Comparative Study of Carbon Dioxide Plasma for Medical Applications

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ABSTRACT

This study aims to compare the performance of argon–carbon dioxide plasma generated by a plasma jet device and a mobile air plasma arc, focusing on carbon monoxide production and trends in pH changes of plasma-treated solutions. Additionally, the study investigates changes in wettability through contact angle measurements. Experimental results show that the plasma generators achieve maximum carbon monoxide production as measured by Optical Emission Spectroscopy, which is consistent with the observed pH and contact angle results. For the plasma jet, the optimal condition requires an argon flow rate of 7 lpm combined with a carbon dioxide flow rate of 100 cc/min at Power Level 3 (0.62 W). For the mobile air plasma arc, the optimal condition requires an argon flow rate of 4 lpm with carbon dioxide at 400 cc/min.The mobile air plasma arc demonstrates superior carbon monoxide production and stronger acidification in DI water compared to the plasma jet. However, both plasma generators can enhance the surface energy of glass slides, with the plasma jet providing better improvement in surface wettability, allowing water droplets to spread more effectively compared to untreated surfaces. These findings indicate that the type of plasma generator and the ratio of argon to carbon dioxide flow rates significantly influence both the chemical processes in the solution and the modification of material surface properties. This serves as a foundation for the future application of argon–carbon dioxide plasma in medical technologies.

THEORY

Mobile air plasma arc and Compact air plasma jet



The Plasma jet operates by accelerating electrons to excite Ar atoms, providing sufficient energy to break CO_2 bonds, and then the plasma is emitted as a flow through the gas stream. In contrast, The mobile air plasma arc operates via microdischarges between electrons and the ground, which excite Ar and provide sufficient energy to dissociate CO_2 bonds.

Electron Temperature

The Boltzmann plot method can be used to calculate electron temperature (T_e) by relating the population of excited energy levels to the intensity of emission lines, based on the Maxwell-Boltzmann distribution.

$$\ln\left(\frac{I_{ki}\lambda_{ki}}{g_k A_{ki}}\right) = -\frac{E_k}{k_B T_e} + C \qquad T_e = -\frac{1}{slope}$$

Assuming a quasi-steady-state, the plasma releases constant energy and follows Boltzmann statistics within the measurement region.

Carbon dioxide Production

Carbon monoxide (CO) can be produced from CO_2 using plasma at room temperature,

$$e^- + CO_2 \rightarrow CO + O + e^-$$

$$Ar^* + CO_2 \rightarrow Ar + CO_2^+ + e^-$$

$$Ar^* + CO_2 \rightarrow Ar + CO + O$$

where high-energy electrons from a CO_2–Ar plasma jet cause electron impact and Penning dissociation, breaking CO_2 bonds to generate CO.

pH change after treat with plasma on deionize water

Treating DI water with Ar–CO_2 plasma generates carbonic acid (H_2CO_3) and reactive species (RONS).

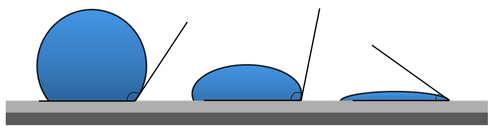
Formation of carbonic acid (H_2CO_3)

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^- \qquad CO_2 + H_2O \rightleftharpoons H_2CO_3$$

leading to a decrease in pH, indicating increased acidity after plasma treatment.

wettbility changing surface

Wettability is the ability of a liquid to wet a surface, depending on the intermolecular forces between the liquid and the surface.



It is measured by the contact angle a small angle indicates good wetting (hydrophilic), while a large angle indicates poor wetting (hydrophobic).

