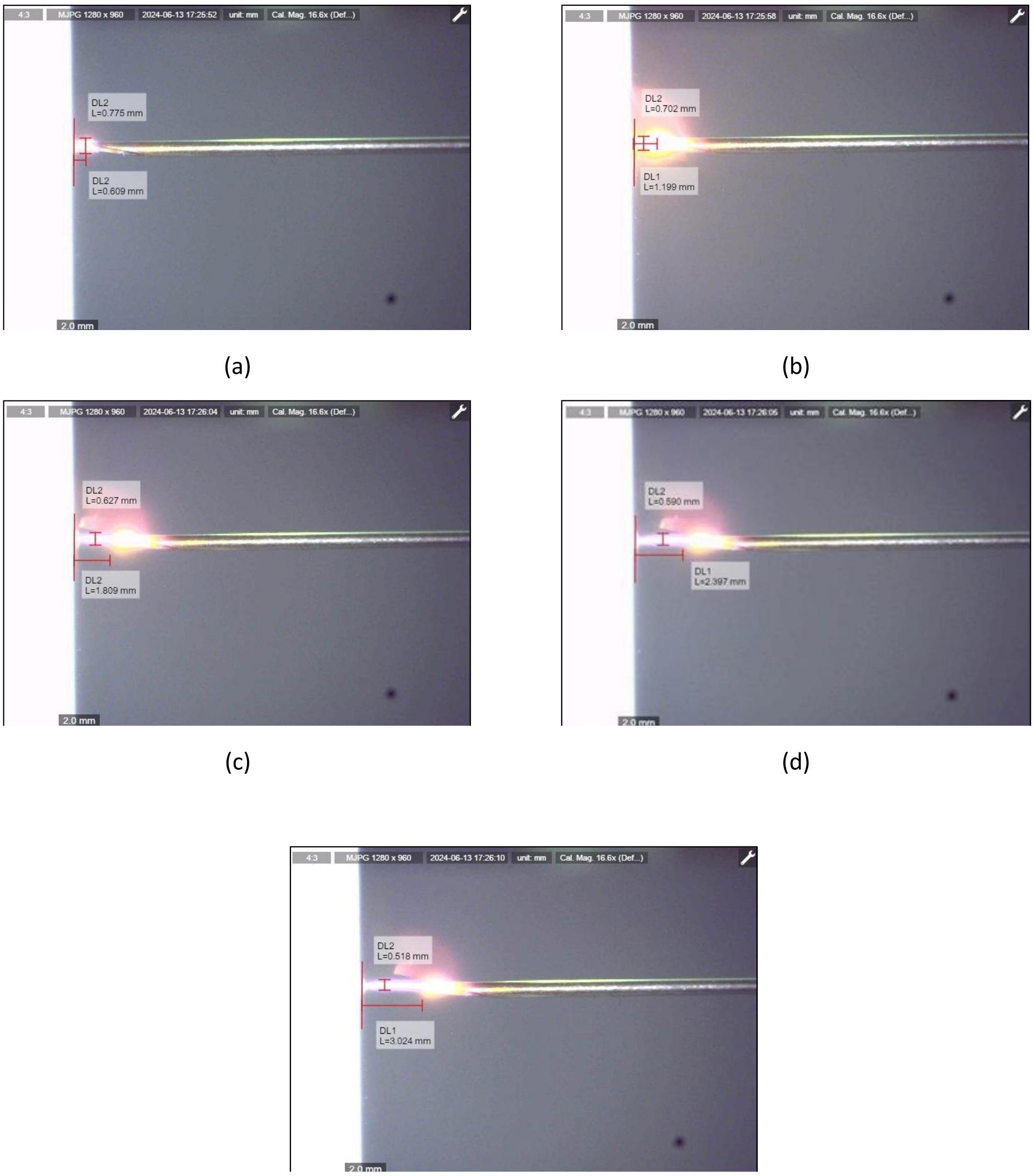
RESULTS AND DISCUSSION

The specifics of how the distance between the conductors to be researched varies are listed below.

