INTERNATIONAL JOURNAL OF ACADEMIC RESEARCH IN BUSINESS & SOCIAL SCIENCES
Vol 14, Issue 12, (2024) E-ISSN: 2222-6990

# Optimizing Copper Electrode for Efficient Plasma Generation Using Microwave System at Atmospheric Pressure

Fadhli Syahrial[1], Andi Amijoyo Mochtar[2], Fudhail Abdul Munir[3], Nazri Md Daud[1]
[1]Faculty of Mechanical Technology and Engineering, Universiti Teknikal Malaysia Melaka, Malaysia, [2]Department of Mechanical Engineering, Faculty of Engineering, Universitas Hasanuddin, Indonesia, [3]Mechanical Engineering Department, Universiti Teknologi PETRONAS, Malaysia
Corresponding Author Email: fadhlisyahrial@utem.edu.my

**To Link this Article:** http://dx.doi.org/10.6007/IJARBSS/v14-i12/24403 DOI:10.6007/IJARBSS/v14-i12/24403

***Published Date:*** 29 December 2024

## Abstract

This study investigates the thermal distribution on copper electrodes during plasma generation using microwave irradiation at 2.45 GHz at atmospheric pressure. Copper electrodes of varying lengths (3 cm, 6 cm, and 18 cm) were tested to determine the optimal length for stable plasma generation. A conventional microwave oven, operating at 17%, 33%, and 55% power, was used to generate plasma, while a thermal imaging camera captured the temperature distribution across the electrodes. The results indicate that the 6 cm electrode, corresponding to half the microwave wavelength, produced the most efficient and stable plasma, with temperatures reaching 182°C within five minutes at 55% power. In contrast, the 3 cm electrode, representing one-quarter wavelength, failed to generate plasma, showing significantly lower temperature rise. The 18 cm electrode demonstrated intermittent plasma generation and a less stable temperature increase, peaking at 118.4°C. These findings confirmed the critical relationship between electrode length and microwave wavelength for optimal plasma generation. The study also observed corrosion on the 6 cm electrode due to prolonged plasma exposure, suggesting further research on corrosion-resistant materials. This work contributes to the understanding of microwave-induced plasma for applications in material processing and waste treatment.

**Keywords:** Microwave Plasma, Copper Electrode, Temperature Distribution, Plasma Generation, Atmospheric Pressure

## Introduction

Plasma discharge using microwave irradiation represents a significant advancement in the field of plasma physics and materials science, offering numerous applications across industrial, environmental, and medical sectors (Fadhli et al, 2017). Plasma, often referred to as the fourth state of matter, is generated when sufficient energy is supplied to ionize a gas, creating a highly energetic medium composed of ions, electrons, and neutral particles. Microwave irradiation, particularly at the frequency of 2.45 GHz, has become a prominent method for inducing plasma due to its ability to provide efficient, localized energy transfer without the need for high-pressure environments.

Microwave-generated plasmas are particularly advantageous because they can be sustained at atmospheric pressure, enabling a wide range of practical applications, including surface treatment, material synthesis, and chemical decomposition. Compared to traditional methods of plasma generation, microwave-induced plasma offers superior control over temperature distribution and energy efficiency, leading to more precise and scalable processes. The unique interaction between microwave energy and plasma provides an enhanced means of generating reactive species, making it an ideal tool for advanced applications such as waste treatment, nanoparticle synthesis, and even medical sterilization. This method continues to be explored and optimized for its economic viability and versatility in modern technological advancements.

Microwave plasma discharge technology has gained significant attention in recent years due to its versatility and efficiency in various industrial applications. This method of plasma generation offers advantages such as improved energy efficiency, reduced operational costs, and the ability to work at atmospheric pressure without requiring additional catalysts. A key area of focus is the decomposition of methane and $CO_2$ for hydrogen production, where microwave plasma enhances the catalytic process by facilitating higher decomposition rates (Choi, Song, & Park, 2020; Yin, Tang, & Yang, 2020). In hydrogen storage, Li et al. (2020) demonstrated that microwave plasma treatment can enhance the performance of carbon nanotubes, offering an efficient means of improving storage capacities.

Another critical area is the application of microwave plasma for surface treatment and materials enhancement. Wu et al. (2019) and Lu et al. (2019) explored how microwave plasma improves surface properties and performance of polyimide films and carbon-based nanomaterials, respectively. Similarly, Gupta and Sharma (2021) reviewed the enhancement of polymer surfaces through microwave plasma, noting improved surface roughness and chemical modification capabilities. The treatment of waste and pollutants has also benefited from microwave plasma systems, as demonstrated by Tan, Wang, and Zhao (2019) and Baskar and Sivasankar (2021), who emphasized its effectiveness in wastewater treatment and advanced oxidation processes.

