

DEVELOPMENT OF DIELECTRIC BARRIER DISCHARGE PLASMA FOR SMOKE TRAPPING FROM ELECTROSURGICAL UNITS

Choopol Phromsuthirak¹ and Prajya Tangjitsomboon^{2,*}

Received: January 10, 2025; Revised: February 16, 2025; Accepted: February 24, 2025

Abstract

Surgical smoke, a byproduct of electrosurgical procedures, contains harmful particulate matter (PM) and volatile compounds, posing health risks to medical personnel. This study explores a dielectric barrier discharge (DBD) plasma system to trap PM from surgical smoke, emphasizing the effects of varying inner and outer electrode configurations. Using an acrylic tube, copper electrodes, and high-voltage alternating current, the system generated plasma by ionizing air between electrodes. The system's effectiveness was tested by measuring PM levels at varying voltages (9-13 kV) using an aerosol monitor while cutting tissue with an electrosurgical unit. Results demonstrated that higher voltages enhanced PM trapping efficiency due to increased plasma interaction and electric forces acting on PM particles. The 18 mm copper inner electrode and a copper plate outer electrode achieved the highest efficiency, attributed to its more substantial and uniform electric field. In contrast, other electrode configurations showed reduced PM trapping efficiency due to inconsistent plasma formation. Findings highlight the potential of DBD plasma systems in improving surgical smoke evacuation, paving the way for integration with commercial systems to safeguard operating room personnel.

Keywords: Dielectric barrier discharge; Electrosurgical unit; Particulate matter; Plasma; Surgical smoke; Trapping smoke

¹ Department of Health Technology, Faculty of Science and Health Technology, Navamindradhiraj University, Bangkok 10300, Thailand. E-mail: choopol@nmu.ac.th

² Department of General Education, Faculty of Science and Health Technology, Navamindradhiraj University, Bangkok 10300, Thailand. E-mail: prajya.t@nmu.ac.th

* Corresponding author

DOI: <https://doi.org/10.55766/sujst8215>

Introduction

Surgical smoke is a gaseous byproduct generated during procedures that utilize electrosurgery, laser ablation, and other energy-based devices. It consists of approximately 95% water vapor and 5% hazardous substances, including particulate matter (PM), volatile organic compounds (VOCs), and viable pathogens (Zhou *et al.*, 2023; Kahramansoy, 2024). Despite its seemingly small proportion, this 5% contains toxic compounds that pose significant health risks to surgical personnel and patients. However, many healthcare facilities still lack adequate smoke evacuation systems, leading to prolonged exposure to these harmful contaminants (Zhou *et al.*, 2023; Kaya and Yıldız, 2024).

One of the most concerning components of surgical smoke is PM, particularly PM_{2.5}, which can penetrate deep into the respiratory system, causing inflammation, respiratory diseases, and even cancer (Dixon *et al.*, 2023; Zhou *et al.*, 2023). In addition to its health risks, the accumulation of smoke during surgery can obscure the visual field, reducing surgical precision and increasing procedural risks (Merajikhah *et al.*, 2022; Soysal *et al.*, 2023; Chou *et al.*, 2024). These combined threats highlight the critical need for effective surgical smoke management systems.

Electrosurgical units (ESUs) are widely used in modern surgery because they provide precise cutting, coagulation, and hemostasis (El-Sayed and Saridogan, 2020; Jena *et al.*, 2023; Kattoor and Iyer, 2024). However, their operation generates large amounts of surgical smoke, affecting air quality and increasing inhalation risks, especially in operating rooms with inadequate ventilation (Swerdlow, 2020; Esenkaya and İyigün, 2024; Yu, 2024). Surgical personnel are frequently exposed to these airborne contaminants, making smoke evacuation systems essential in mitigating health risks.

