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The Influence of Gas Type and Flow Rate on Plasma Jet Length and Gas Temperature

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Abstract
This study developed a plasma jet system using a power source that provides a high voltage of 10 kV and a total output power of 30 W. The system operates with three gases: air, nitrogen, and argon. The setup features a plasma torch placed within a steel tube with an internal diameter of 1.4 mm and a length of 5 cm. The research focused on the significance of gas temperature and plasma jet length, investigating how the type of gas and its flow rate influence these parameters. Electrical diagnostics were performed on the system using a high-voltage probe and a calibrated current probe with resistive measurements. The working gas temperature was found to be close to the ambient temperature across various flow rates. Nitrogen exhibited the highest temperature, measuring 22.8°C at a gas flow rate of 1 L/min and decreasing slightly to 22.6°C at 5 L/min. Air showed a relatively stable temperature, with 22.4°C at 1L/min and 22.3°C at 5 L/min. Argon had the lowest temperature, with 22.6°C at 1 L/min, decreasing to 21.8°C at 5 L/min. The plasma jet length varied by gas type, with argon producing the longest jet 5.6 cm, followed by air 4.1 cm and nitrogen 2.6 cm at a gas flow rate of 5 L/min. The jet length increased with higher gas flow rates for all three gases. The system operates with air, nitrogen, and argon, maintaining near-ambient temperatures, making it suitable for biological and medical applications like seed germination and wound sterilization.

Article Info.

Keywords:
Plasma Jet, Nitrogen Plasma, Biological Applications, Plasma Needle, Non-thermal Plasma.

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1. Introduction
A plasma system that can function with many gases is necessary for many practical plasma applications in order to be appropriate for a range of industrial, medicinal, and environmental applications. Air, nitrogen, and argon are the gases used by one kind of single-electrode non-thermal atmospheric glow discharge plasma needle. This kind of plasma can operate at temperatures nearly equal to room temperature, which guarantees that it won't heat an object when it comes in touch with it. This characteristic allows the treatment of heat-sensitive materials without the risk of thermal damage. Atmospheric pressure discharge plasma is very beneficial because of its inexpensive price and ease of usage [1]. Non-thermodynamic (cold) plasma refers to a state where the plasma is not in thermodynamic equilibrium. In this case, the temperatures of molecules, atoms, and ions differ from the electron temperature, meaning they do not reach a uniform thermal balance [2, 3]. For these reasons, plasma jet systems are multipurpose tools capable of a wide range of research activities. They are employed for polymer surface activation, solar cell fabrication, and material etching [4, 5]. Their use goes beyond those purposes to include the treatment of sterilization [5], living cells [6, 7], blood coagulation [8, 9], wound healing [10-14], bacteria activation [15-17], teeth whitening [18, 19], and air purification [20, 21] are some of the applications [22]. Also, a cold atmospheric plasma jet is used in the treatment of cancer cells [23]. Air plasma can also be used to active water and produce reactive oxygen and nitrogen species (RONS) [24]. Nitrogen plasma technology is a safe and effective treatment for significant skin rejuvenation, eliminating the potential complications and recovery time associated with more invasive cosmetic procedures.

Several crucial components are required to generate an atmospheric plasma jet: a high-voltage power source to generate plasma discharge, an electrode configuration to initiate and sustain the plasma, and a gas distribution system to feed gas into the plasma [25, 26]. Nitrogen gas and ambient air are frequently employed as working gases in plasma jet systems. Nitrogen is typically selected because of its chemical stability and high reactivity with particular chemicals, while air is widely accessible and affordable. Plasma will interact with nitrogen molecules, producing nitrogen radicals and ions. The gas used in the plasma jet system is determined according to the research application. Electrode configurations may be modified to create various plasma shapes and characteristics. For example, a needle-to-plate electrode design can produce a highly focused plasma jet, but a wire-to-cylinder design generates diffuse plasma. After creating the atmospheric plasma jet, its characteristics may be investigated using various diagnostic techniques. Generating an atmospheric plasma jet and analyzing its features can be a complex and difficult procedure, but it has the potential to open new areas of research and innovation in a wide range of fields [27].

In this work, a plasma system operating on a DC, high voltage of 10kV power supply under atmospheric pressure utilizing three different types of gases, was developed. The effect of gas type, like argon, nitrogen, and air, and gas flow rate on the length of the plasma jet and the working gas temperature were investigated. The gas type expands the range of applications of the plasma system. The length of the plasma jet gives flexibility in utilizing plasma for various purposes. The temperature of the working gas is a criterion for the possibility of using plasma in temperature-sensitive applications, such as medical and biological applications.