Table 1. Deviation in the distance between conductors

Specimen	Distance Between Conductors (mm)
1	0.6
2	1.2
3	1.8
4	2.4
5	3.0

The experiment's visual results, captured using DinoLite, are shown in the following. These numbers line up with the information in Table 1**.**



(a) (b) (c) (d) (e)

Figure 2. Figure Specimen : (a) Specimen 1, (b) Specimen 2, (c) Specimen 3, (d) Specimen 4, (e) Specimen 5

The following are the measurement results from the study of the effect of the distance between conductors on the plasma intensity of the corona discharge phenomenon represented by the plasma diameter value can be seen Table 2.

Table 2. Deviation in the distance between conductors

Specimen	Distance Between Conductors (mm)	Plasma Diameter (mm)
1	0.6	0.78
2	1.2	0.70
3	1.8	0.63
4	2.4	0.59
5	3.0	0.52

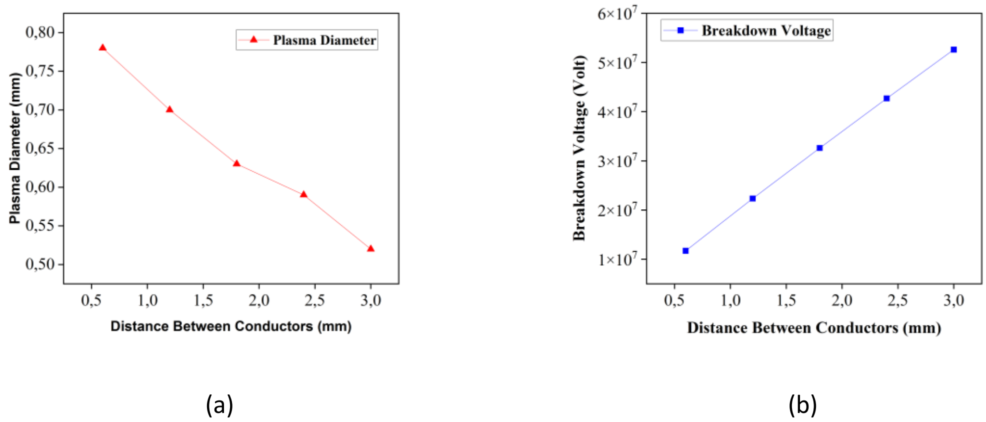


Figure 2. Graph of phenomena : (a) Comparison of Distance Between Conductors to Plasma Diameter, (b) Paschen Curve For Air at Atmospheric Pressure

The data presented indicates that the fluctuation in the distance between the conductors has a notable influence on the magnitude of the plasma generated via corona discharge. The plasma diameter is 0.77 mm when the conductor distance is 0.6 mm. When the distance is 1.2 mm, the plasma radius is 0.70 mm. When the distance is 1.8 mm, the diameter is 0.63 mm. When the distance is 2.4 mm, the diameter is 0.59 mm. When the distance is 3.0 mm, the diameter is 0.53 mm. In general, a shorter distance between the conductors leads to the generation of greater plasma diameters. This implies that there is a stronger electric field at closer proximity, leading to a greater intensity of corona discharge. In contrast, greater distances result in a decrease in the intensity of coronary discharges due to the insufficient strength of the electric field to sustain the phenomena.

The Paschen Curve graphic displays a direct correlation between the separation distance of the conductor (d) and the breakdown voltage (V), represented in volts (V). Consequently, a larger separation between conductors necessitates a bigger voltage to trigger a breakdown. As an illustration, a conductor with a distance of 3 mm necessitates a breakdown voltage of approximately 52,605,572 Volts, while a distance of 0.6 mm only requires about 11,712,840 Volts. This equation confirms that electrical discharges are more probable to happen at shorter distances due to the stronger electric field generated at closer distances. The graph presented here utilises the Paschen constant values for air, specifically A = 112.5 $Pa^{-1}\ mm^{-1}$ and B = 2737.5 V $Pa^{-1}\ mm^{-1}$, together with a secondary electron emission coefficient (γ_{se}) of 0.01. Using a different gas as an insulation medium will result in different values for the constants A and B, hence altering the shape of the Paschen curve. Hence, the careful choice of gases is crucial in particular applications to impact the effectiveness and security of the system. From a pragmatic perspective, the design of an electrical system should consider the spacing between the conductors in accordance with the anticipated operating voltage. To prevent insulation failure, a design can be optimised by ensuring that the distance between conductors is sufficient to withstand the required voltage for breakdown initiation. For instance, in an electrical system operating at a voltage of approximately 50 megavolts (MV), the separation between conductors must exceed 3 millimetres to avoid electrical breakdown.

