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Study of Positive Corona Plasma on Organdy Silk: Analysis of Current–Voltage Characteristics and Their Influence on Water Absorption Time in Moving Samples

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ABSTRACT

A study was conducted to investigate the effects of positive corona discharge plasma radiation on organdy silk fabric samples in motion. The primary objectives were to characterize the current–voltage (I–V) relationship of the positive corona plasma for both stationary and moving samples, and to evaluate the water absorption behavior of irradiated samples under dynamic conditions. The plasma was generated using a DC high-voltage power supply connected to electrodes arranged in a multi-point-to-plane configuration, integrated with a conveyor system. In this setup, the multi-point electrode functioned as the anode, while the plane electrode served as the cathode. Plasma irradiation was applied to the fabric samples by varying three key parameters: irradiation duration (t), electrode gap, and sample movement speed. To assess the impact of plasma treatment, a water absorption test was performed by applying 1 mL of water to the irradiated surface and recording the time required for complete absorption. The characterization results revealed that the discharge current increased as the electrode gap decreased. Additionally, samples exposed to longer irradiation durations exhibited faster water absorption. Notably, samples irradiated at a speed of 13.13 cm/s absorbed water more quickly than those treated at 4.8 cm/s, indicating enhanced surface modification at higher movement speeds.This document provides some minimal guidelines (and requirements) for writing a research paper. Issues related to the contents, originality, contributions, organization, bibliographic information, and writing style are briefly covered. Evaluation criteria and due dates for the research paper are also provided.

Keywords: Positive Corona Plasma, Multi-Point to Plane Electrode, Organdy Silk Fabric, Moving Sample, Water Absorption Time

I. INTRODUCTION

Silk is one of the most elegant natural fibers, long admired for its exceptional softness and visual appeal. These unique properties have made silk a preferred material for a wide range of luxury textile products. However, beneath its luxurious qualities lies a functional drawback: silk possesses a naturally hydrophobic character due to the presence of sericin, a protective protein layer that coats the fibers. This layer hinders the fabric's water absorption capacity, making it less comfortable for use in hot or humid environments.[1]

As consumer awareness continues to grow regarding the importance of comfort, ease of maintenance, and the environmental impact of the products they use, the textile industry is under increasing pressure to innovate. The focus has shifted towards the development of hydrophilic textile materials—fabrics that more readily absorb water, offer better thermal comfort, and facilitate easier dyeing and washing processes. Furthermore, such materials contribute to improved efficiency and sustainability in textile production.[2]

Unfortunately, conventional methods used to enhance the hydrophilicity of fabrics—such as degumming, bleaching, and chemical coating—come with notable limitations. These techniques typically require high energy and water consumption and result in chemical waste that harms the environment.[3] Moreover, aggressive chemical treatments can compromise the structure of natural fibers, potentially diminishing the quality and comfort of the final textile product.

In response to these challenges, plasma technology has emerged as a more environmentally friendly and efficient solution. This technique involves the exposure of fibers to ionized gases containing electrons, ions, and free radicals, enabling surface modification without the use of water or additional chemicals. The process enhances the water absorbency of fabrics while preserving the internal structure of the fibers, thus maintaining their quality.[5]

One of the most promising innovations in this field is the application of positive corona plasma. As a type of cold plasma, positive corona plasma can be generated under atmospheric pressure and room temperature, eliminating the need for vacuum systems or high temperatures. Its simplicity and energy efficiency make it highly suitable for widespread adoption in the textile industry.[6]

The effectiveness of this technology has been demonstrated in numerous studies. Research by Ssekasamba et al. (2024) found that positive corona plasma treatment significantly enhances the hydrophilicity of various fabrics, including natural fibers like silk, without causing significant environmental impact.[7] Similar results were reported by Wang et al. (2023), who observed improvements in both water absorption and antimicrobial properties following plasma treatment.[8] Zhang et al. (2023) further noted that corona plasma induces micro-etching on the fabric surface, increasing the contact area and facilitating water adhesion. Liu et al. (2024) confirmed that these improvements in hydrophilic properties result from physical surface modification rather than the formation of new functional groups, thereby preserving the fabric's original chemical structure.[9,10]

In this context, the present study was conducted to further explore the application of positive corona plasma radiation on the surface of moving organdy silk fabric. The treatment was performed under atmospheric conditions, with variations in exposure time and fabric speed on a conveyor system. This research not only investigates the characteristics of positive corona plasma when interacting with moving silk surfaces but also examines changes in the fabric's water absorption behavior as a result of plasma treatment under dynamic conditions. The findings are expected to contribute to a deeper understanding of plasma technology applications in real industrial settings, particularly in enhancing silk quality in a sustainable manner.