2. Experimental Work

A simple method for generating plasma jets was developed. Fig. 1 shows the experimental setup, which contains a 10 kV DC high voltage power supply with an output power of 30 W and a plasma torch made from a hollow steel tube 5 cm long with a 1.4 mm internal diameter. The working gas enters one end of the steel tube through a Teflon tube attached to a gas rate regulator. The steel tube is directly connected to the positive terminal of a high-voltage DC power supply, serving as the first electrode. The second electrode is connected to the ground, ensuring that the system is grounded. The working gas temperature was measured remotely with a Fluke 62 MAX Infrared thermometer shown in Fig. 2, which measures temperature by taking a percentage of the thermal radiation emitted by the object being measured, commonly known as black-body radiation, and converting it to a temperature reading. The measurement process was done by exposing a glass slide to a plasma jet, waiting enough time for the glass slide temperature to stabilize and then recording the gas temperature, as shown in Fig. 3. This study focused on investigating the impact of different working gasses (nitrogen, air, and argon) and their different flow rates on the length of the plasma jet. The flow rate, ranging from 1 to 5 L/min, was carefully controlled using a flow rate meter. The length of the plasma jet was measured using a clearly marked standard ruler placed behind the jet, as shown in Fig. 4. The system was equipped with three types of gases (nitrogen, air, and argon). The system voltage was measured using a high-voltage probe, and the current was measured using a current probe calibrated by a standard resistor.

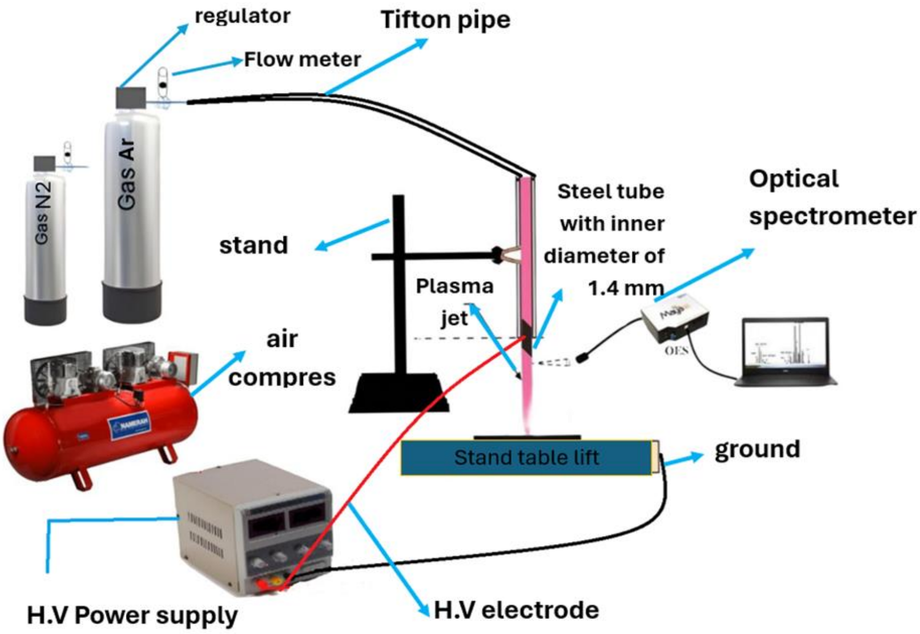


***Figure 1: Plasma jet system*.**

Figure 2: Infrared thermopile sensor.