Microwave plasma is further utilized in nanomaterials synthesis and VOC decomposition, with Sharma and Gupta (2021) and Liu et al. (2022) showing how plasma-assisted techniques lead to more efficient synthesis and decomposition processes. In the realm of sterilization, Martínez, Rodríguez, and Santana (2023) discussed the potential of reactive species generated by microwave plasma for sterilizing medical devices. The automotive and chemical industries are also exploring the use of microwave plasma in plastic pyrolysis and chemical production, as noted by Park, Kim, and Lee (2022).

Overall, the widespread applicability and efficiency of microwave plasma technology are clear. Its capability to generate high-energy reactions in a controlled environment offers significant potential for advancements across various fields (Zhou, Zhang, & Cheng, 2020; Zeng, Wang, & Zhang, 2024).

In this project, the focus was on identifying the temperature distribution on copper electrodes after plasma generation using a conventional microwave oven. By applying microwave radiation at 2.45 GHz, plasma was generated at atmospheric pressure, and the thermal effects on the copper electrode were observed. Different electrode lengths and power levels were tested to determine the optimal conditions for plasma formation and the resulting heat distribution. The aims of this study were to contribute to the understanding of how electrode configuration influences the efficiency of microwave-induced plasma and its applications in various fields, including materials processing and waste treatment.

## Methodology

The schematic diagram for plasma generation using microwave oven was shown in Figure 1. To successfully identifying the temperature distribution on copper electrodes post-plasma generation using a microwave oven, a systematic and highly precise methodology is essential. The first step is to prepare copper electrodes of varying lengths (e.g., 3 cm, 6 cm, and 18 cm), as the length and geometry of the electrodes have been shown to influence plasma generation and heat distribution (Wu, Zhang, Chen, & Fan, 2019; Zeng, Wang, & Zhang, 2024). These electrodes should be shaped to optimize plasma formation, with bullet-shaped tips concentrating heat, enhancing plasma generation (Martínez, Rodríguez, & Santana, 2023).