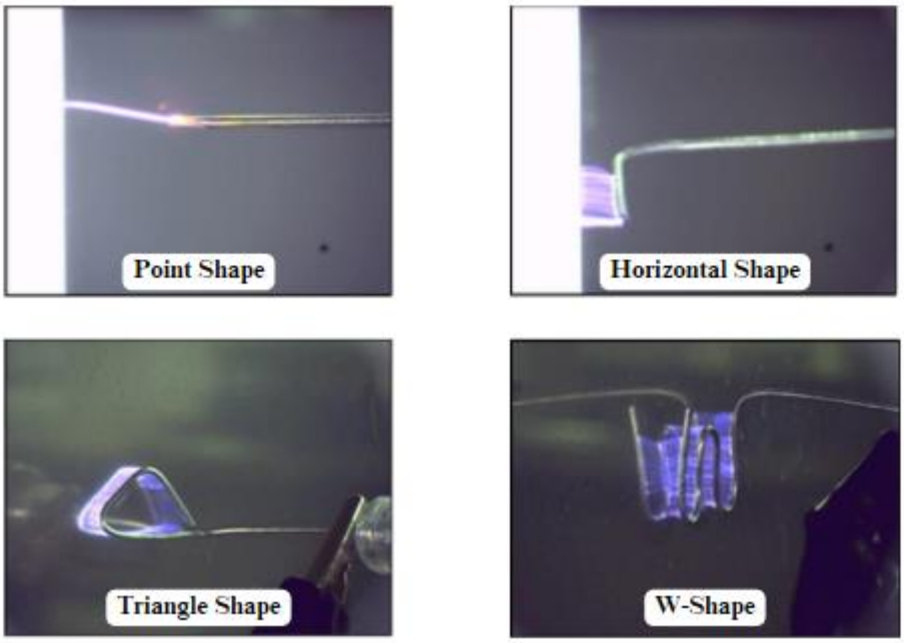


Figure 3. Geometric Shape of The Electrode

As demonstrated As demonstrated by the images in Figure 3, the geometric shape of the electrodes has a significant impact on the shape of the plasma generated by the corona discharge phenomena. The conductor shapes tested—triangle, W-shaped, needle, and L-shaped—were all manufactured to the same dimensions to ensure consistent comparison. Notations on each electrode figure specify their respective geometries and positions during the experiments. This ensures that the results can be directly attributed to shape differences rather than variations in size or placement. The distribution of the generated plasma is influenced by the distinct patterns of electric field distribution produced by each electrode geometry.

CONCLUSION

This study demonstrates that corona discharge, a phenomenon that occurs in high-voltage systems, generates powerful electric fields that ionize the surrounding air molecules, leading to plasma formation. The experimental findings confirmed that both the intensity and distribution of the generated plasma are highly dependent on the spacing and shape of the electrodes used. Shorter electrode distances resulted in stronger electric fields and, subsequently, higher plasma intensities, in line with Paschen's law. Moreover, the geometric shape of the electrodes significantly affected plasma distribution. For instance, the L-shaped electrode produced a horizontally dispersed plasma, making it ideal for broad surface treatments, while the needle-shaped electrode generated a more focused plasma column, suitable for precision applications. The triangular and W-shaped electrodes exhibited intermediate and multi-directional plasma distributions, respectively, offering diverse functionalities for industrial processes. The results of this study have practical implications for the design of electrodes in plasma generation systems across various industries. For precision tasks, such as micromachining or electronic component fabrication, needle-shaped electrodes can offer localized plasma treatment. In contrast, L-shaped electrodes are better suited for large-area surface treatments, such as in polymer surface modification or textile processing. W-shaped electrodes can be applied in processes that require multi-directional plasma exposure, such as in material synthesis or environmental air treatment. Finally, triangular electrodes are useful for applications that require a balance between focused and dispersed plasma, such as surface cleaning or decontamination. These findings contribute to the optimization of plasma generation systems by showing how the shape and spacing of the electrodes can be adapted to specific industrial applications such as biomedical and specific industries, there by improving the efficacy and efficiency of plasma surface treatment technology.

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