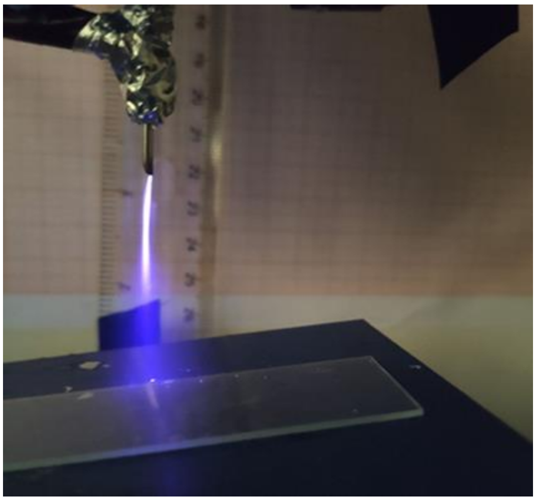


***Figure 3: Plasma jet gas temperature measurement*.**

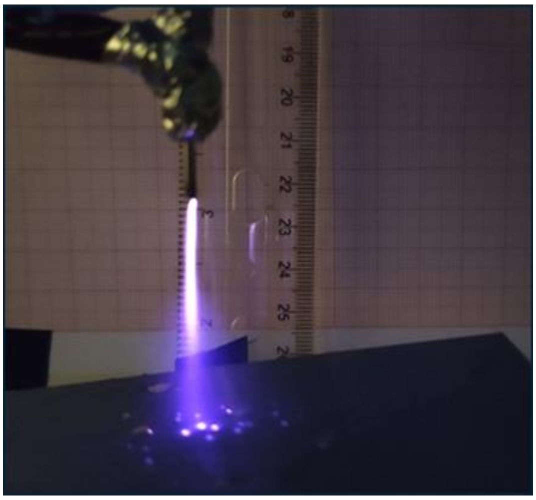


Figure 4: Plasma plume length measurement.

3. Results and Discussion

Fig. 5 shows the relationship between the temperature of the plasma working gas and the gas flow rate for the three types of the used gases: argon, nitrogen, and air. The average difference in temperature, depending on the type of gas, was about one degree Celsius. The highest temperature was for nitrogen gas, air, and argon gas. It was noted that the effect of the gas flow rate between 1 and 5 L/min on plasma working gas temperature in the case of air and nitrogen was almost of the same behavior. In general, the temperature of the plasma working gas depends on the electrical power supplied to the plasma, the gas pressure, and the gas flow rate. These factors are affected in the same way by all three gases, as the system operates under atmospheric pressure, with a similar flow rate range and identical electrical power input. Other influencing factors include the ionization potential of the gas and its composition-whether atomic or molecular. Nitrogen and air (a mixture primarily of nitrogen and oxygen) are molecular gases, whereas argon is an atomic gas. Increasing the flow rate reduces the gas temperature, as increasing the flow rate means an increase in the amount of gas available to transfer heat out of the plasma. From these results, the temperature of the working gas increased by three degrees Celsius above the ambient temperature (22°C) for all flow rates and for all three types of gases. This makes the system suitable for medical and biological applications, using any of the three gases without preference. These results agree with those of Abdulwahab and Humud [26].

Increasing the flow rate of the working gases (argon, nitrogen, and air) led to a decrease in their temperatures due to the following factors:

a- Dynamic cooling: As the gas flow rate increases, the molecules carry more heat away from the plasma, leading to a continuous decrease in temperature.

b- Distribution of thermal energy: The amount of gas flowing increases, leading to the same thermal energy being distributed to a larger number of molecules, thus decreasing the average temperature.

The largest decrease was when using argon, as the working gas, due to its high density and poor thermal conductivity; for nitrogen, the relation was characterized by a gradual and simple decrease due to its moderate heat capacity; as for air, which contains a mixture of nitrogen and oxygen, the relation is similar to that of nitrogen but at slightly lower temperatures. Increasing the gas flow rate reduces the plasma concentration and increases its diffusion, which weakens the efficiency of transferring thermal energy to the gas.