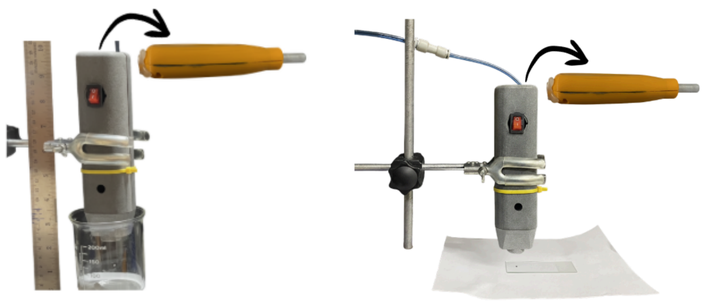
METHODS

A comparative study of the performance of a mobile air plasma arc and a plasma jet based on the pH of argon–carbon dioxide plasma.

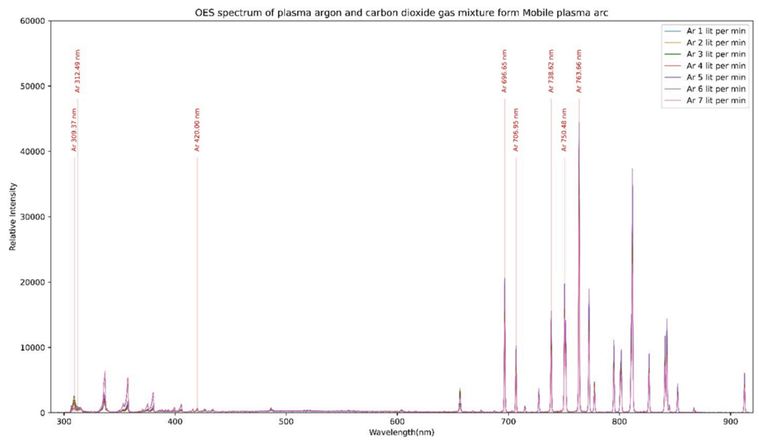
The pH meter was calibrated and the pH of 25 mL of DI water was measured before treatment. The water was then treated using both the mobile air plasma arc and the plasma jet at distances of 1 and 3 cm for 1, 3, and 5 minutes, under gas flow rates of Ar 2 L/min with CO_2 100 cc/min and Ar 4 L/min with CO_2 200 cc/min. The water was stirred continuously during treatment, and the pH after treatment was measured to compare the acidity produced by the two devices.

Comparative study of the effects of plasma on material surface properties, particularly the wettability of slide surfaces

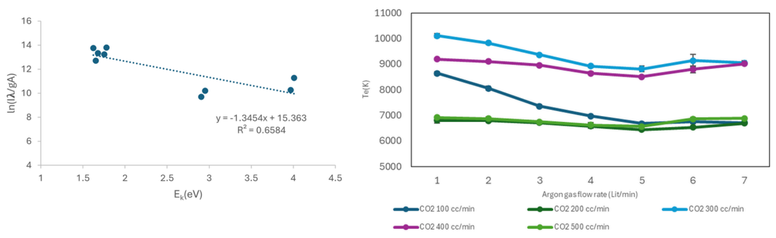
The experiment was conducted using both the Mobile air plasma arc and the plasma jet under their optimal conditions. The slides were plasma-treated for 3 minutes at a distance of 1 cm. Then, a single drop of DI water was placed on both the treated and untreated areas, and the droplet shapes were recorded to calculate the surface energy of the material.



MOBILE AIR PLASMA ARC



The emission spectrum of a linear argon gas plasma arc under different argon gas flow rates of 1 to 7 L/min and carbon dioxide gas flow rates of 100 cc/min is shown.