II. METHODS AND MATERIAL

Positive corona plasma was generated by connecting a DC high-voltage power supply to a set of electrodes under atmospheric conditions. The electrode configuration employed a multi-point-to-plane arrangement. The multi-point electrode comprised 45 tips arranged in a 9 × 5 matrix (9 rows with 5 tips each), with a spacing of 1.2 cm between adjacent tips. The plane electrode was a flat copper sheet. Both electrodes were integrated into a fabric conveyor system, as illustrated in Figure 1.

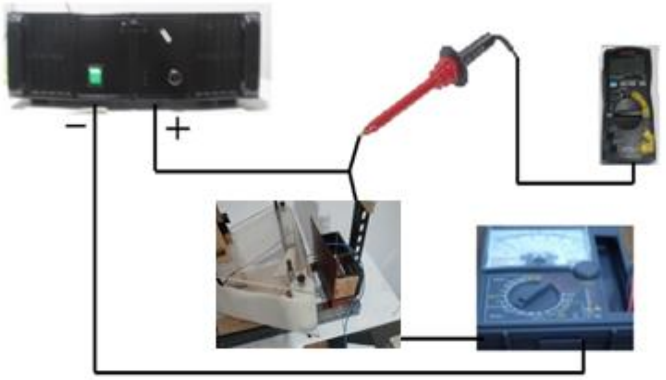

Figure 1. Experimental setup.

The experimental procedures included:

- Current-voltage (I–V) characterization of the positive corona discharge, both with and without organdy silk fabric.
- Sample irradiation under controlled conditions.
- Post-irradiation analysis of the treated samples.

The I–V characterization aimed to establish baseline data under stable glow corona discharge conditions. For tests without the fabric sample, the electrode gap was varied. For tests with the sample, both the electrode gap and the fabric's linear speed were adjusted. Electrode distances ranged from 1.7 cm to 2.6 cm in 0.3 cm increments, while fabric speeds were set at 4.8 cm/s and 13.13 cm/s.

During characterization, voltage was gradually increased, and the resulting current was recorded to monitor plasma discharge behavior. The data were analyzed through graphical representations to explore the relationships among current (I), voltage (V), electrode distance (d), and sample speed (S).

In the irradiation phase, fabric samples measuring 9.5 × 95 cm² were positioned between the electrodes based on optimal parameters identified during characterization. Irradiation durations were set at six intervals: 5, 10, 15, 20, 25, and 30 minutes. Two variables were manipulated: electrode distance (2.0–2.6 cm) and sample speed (4.8 cm/s and 13.13 cm/s).

Following irradiation, water absorption tests were conducted on the treated fabric surfaces. Samples were rested for over 24 hours before testing. Using a graduated pipette, 10 drops of water were randomly applied to each sample's surface. The time required for complete absorption was recorded for analysis.

III.RESULTS AND DISCUSSION

The characteristics of the voltage (kV) and current (A) relationship curves for the positive corona plasma system, both with and without the presence of organdy silk fabric as a sample, tested under static and dynamic conditions, are shown in Figure 2. The electrode gap for this test was set at 2.0 cm. The graph presents four conditions: plasma corona characteristics without a sample (control), with a static sample (0 cm/s), and with moving samples at speeds of 4.8 cm/s and 13.13 cm/s.