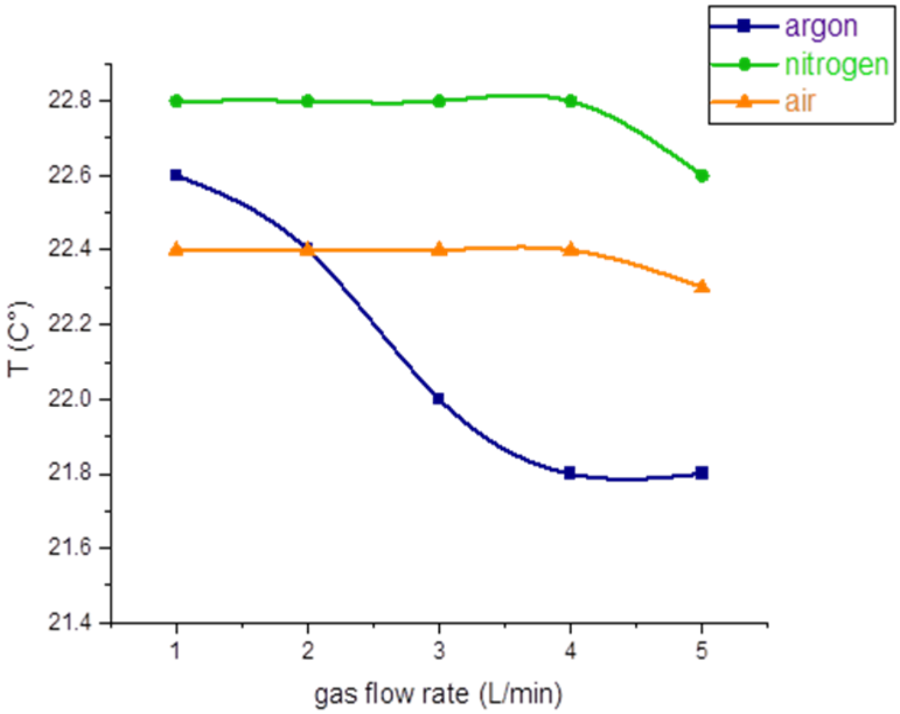


Figure 5: The relationship between gas temperature and gas flow rate for the different gases.

Fig. 6 illustrates the relationship between the length of the plasma jet and the flow rate of the three different gases. It is noted from the figure that the longest jet length was for argon gas, followed by air, and then nitrogen. The length of the jet increased with the increase in the gas flow rate. At a gas flow rate of 5 L/min, the plasma jet length was 5.6 cm for the argon gas, 2.6 cm for N_2 gas and 4.1cm for air. In general, increasing the gas flow rate means an increase in the amount of gas available to sustain the jet length. The jet length depends on the gas type. It is affected by two essential factors: the density of the gas and the energy required to generate and sustain the plasma from that gas, which depends mainly on the ionization potential and the gas composition, atomic or molecular. This result agrees with that of Abdulwahab and Humud [26].

It is well-known that argon exhibits a higher ionization sustainability due to its relatively low ionization energy 15.76 eV and chemically inert nature. This makes argon easier to ionize and requires less energy to maintain its ionized state. Consequently, argon plasma demonstrates greater continuity and stability, resulting in longer and more stable jets.

In contrast, air has lower ionization sustainability due to energy-consuming chemical reactions. As a mixture of nitrogen and oxygen, air has an ionization energy of 13.62 eV for oxygen, which is lower than that of nitrogen 14.53 eV. That makes air more ionizable than pure nitrogen. However, chemical reactions in the air, such as making nitrogen oxides, take some energy from the system, making plasma less sustainable than argon. Still, air slightly outperforms nitrogen due to relatively lower ionization energy of oxygen. However, nitrogen shows less ionizing sustainability due to its diatomic nature and the greater energy involved in ionization, leading to shorter lengths of the plasma jet.

Moreover, the density of the gas itself had a big impact on the difference in jet lengths. Plasma jets generated by argon, as argon has higher density, are longer, denser, and more stable. Since air is of moderate density, it is classified as of intermediate performance, whereas nitrogen being of low density, resulting in loss of heat at a quicker rate, resulting in a shorter plasma jet.

In this way, not only the density but also the energy to maintain the plasma plays a role in extending the length of the plasma jet. Therefore, the interplay of these effects leads argon plasma jets to be longer than those of air and nitrogen, even though the latter has lower ionization energies. The conclusion from these results indicates that the jets resulting from these three gases have lengths that are long enough for several usages, and argon is the best of the three gases in terms of jet length. If the availability of gas and its production cost are considered, air and nitrogen are the best to work with at moderate gas flow rates. Air is less expensive and has a longer jet but is less stable, while nitrogen has a shorter jet but is more stable.