Portable smoke evacuation systems have been introduced to address this issue. These systems typically employ a multi-layered filtration process consisting of pre-filters, activated carbon filters, and ultra-low penetration air (ULPA) filters to capture PM, toxic gases, and odors, thereby improving air quality in operating rooms (Dennis, 2022; Gioutsos *et al.*, 2022; Kocher *et al.*, 2022). While these systems are effective, they face several limitations, including filter maintenance challenges, noise disruption during surgery, and high costs, which hinder their widespread adoption (Alqadi and Saxena, 2020; Wong *et al.*, 2020). Moreover, relying on ULPA filters to capture OK PM burdens

the system's efficiency, requiring frequent replacements to maintain optimal performance.

To overcome these challenges, researchers have been exploring alternative methods for surgical smoke management. One promising approach involves nanofiber filters, widely used for PM filtration. However, their efficiency varies depending on particle size, and they may not effectively trap smaller PM_{2.5} particles (Liu *et al.*, 2020; Ma *et al.*, 2023). In contrast, electrical discharge systems, such as electrostatic precipitators (ESP), offer a non-mechanical filtration method that captures airborne particles through electrostatic attraction, providing a more efficient and durable alternative (Xu *et al.*, 2016; Tian *et al.*, 2023).

Dielectric barrier discharge (DBD) plasma systems are a promising technology. DBD technology generates plasma through electrical discharge, effectively trapping PM, including PM_{2.5}. Unlike conventional filtration systems, which rely on physical barriers, DBD systems use ionized gas to charge and capture airborne particles, reducing filter clogging and extending operational lifespan. Studies have demonstrated that DBD systems can achieve up to 53% trapping efficiency, making them a viable alternative for surgical smoke management (Huang *et al.*, 2016; Tangjitsomboon *et al.*, 2021).

DBD systems offer several advantages over traditional smoke evacuation methods. They require lower maintenance, operate efficiently at atmospheric pressure, and can be integrated into portable smoke evacuation systems without significant modifications. Additionally, their non-invasive nature aligns with the strict safety requirements of surgical environments, making them a suitable option for real-world applications. However, optimizing DBD technology for surgical smoke management requires further research, particularly in refining electrode configurations to enhance trapping efficiency.

This research aims to develop an atmospheric pressure DBD plasma system for trapping smoke generated during electrosurgical procedures. By investigating various configurations of inner and outer electrodes, the study seeks to optimize the smoke-trapping efficiency of DBD systems. The findings from this research are expected to enhance the performance of commercial portable smoke evacuation systems by improving their ability to capture delicate PM and other harmful components of surgical smoke. These improvements could significantly enhance surgical

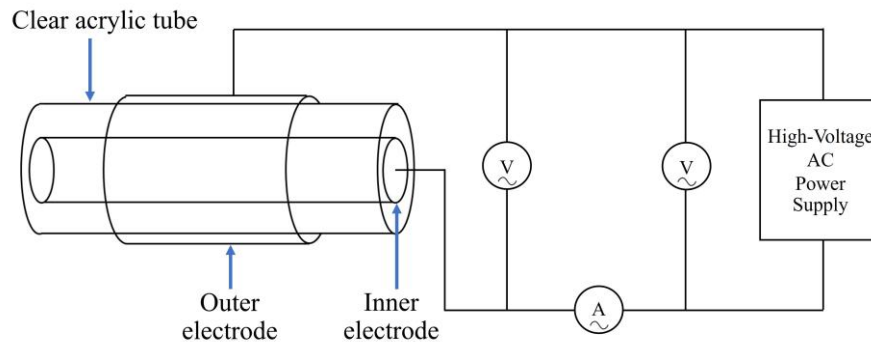


Figure 1. The electrical circuit of the DBD system

efficiency and safeguard the health of operating room personnel.