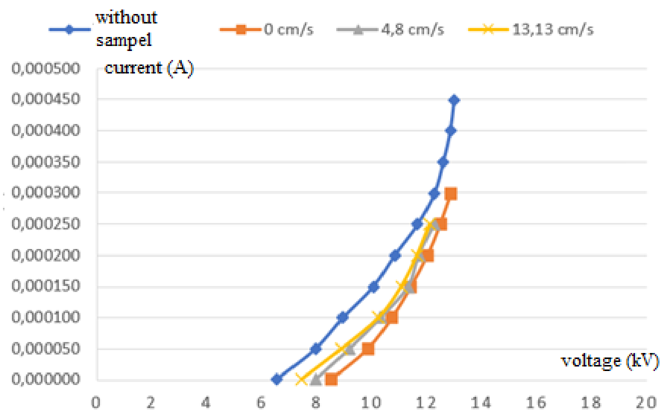

Figure 2. I–V Characterization of Positive Corona Plasma at an Electrode Gap of 2.0 cm

From the graph, it is observed that the current increases exponentially with increasing voltage under all conditions. This phenomenon aligns with the Townsend ionization principle, in which increasing voltage strengthens the electric field, accelerates free electrons, and increases the frequency of ionizing collisions with gas molecules, thereby generating higher current.[1]

Under the no-sample condition, the current produced is the highest. This indicates that the absence of material resistance allows electrical charges in the plasma to flow more freely, resulting in maximum current. The plasma can develop optimally across the entire electrode gap.[6]

When a static sample is placed in the plasma path, a significant drop in current occurs. This is due to the absorption of some plasma energy by the sample surface, which obstructs ion flow through the fiber structure. The fabric surface acts as a partial barrier, absorbing charge and disrupting the path of free electrons.[9]

For samples moving at speeds of 4.8 cm/s and 13.13 cm/s, the recorded current is higher compared to the static sample condition. This can be explained by the reduced plasma–surface interaction time. As the sample moves faster, the plasma has less time to interact with any given point on the fabric surface, limiting the amount of transferred charge and the ionization process. This phenomenon is known as the transit time effect, common in dynamic plasma systems.[7]

Figure 3 presents a similar curve, but with the electrode gap increased to 2.6 cm. Overall, the recorded current is lower than that in Figure 2. This decrease is due to the weakening of the electric field as the electrode distance increases, in accordance with Gauss's law and the principles of electric field distribution. A weaker field results in fewer ionizing collisions, thereby reducing plasma density and current.[5]

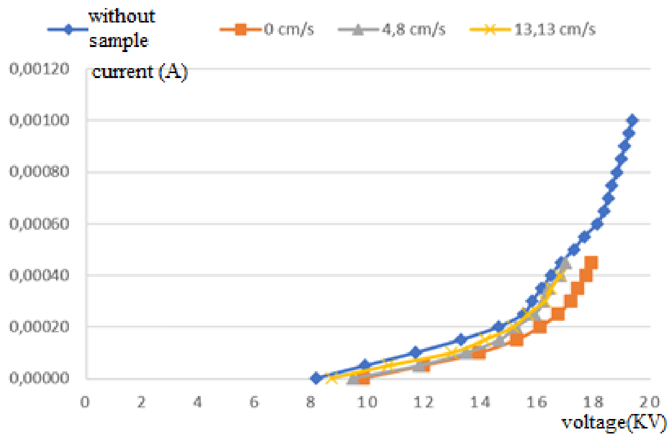

Figure 3. I–V Characterization of Positive Corona Plasma at an Electrode Gap of 2.6 cm

The pattern of decreasing current based on the fabric movement speed remains consistent: the highest current occurs without a sample, followed by 0 cm/s, then 4.8 cm/s, and the lowest at 13.13 cm/s. This indicates that both fabric movement speed and electrode gap are key parameters influencing plasma generation efficiency and charge transfer.[8]

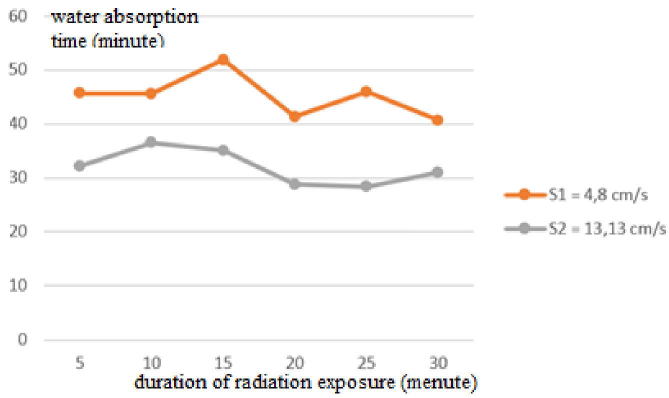

Figure 4. Water Absorption Test Results on Organdy Silk Moving Through a Positive Corona Plasma Region at Varying Speeds with an Electrode Gap of 2.0 cm