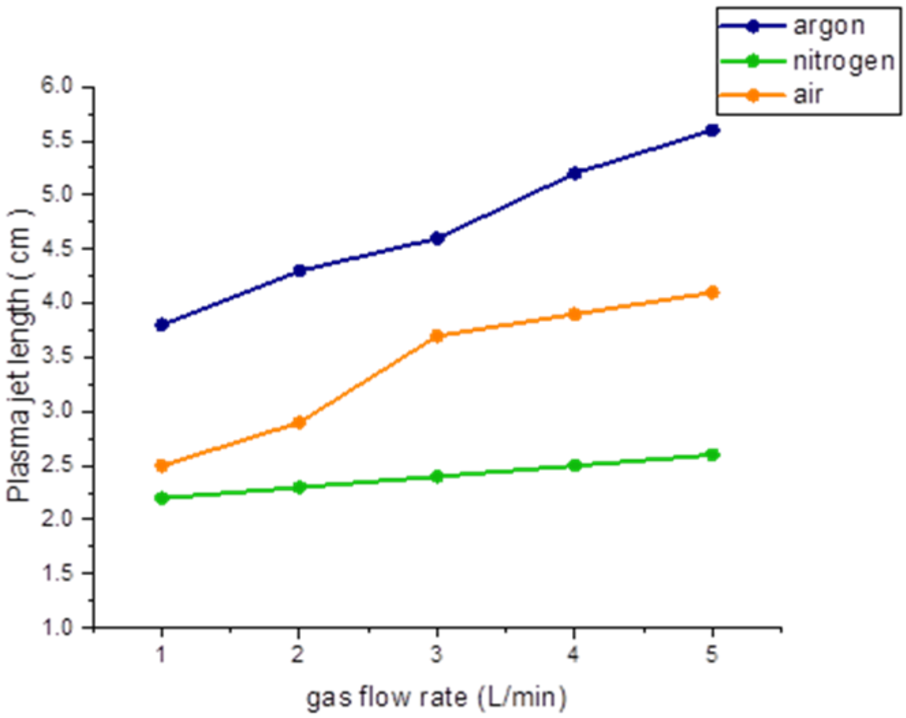
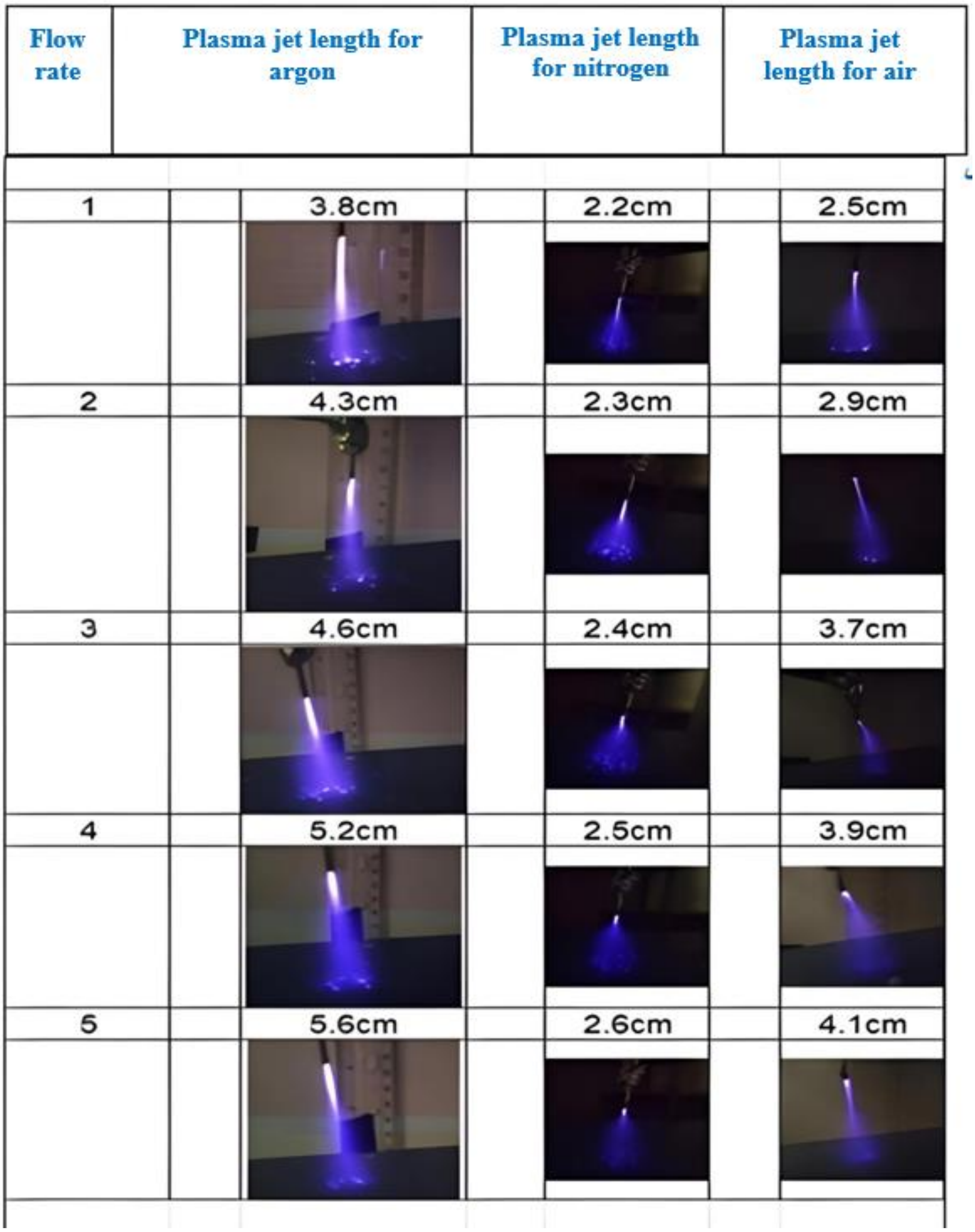