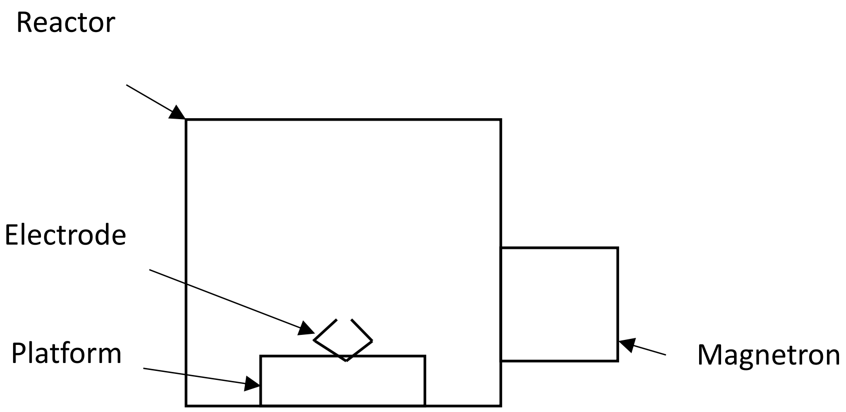


Figure 1: Schematic diagram of experimental setup

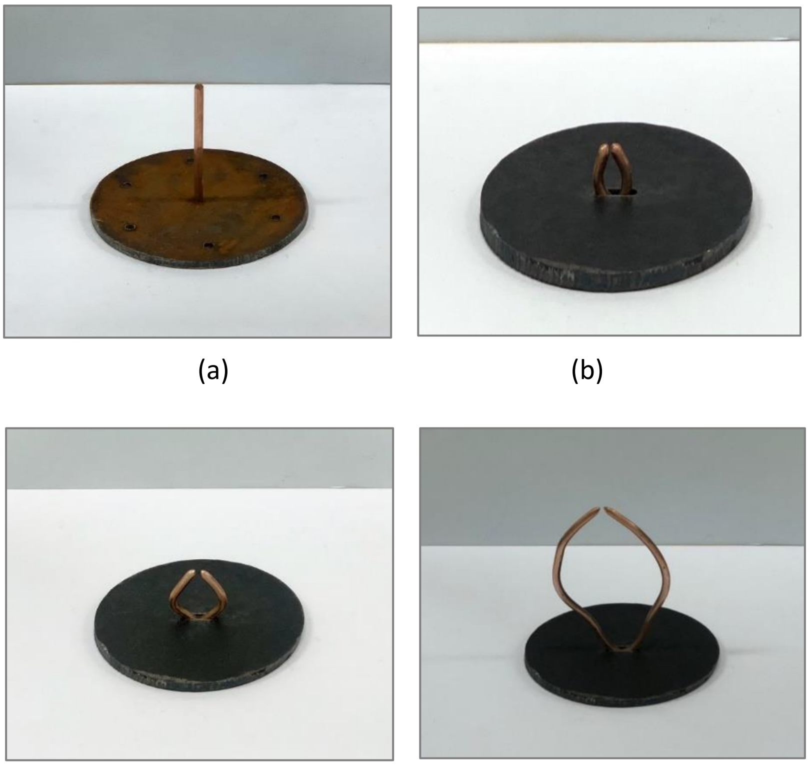
The microwave oven, operating at 2.45 GHz, should have adjustable power settings (e.g., 17%, 33%, 55%), similar to the methodology used in previous studies (Liu, Zeng, Gao, & Yang, 2022; Park, Kim, & Lee, 2022). These variations allow the analysis of how power levels affect plasma formation and temperature distribution. To capture the temperature distribution in real time, a thermal imaging camera (such as the FLIR camera) is essential, as it provides detailed temperature data and heat contouring (Tan, Wang, & Zhao, 2019). This approach will allow for a precise qualitative and quantitative analysis of heat behavior.

The data collection should consist of multiple trials for each configuration to ensure accuracy, as conducted in other research (Bae, Lee, & Kim, 2019; Baskar & Sivasankar, 2021). Record temperature data at intervals (e.g., every minute up to 5 minutes) after plasma generation, noting the thermal effects and plasma stability (Li, Peng, Liu, Wang, & Yu, 2020; Lu, Chen, & Lin, 2019). Software like FLIR Tools will help in analyzing the temperature distribution patterns across the electrode surface, providing insight into the optimal conditions for plasma formation.

This comprehensive methodology, supported by existing literature, will yield robust insights into the thermal effects of microwave-induced plasma on copper electrodes, contributing to advancements in material processing and waste treatment technologies (Wu et al., 2019; Zeng et al., 2024).

## Results and Discussion

A detailed examination of copper electrode configurations and their role in plasma generation using microwave irradiation at 2.45 GHz was observed. Two configurations of electrodes which were a straight electrode and a ring-shaped electrode were examined. The result showed that a ring-shaped electrode proving more effective at generating plasma. The experiment further explored three different electrode lengths (3 cm, 6 cm, and 18 cm), selected based on their relationship to the microwave wavelength.



(a) (b)

(c) (d)

Figure 2: Straight electrode at (a) 6.0 cm and ring-shaped copper electrode at (b) 3.0 cm, (c) 6.0 cm and (d) 18.0 cm

The analysis of the temperature distribution shows that the 6 cm electrode, representing half of the microwave wavelength successfully generated plasma as shown in Figure 3. At this length, plasma was produced in the most stable and efficient. The temperature of the electrode during post plasma generation was higher and consistently increases across all power levels. This can be attributed to the resonance of the microwave wavelength with the electrode length, optimizing energy transfer.

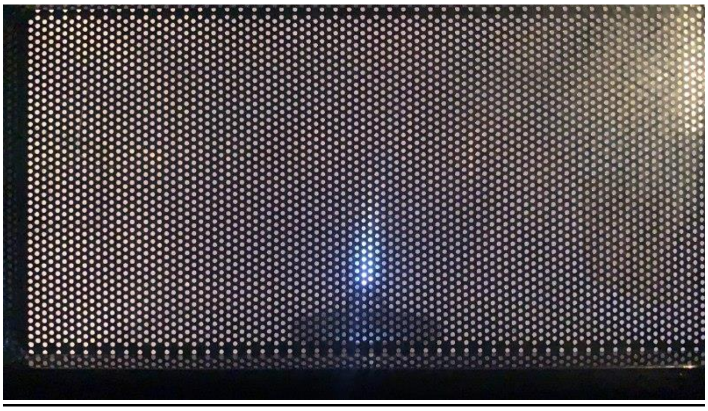


Figure 3: Plasma generation at 6.0 cm length copper electrode

As shown in Figure 4, at 55% power, the 6 cm electrode reached a maximum temperature of 182°C after 5 minutes, a clear indicator of stable plasma generation. In contrast, the 3 cm electrode where it failed to generate plasma at any power level and exhibited the lowest temperature rise, peaking at 103°C at 55% power level. The 18 cm electrode, while capable of generating plasma, showed less thermal stability, reaching only 118°C at the same power level.