Figure 4 shows the water absorption test results on silk fabric treated with positive corona plasma under varying fabric movement speeds during plasma exposure. The test was conducted at two speeds: 4.8 cm/s and 13.13 cm/s, with a fixed electrode distance of 2 cm. The horizontal axis represents the radiation duration (minutes), while the vertical axis indicates the time required for the fabric to absorb 1 mL of water (minutes). In this context, a shorter water absorption time indicates a more effective treatment, as it reflects enhanced hydrophilicity of the fabric.[1]

Test results show that samples moving at 13.13 cm/s tend to absorb water more quickly than those moving at 4.8 cm/s. The shortest absorption time was observed after 20 minutes of treatment at 13.13 cm/s, with water absorption taking approximately 30 minutes. This phenomenon is believed to occur because samples moving at 13.13 cm/s experience more repeated exposures to the positive corona plasma radiation. As a result, the fabric has a longer cumulative contact time with the plasma, causing more significant surface modifications that enhance hydrophilicity, unlike slower-moving samples that may reduce the treatment's efficiency.[7]

Overall, it can be concluded that the fabric movement speed during plasma exposure plays a crucial role in determining treatment effectiveness. A higher speed (13.13 cm/s) allows sufficient exposure time without causing excessive damage, thereby optimizing the fabric's hydrophilicity.[8]

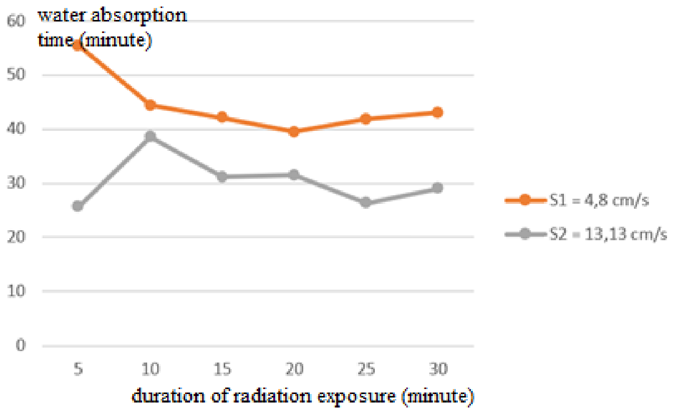

Figure 5. Water Absorption Test Results on Organdy Silk Moving Through a Positive Corona Plasma Region at Varying Speeds with an Electrode Gap of 2.6 cm

Figure 5 complements Figure 4 but with a larger electrode distance of 2.6 cm. According to the graph in Figure 5, samples moving at 13.13 cm/s again show shorter absorption times compared to those moving at 4.8 cm/s at nearly all radiation duration points. This trend aligns with the pattern shown in Figure 4, though the overall water absorption times are longer.

The comparison of Figures 4 and 5 shows that variations in electrode distance (2 cm vs. 2.6 cm) and fabric movement speed significantly influence the effectiveness of reducing water absorption time. In both graphs, samples moving at higher speeds consistently show shorter water absorption times than those moving slower, indicating more optimal hydrophilicity enhancement at higher speeds. However, a notable difference is observed in the effect of electrode distance: at a 2.6 cm gap, the water absorption time for sample S2 decreases more significantly, reaching a minimum of about 28 minutes. This suggests that increasing the electrode distance results in better water absorption, particularly at higher fabric speeds.[6]

In conclusion, the combination of a larger electrode gap (2.6 cm) and higher fabric movement speed (13.13 cm/s) yields the best results in enhancing water absorption in silk fabric. This demonstrates that electrode distance and movement speed are critical parameters in plasma treatment outcomes, and selecting the right combination can significantly improve the hydrophilic properties of the fabric surface.[6]

IV. CONCLUSION

Although a conclusion may review the main points of the paper, do not replicate the abstract as the conclusion. A conclusion might elaborate on the importance of the work or suggest applications and extensions. Authors are strongly encouraged not to call out multiple figures or tables in the conclusion—these should be referenced in the body of the paper.

V. ACKNOWLEDGMENT

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