Figure 6: The relationship between plasma jet length and gas flow rate.

A new versatile plasma jet system that creates plasma with a suitable length for a range of biological and medical applications is one of the key highlights of the study. This system functions efficiently with all three gases, air, argon, and nitrogen while maintaining temperatures close to the gas temperature level. Additionally, the system maintains the gas temperature level close to the ambient level. Improving seed germination is one area where further research using this system may be conducted. Other processes include stimulating seeds, increasing disease resistance, and activating genes related to growth, which accelerates growth. Plasma jets stand out as an exceptional tool to tackle these processes.

The system can also be used for wound sterilisation, which falls in the medical field. The system’s flexibility means that air, nitrogen, or argon can freely be used as operating gases. From an economic standpoint, nitrogen and air are the most cost-effective choices for plasma jet length and overall expense, taking gas production costs into account, Fig. 7. Air is the cheapest option and generates a long plasma jet, but it is significantly less stable than nitrogen. In contrast, nitrogen produces shorter plasma jets but offers greater stability, making it advantageous for specific applications.



Flow rate	Plasma jet length for argon	Plasma jet length for nitrogen	Plasma jet length for air
1	3.8cm	2.2cm	2.5cm
2	4.3cm	2.3cm	2.9cm
3	4.6cm	2.4cm	3.7cm
4	5.2cm	2.5cm	3.9cm
5	5.6cm	2.6cm	4.1cm

Figure 7: Relationship between plasma jet length and gas flow rate for different gases.

4. Conclusions

This study aimed to develop a plasma jet system working at 10 kV and 30 W of power output. The plasma jet operated using air, nitrogen, and argon. The setup included a plasma torch made from hollow steel, measuring 5 cm in length with an internal diameter of 1.4 mm. The investigation focused on the impact of the type of gas used and the gas flow rate on the gas temperature and the length of the plasma jet. The temperature of the working gas reached a maximum of 3°C above the ambient temperature of 22°C, while the operating temperature remained constant for all three gases. Moreover, it was observed that the length of the plasma jet depended on the type of gas used. The greatest jet length was for argon plasma at 5.6 and 2.6 cm for nitrogen plasma, and 4.1 cm for air plasma at a gas flow rate of 5 L/min. The results also showed that the jet length increased with gas flow rates for all the gases. The most significant outcome of this work is the development of a multifaceted plasma jet system that operates with three different gases (air, nitrogen, and argon) at near-ambient gas temperatures. The system can produce plasma jets of appropriate lengths for diverse medical and biological uses. The plasma jet system has the potential to enhance seed germination. Plasma jets are a powerful means of stimulating seeds to bestow increased germination, disease resistance, and accelerated growth.

Additionally, the system is applicable in medical fields, such as wound sterilization. The system's versatility allows for the interchangeable use of air, nitrogen, or argon as operating gases. When considering the cost of gas production and the length of the plasma jet, nitrogen and air are the most suitable options for applications. Air is the least expensive option, producing longer plasma jets, but its stability is lower. In contrast, nitrogen provides shorter plasma jets but ensures higher stability, making it advantageous for specific applications.

Conflict of Interest

The authors declare that they have no conflict of interest.