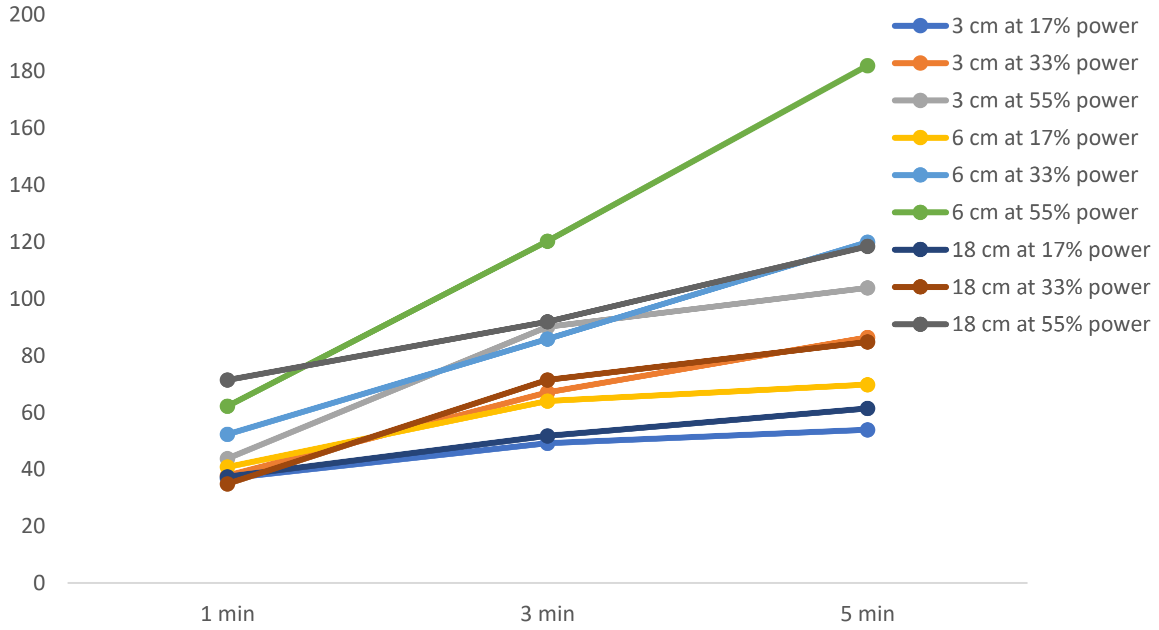


Figure 4: Temperature distribution of copper electrode during plasma generation

These results suggest that electrode length is critical for plasma stability and efficiency. The 6.0 cm electrode appears to be the optimal configuration, aligning with theoretical predictions regarding energy resonance and plasma formation.

Corrosion was observed predominantly on the 6 cm electrode, indicating that prolonged plasma generation can lead to surface degradation, especially at higher temperature. This highlight the need for further research into corrosion-resistant electrode materials to improve the longevity of the system.

## Conclusion

In In conclusion, this study successfully demonstrated that the length of copper electrodes plays a critical role in plasma generation and temperature distribution when using microwave irradiation at 2.45 GHz. The experiments confirmed that the 6 cm electrode, corresponding to half the wavelength of the microwave, produced the most stable and efficient plasma generation, as evidenced by the highest and most consistent temperature increase across all power levels. The temperature at the 6 cm electrode rose significantly, reaching 182°C within five minutes at 55% power, making it the ideal configuration for plasma generation.

In contrast, the 3 cm electrode, which represents one-quarter of the wavelength, failed to generate plasma and showed the lowest temperature rise, indicating its inefficiency in the plasma process. The 18 cm electrode, although capable of generating plasma, demonstrated less stability and a lower overall temperature rise, making it less optimal compared to the 6 cm electrode.

The study also highlighted the impact of plasma on electrode surface degradation, with the 6 cm electrode showing signs of corrosion due to consistent plasma exposure. These findings suggest that, for applications requiring stable plasma generation, a 6 cm electrode offers the best performance, while further research into corrosion-resistant materials is recommended to improve electrode longevity.