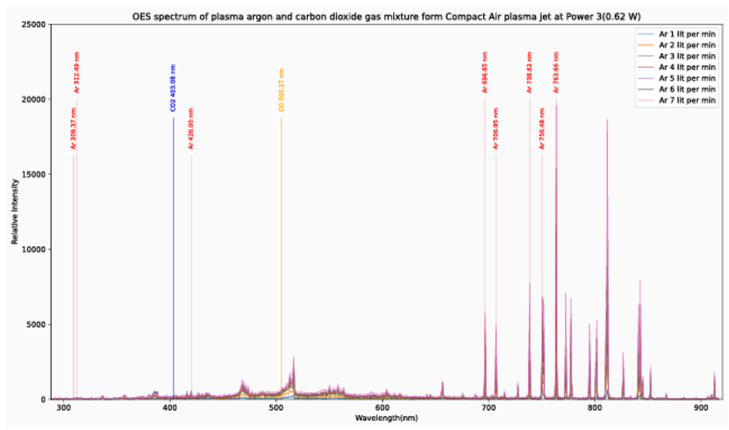


Comparison of T_e values of plasma arc containing 100 to 500 cc/min of carbon dioxide at argon gas flow rates between 1 and 7 L/min showed that the Te tends to decrease for all values of CO_2, with the maximum Te being found at CO_2 300 cc/min, indicating a equilibrium condition between CO_2 and Ar gas contents.

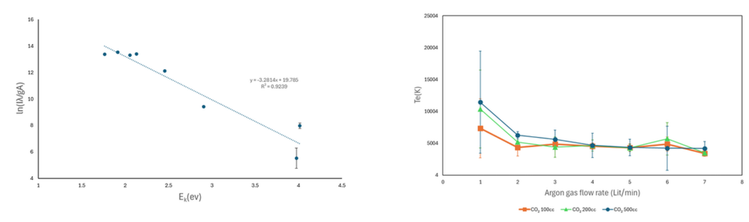


Plasma color during arc formation of carbon dioxide (CO2) mixed gas.

COMPACT AIR PLASMA JET



The emission spectrum of a linear argon gas plasma jet at Power 3 (0.62 W) under different argon gas flow rates of 1 to 7 L/min and carbon dioxide gas flow rates of 100 cc/min is shown.



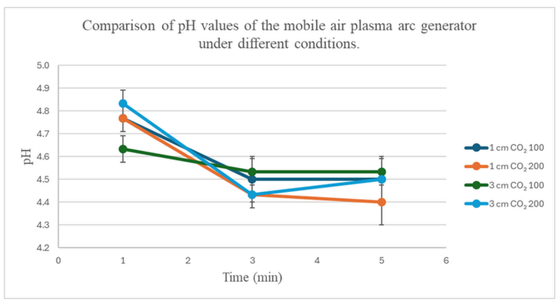
Comparison of T_e values of plasma jets containing 100, 300 and 500 cc/min of carbon dioxide at argon gas flow rates between 1 and 7 L/min showed that the trend at 100 cc/min showed less electron temperature drift which is consistent with the uniform plasma channel characteristics.

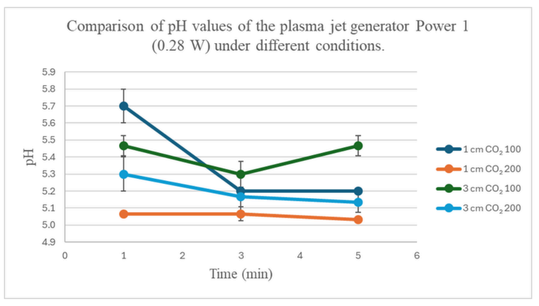


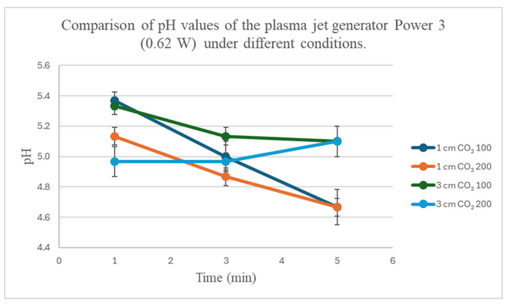
The characteristics of the plasma beam from Compact Air plasma jet

RESULTS

Performance analysis of mobile air plasma arc and plasma jet generator based on pH value of argon–carbon dioxide plasma