References

1. M. Domonkos, P. Tichá, J. Trejbal, and P. Demo, Appl. Sci. **11**, 4809 (2021). https://doi.org/10.3390/app11114809 .
2. A. Bogaerts, E. Neyts, R. Gijbels, and J. Van Der Mullen, Spectrochim. Acta Part B Atom. Spectros. **57**, 609 (2002). https://doi.org/10.1016/S0584-8547(01)00406-2.
3. S. Sharma, R. Chalise, S. Basnet, H. P. Lamichhane, and R. Khanal, Phys. Plasmas **31**, 043509 (2024). https://doi.org/10.1063/5.0187159.
4. T. Wang, J. Wang, S. Wang, L. Lv, M. Li, and L. Shi, App. Surf. Sci. **570**, 151258 (2021). https://doi.org/10.1016/j.apsusc.2021.151258.
5. S. Milan and S. Pavel, Plasma Sour. Sci. Tech. **17**, 020201 (2008). https://doi.org/10.1088/0963-0252/17/2/020201.
6. A. Shashurin, M. Keidar, S. Bronnikov, R. A. Jurjus, and M. A. Stepp, Appl. Phys. Lett. **93**, 181501 (2008). https://doi.org/10.1063/1.3020223.
7. J.-W. Lackmann, G. Bruno, H. Jablonowski, F. Kogelheide, B. Offerhaus, J. Held, V. Schulz-Von Der Gathen, K. Stapelmann, T. Von Woedtke, and K. Wende, PLOS ONE **14**, e0216606 (2019). https://doi.org/10.1371/journal.pone.0216606.
8. S. Bekeschus, B. Poschkamp, and J. Van Der Linde, Biomaterials **278**, 120433 (2021). https://doi.org/10.1016/j.biomaterials.2020.120433.
9. S. Yoshimura, Y. Otsubo, A. Yamashita, and K. Ishikawa, Japanese J. Appl. Phys. **60**, 010502 (2021). https://doi.org/10.35848/1347-4065/abcbd2.
10. O. A. Emelyanov, E. G. Feklistov, N. V. Smirnova, K. A. Kolbe, E. V. Zinoviev, M. S. Asadulaev, A. A. Popov, A. S. Shabunin, and K. F. Osmanov, AIP Conf. Proc. **2179**, 020006 (2019). https://doi.org/10.1063/1.5135479.
11. B.-S. Lou, J.-H. Hsieh, C.-M. Chen, C.-W. Hou, H.-Y. Wu, P.-Y. Chou, C.-H. Lai, and J.-W. Lee, Front. Bioeng. Biotech. **8**, 683 (2020). https://doi.org/10.3389/fbioe.2020.00683.
12. S. Darmawati, A. Rohmani, L. H. Nurani, M. E. Prastiyanto, S. S. Dewi, N. Salsabila, E. S. Wahyuningtyas, F. Murdiya, I. M. Sikumbang, R. N. Rohmah, Y. A. Fatimah, A. Widiyanto, T. Ishijima, J. Sugama, T. Nakatani, and N. Nasruddin, Clinic. Plasma Med. **14**, 100085 (2019). https://doi.org/10.1016/j.cpme.2019.100085.
13. Z. Shahbazi Rad and F. Abbasi Davani, Measurement **155**, 107545 (2020). https://doi.org/10.1016/j.measurement.2020.107545.
14. S. Darmawati, N. Nasruddin, P. Kurniasiwi, A. Mukaromah, A. Iswara, G. S. A. Putri, H. Rahayu, E. S. Wahyuningtyas, H. Lutfiyati, and A. Kartikadewi, Plasma Med. **10**, 259 (2020). https://doi.org/10.1615/PlasmaMed.2021037264.
15. K. Lotfy, AIP Advan. **10**, 015303 (2020). https://doi.org/10.1063/1.5099923.
16. P. Thana, C. Kuensaen, P. Poramapijitwat, S. Sarapirom, L. Yu, and D. Boonyawan, Surf. Coat. Tech. **400**, 126229 (2020). https://doi.org/10.1016/j.surfcoat.2020.126229.
17. G. Liu, F. Shi, Q. Wang, Z. Zhang, J. Guo, and J. Zhuang, Microchem. J. **183**, 107973 (2022). https://doi.org/10.1016/j.microc.2022.107973.