## References

Bae, K., Lee, J., & Kim, D. (2019). Study on the characteristics of microwave plasma discharges in air. *Journal of Applied Physics*, *126*(3), 033305. https://doi.org/10.1063/1.5097113

Baskar, G., & Sivasankar, T. (2021). Microwave-assisted plasma discharge for the treatment of industrial wastewater: A review. *Environmental Science and Pollution Research*, *28*(10), 11781–11794. https://doi.org/10.1007/s11356-020-12295-9

Choi, H., Song, Y., & Park, J. (2020). Microwave plasma-enhanced catalytic decomposition of methane for hydrogen production. *Journal of Industrial and Engineering Chemistry*, *89*, 224–230. https://doi.org/10.1016/j.jiec.2020.06.036

Fadhli, S., Kasuki, T., Shinfuku, N., Shinobu, M., Hiromichi, T. (2017) Investigation on the Effects of Ultrasonic Irradiation and Sodium Hydroxide on Decomposition of Cellulose Using RF Plasma in Liquid for Hydrogen Production at Atmospheric Pressure. *Journal of the Japan Institute of Energy*, 96, 451-455. https://doi.org/10.3775/jie.96.451

Gupta, A. K., & Sharma, P. (2021). Enhancement of surface properties of polymers using microwave plasma: A review. *Plasma Chemistry and Plasma Processing*, *41*(4), 1273–1303. https://doi.org/10.1007/s11090-021-10198-w

Hakimi, H., Kamalrudin, M., & Abdullah, R. S. (2023). Software Security Readiness Model For Remote Working In Malaysian Public Sectors: Conceptual Framework. Journal Of Theoretical And Applied Information Technology, 101(8).

Li, X., Peng, Z., Liu, G., Wang, T., & Yu, J. (2020). Microwave plasma treatment of carbon nanotubes for improved hydrogen storage performance. *International Journal of Hydrogen Energy*, *45*(3), 1853–1863. https://doi.org/10.1016/j.ijhydene.2019.10.234

Liu, J., Zeng, J., Gao, X., & Yang, C. (2022). Decomposition of volatile organic compounds using microwave-induced plasma discharge: A comparative study. *Journal of Environmental Chemical Engineering*, *10*(1), 106824. https://doi.org/10.1016/j.jece.2021.106824

Lu, H., Chen, J., & Lin, C. (2019). Effects of microwave plasma on carbon-based nanomaterials for enhanced supercapacitor performance. *Materials Letters*, *256*, 126671. https://doi.org/10.1016/j.matlet.2019.126671

Martínez, A., Rodríguez, R., & Santana, D. (2023). Generation of reactive species in a microwave plasma discharge for sterilization purposes. *Plasma Science and Technology*, *25*(3), 035402. https://doi.org/10.1088/2058-6272/aca623

Park, S., Kim, H., & Lee, K. (2022). Microwave plasma-assisted pyrolysis of plastics for hydrogen and valuable chemicals production. *Fuel Processing Technology*, *225*, 107044. https://doi.org/10.1016/j.fuproc.2022.107044

Sharma, V., & Gupta, R. (2021). Microwave plasma-assisted synthesis of nanomaterials: A review. *Journal of Materials Science: Materials in Electronics*, *32*(5), 5839–5860. https://doi.org/10.1007/s10854-021-05529-1

Tan, W., Wang, J., & Zhao, X. (2019). Development of microwave plasma system for advanced oxidation of pollutants in water. *Plasma Processes and Polymers*, *16*(5), 1800142. https://doi.org/10.1002/ppap.201800142

Veenoth, A., Shankarvelu, L., Hakimi, H., Marlia, Z., & Octaviani, D. (2023). Food Donation Application to Improve the Distribution and Verification Process Within Selangor: Feedback. Journal of Applied Technology and Innovation (e-ISSN: 2600-7304), 7(3), 7.

Wu, Y., Zhang, X., Chen, H., & Fan, J. (2019). Atmospheric pressure microwave plasma treatment for enhancing surface properties of polyimide films. *Plasma Chemistry and Plasma Processing*, *39*(6), 1475–1490. https://doi.org/10.1007/s11090-019-10017-6

Yin, Y., Tang, Z., & Yang, L. (2020). Plasma-assisted decomposition of CO2 using microwave discharge under atmospheric pressure. *Chemical Engineering Journal*, *395*, 125050. https://doi.org/10.1016/j.cej.2020.125050

Zeng, H., Wang, J., & Zhang, X. (2024). Atmospheric microwave plasma generation for sustainable energy applications. *Journal of Energy Chemistry*, *80*, 103493. https://doi.org/10.1016/j.jechem.2023.103493

Zhou, Y., Zhang, W., & Cheng, X. (2020). Microwave-induced plasma discharge for the synthesis of graphene nanocomposites. *Journal of Materials Research*, *35*(6), 864–874. https://doi.org/10.1557/jmr.2020.84