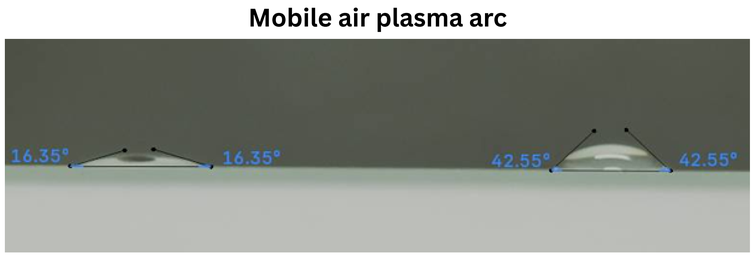




This experiment compares the performance of a mobile air plasma arc and a plasma jet by examining the pH change of DI water treated with argon–carbon dioxide plasma. The results show that the pH of the DI water decreases over time in both systems; however, the mobile air plasma arc produces a greater reduction in pH due to its higher CO production and stronger acidification effect under both Power 1 (0.28 W) and Power 3 (0.62 W) conditions. Additionally, plasma treatment at a distance of 1 cm results in a more pronounced pH decrease compared to treatment at 3 cm.

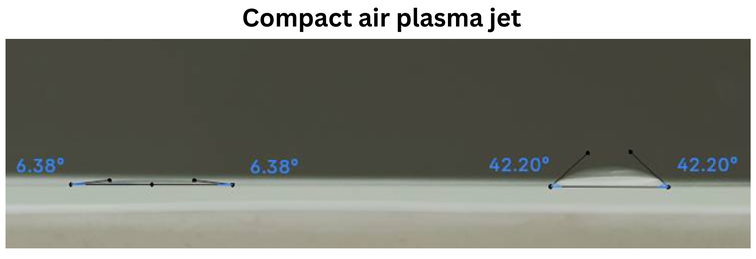
Comparative study of the effects of plasma on material surface properties, particularly the wettability of slide surfaces

Mobile air plasma arc



Under the optimal conditions (Ar 4 L/min, CO_2 400 cc/min, 1 cm distance, 3 min), the Mobile air plasma arc reduced the contact angle of the glass slide from 42.55° to 16.35°, increasing the surface energy from 0.126 N/m to 0.142 N/m.

Compact air plasma jet



Under the optimal conditions (Power 3–0.62 W, Ar 7 L/min, CO_2 100 cc/min, 1 cm distance, 3 min), the plasma jet reduced the contact angle of the glass slide from 42.20° to 6.38°, increasing the surface energy from 0.126 N/m to 0.145 N/m.

CONCLUSION

This study compared the performance of a Mobile air plasma arc and a Plasma jet using Argon– Carbon dioxide plasma. pH measurements of 25 mL DI water showed that the mobile air plasma arc produced more CO and stronger acidification than plasma jets (Power 1: 0.28 W, Power 3: 0.62 W), with closer distances (1 cm) resulting in greater pH reduction. Surface treatment of glass slides revealed that both devices improved wettability, with the plasma jet achieving slightly higher surface energy (0.145 N/m) than the Mobile air plasma arc (0.143 N/m). Results indicate that the type of generator and gas flow ratio affect chemical processes in solution and surface modification, supporting potential medical applications of Argon– Carbon dioxide plasma.

REFERRENCE

[1] ธีรวรรณ บุญญวรรณ. (2561). ฟิสิกส์ของพลาสมาและการประยุกต์ (พิมพ์ครั้งที่ 2). ภาควิชาฟิสิกส์และวัสดุศาสตร์ มหาวิทยาลัยเชียงใหม่.

[2] Plasma medicine—current state of research and medical application. (2016, November). Retrieved from Plasma Physics and Controlled Fusion: https://www.researchgate.net/publication/309657403_Plasma_medicine

[3] Nanoscience Instruments, "What Probe Liquid Should You Use for Contact Angle Measurements?," Nanoscience Instruments Blog. [Online]. Available: https://www.nanoscience.com/blogs/what-probe-liquid-should-you-use-for-contact-angle-measurements/