18. S. Lata, S. Chakravorty, T. Mitra, P. K. Pradhan, S. Mohanty, P. Patel, E. Jha, P. K. Panda, S. K. Verma, and M. Suar, Mat. Today Bio **13**, 100200 (2022). https://doi.org/10.1016/j.mtbio.2021.100200.
19. H. R. Humud, Q. A. Abbas, and K. F. Abdullah, Der Pharm. Lett. **8**, 229 (2016).
20. H. Whiley, T. P. Keerthirathne, E. J. Kuhn, M. A. Nisar, A. Sibley, P. Speck, and K. E. Ross, Electrochem **3**, 276 (2022). https://doi.org/10.3390/electrochem3020019.
21. R. Zouzelka, J. Olejnicek, P. Ksirova, Z. Hubicka, J. Duchon, I. Martiniakova, B. Muzikova, M. Mergl, M. Kalbac, L. Brabec, M. Kocirik, M. Remzova, E. Vaneckova, and J. Rathousky, Nanomaterials **11**, 3254 (2021). https://doi.org/10.3390/nano11123254 .
22. H. R. Humud, Iraqi J. Phys. **11**, 110 (2019). https://doi.org/10.30723/ijp.v11i20.388.
23. E. Patrakova, M. Biryukov, O. Troitskaya, P. Gugin, E. Milakhina, D. Semenov, J. Poletaeva, E. Ryabchikova, D. Novak, N. Kryachkova, A. Polyakova, M. Zhilnikova, D. Zakrevsky, I. Schweigert, and O. Koval, Cells **12**, 290 (2023). https://doi.org/10.3390/cells12020290.
24. A. Khlyustova, C. Labay, Z. Machala, M.-P. Ginebra, and C. Canal, Front. Chem. Sci. Eng. **13**, 238 (2019). https://doi.org/10.1007/s11705-019-1801-8.
25. H. R. Humud, Iraqi J. Phys. **10**, 53 (2012).
26. H. M. Abdulwahab and H. R. Humud, AIP Conf. Proc. **2977**, 040143 (2023). https://doi.org/10.1063/5.0183707.
27. C. Corbella, S. Portal, and M. Keidar, Plasma **6**, 72 (2023). https://doi.org/10.3390/plasma6010007.

دراسة تأثير نوع الغاز (الأرجون والنيتروجين والهواء) ومعدل تدفق الغاز على طول نفث البلازما ودرجة حرارة الغاز العامل

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الخلاصة

تم تطوير نظام نفث بلازما للدراسة مزود بمصدر طاقة يوفر جهدًا يبلغ 10 كيلوفولت وإجمالي قدرة خرج تبلغ 30 واط. يستخدم النظام ثلاثة أنواع من الغازات: الهواء، والنيتروجين، والأرجون. تم تصميم المشعل البلازمي باستخدام أنبوب فولاذي بأبعاد قطر 1.4 مم وطول 5 سم. ركزت الدراسة على أهمية درجة حرارة الغاز وطول نفث البلازما في التطبيقات المختلفة، حيث تم استكشاف تأثير نوع الغاز ومعدل تدفقه على هذه العوامل. بلغت درجة حرارة الغاز العامل ذروتها عند 3 درجات مئوية فوق درجة حرارة 22 درجة مئوية، مع ملاحظات مماثلة لدرجات الحرارة لجميع الغازات الثلاثة. بالإضافة إلى ذلك، لوحظ أن طول نفث البلازما يتأثر بنوع الغاز المستخدم. تم قياس أطول نفث للبلازما عند 5.6 سم لبلازما الأرجون، و2.6 سم لبلازما النيتروجين، و4.1 سم لبلازما الهواء عند معدل تدفق غاز يبلغ 5 لترات في الدقيقة. كما لوحظ أن طول النفث يزداد بزيادة معدل تدفق الغاز في جميع الغازات. أحد أبرز نتائج هذه الدراسة هو تطوير نظام نفث بلازما متعدد الاستخدامات يعمل بكفاءة مع ثلاثة أنواع من الغازات (الهواء، والنيتروجين، والأرجون) مع الحفاظ على درجات حرارة قريبة من مستويات درجة الحرارة المحيطة. يتميز النظام بقدرته على إنتاج نفث بلازما بأطوال مناسبة لمجموعة متنوعة من التطبيقات الطبية والبيولوجية. يتيح تنوع النظام استخدام الهواء أو النيتروجين أو الأرجون. وبالنظر إلى التكلفة وطول النفاثات، يُعدّ النيتروجين والهواء الخيارين الأمثل. فالهواء أرخص ويُنتج نفاثات أطول ولكنه أقل استقرارًا، بينما يُوفر النيتروجين نفاثات أقصر وأكثر استقرارًا لتطبيقات مُحددة.

الكلمات المفتاحية: البلازما النفاثة، بلازما النيتروجين، التطبيقات البيولوجية، إبرة البلازما، البلازما غير الحرارية.