Materials and Methods

This study's DBD system traps smoke particles generated from the electrosurgical unit. This system consisted of: 1. A clear acrylic tube, 120 mm long, 25 mm outer diameter, 2 mm thick, of dielectric material that distributes an electric charge on the material's surface, creating a uniform plasma between the electrodes. 2. Inner electrodes (IE) and outer electrodes (OE) with different characteristics to assist with studying the effect of trapping smoke particles. The inner electrodes were copper tubes, 160 mm long, two sizes, the first having an outer diameter of 18 mm and a thickness of 1 mm, and the second having an outer diameter of 10 mm and a thickness of 0.5 mm. Two types of outer electrodes were used: a copper plate (CP) outer electrode, 750 mm long, with a thickness of 0.3 mm, wrapped around a clear acrylic tube once, and a copper tube coil (CTC), 750 mm long made of copper wire with a cross-sectional area of 4 mm², coiled into a spiral with a spacing between the spirals of 5 mm.

The inner and outer electrodes were connected to a high-voltage AC power supply with a frequency of 50 Hz, which can be adjusted for voltage. The electrical circuit of the DBD system used in this research is shown in Figure 1. Clear acrylic tubes and various types of inner and outer electrodes are shown in Figure 2.

The high voltage applied in the DBD system affects the trapping of PM from the smoke generated by the electrosurgical unit. The voltage accelerates the free electrons on the surface of the dielectric material to collide with the air molecules between the inner and outer electrodes, causing the air to break into plasma, as shown in Figure 3.

The charged particles in the plasma, namely electrons and ions, interact with the PM particles, resulting in changes in the electrical properties of the PM. The electric field between the electrodes then acts upon the PM, causing the PM to be trapped on the surface of the inner electrode and the dielectric material surface.

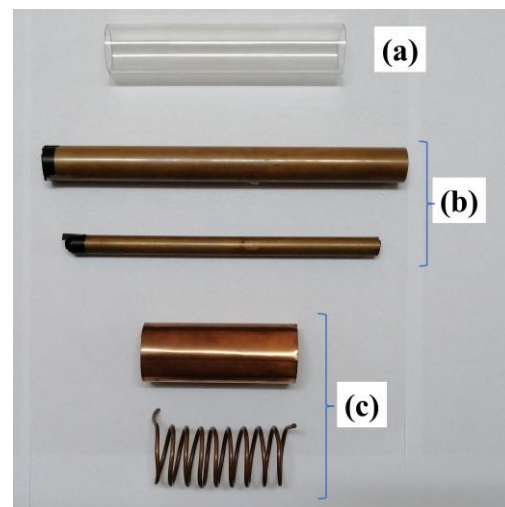


Figure 2. Clear acrylic tube and various types of inner and outer electrodes consisting of (a) a clear acrylic tube (120 mm length, 25 mm outer diameter, 2 mm thickness), (b) inner electrode (IE): 18 mm and 10 mm copper tubes (160 mm length, 1 mm and 0.5 mm thickness, respectively), and (c) outer electrode (OE): copper plate (CP) (750 mm length, 0.3 mm thickness) and copper tube coil (CTC) (750 mm length, 4 mm² cross-sectional area, 5 mm coil spacing). The electrodes were connected to a high-voltage AC power supply (9, 11, and 13 kV) to generate plasma for PM trapping

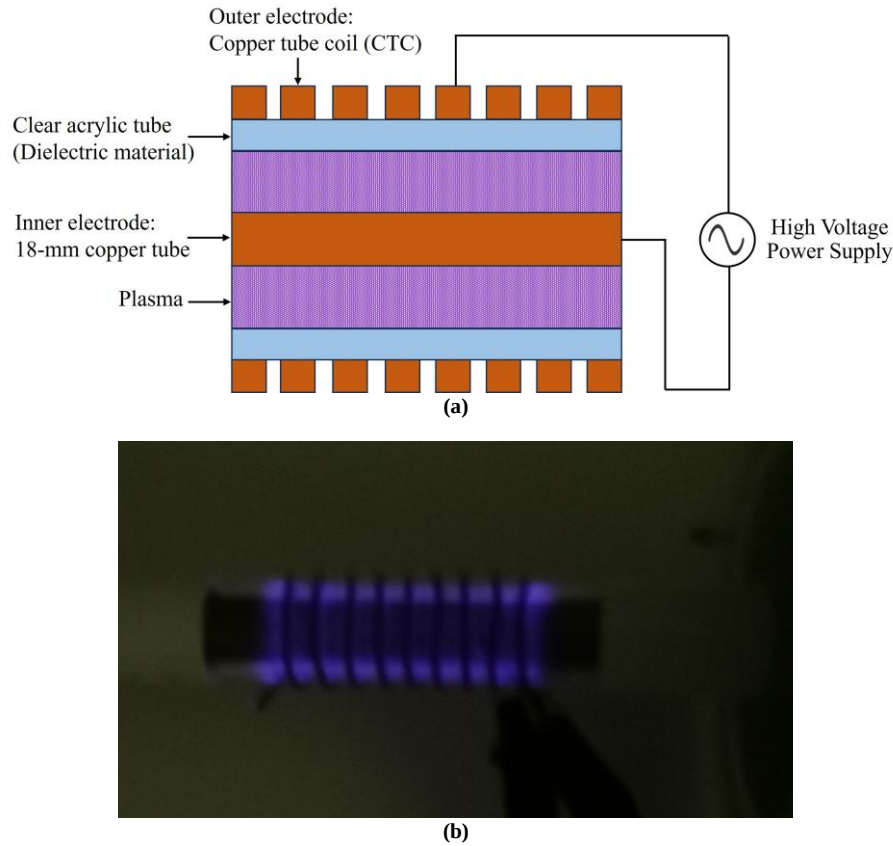


Figure 3. (a) Schematic representation of plasma generation in the DBD system. A high-voltage AC power supply (9, 11, and 13 kV) ionizes the air between the inner and outer electrodes, forming plasma, and (b) Plasma generated by the DBD system

Valleylab Force FX Electrosurgical Unit generated smoke by cutting a pork sample. The smoke was drawn out by an exhaust fan with a 220 m³/h flow rate. The exhaust fan was connected to a DBD system connected to an evacuation tubing 3 m long and 25 mm in diameter, which is the size used in a commercial portable smoke evacuation system. The smoke drawn by the exhaust fan was measured for the amount of PM using DustTrak™ DRX Aerosol Monitor 8533, which can measure PM up to 150 mg/m³. The DustTrak™ DRX Aerosol Monitor 8533 measured PM levels every second (log interval), providing the highest resolution possible with this device. The PM amount was measured from the aerosol monitor. The system setup and equipment used in this research are shown in Figure 4. The system was simulated to be close to the surgical smoke trapping from the electrosurgical unit in the operating room.

In the experiment of surgical smoke trapping from an electrosurgical unit using a developed atmospheric pressure DBD plasma system, the independent variables included the potential

difference between the inner and outer electrodes, starting at 9 kV, which is the minimum potential that causes plasma that is observable by the naked eye, and increasing the electric potential between the electrodes by 2 kV each time until the maximum potential of the experiment was 13 kV, which is the maximum operational potential of the machine. This research determined the controlled variables: 1. The time of cutting the tissue was 15 sec. The 15-sec tissue cutting duration exceeded the actual surgical cutting time by 15 sec, ensuring that the experiment covered the actual surgical cutting duration. 2. The size and type of tissue used in cutting. 3. The electric power of the electrosurgical unit was 40 watts, which is the commonly used electric power for surgery (Abu-Rafea *et al.*, 2011; Ata *et al.*, 2022), and 4. The operation mode of the electrosurgical unit, which was selected as the cutting mode, appropriately responded to the research objective of measuring the amount of smoke particles generated from tissue cutting (Casey *et al.*, 2021). Each experimental condition was conducted in

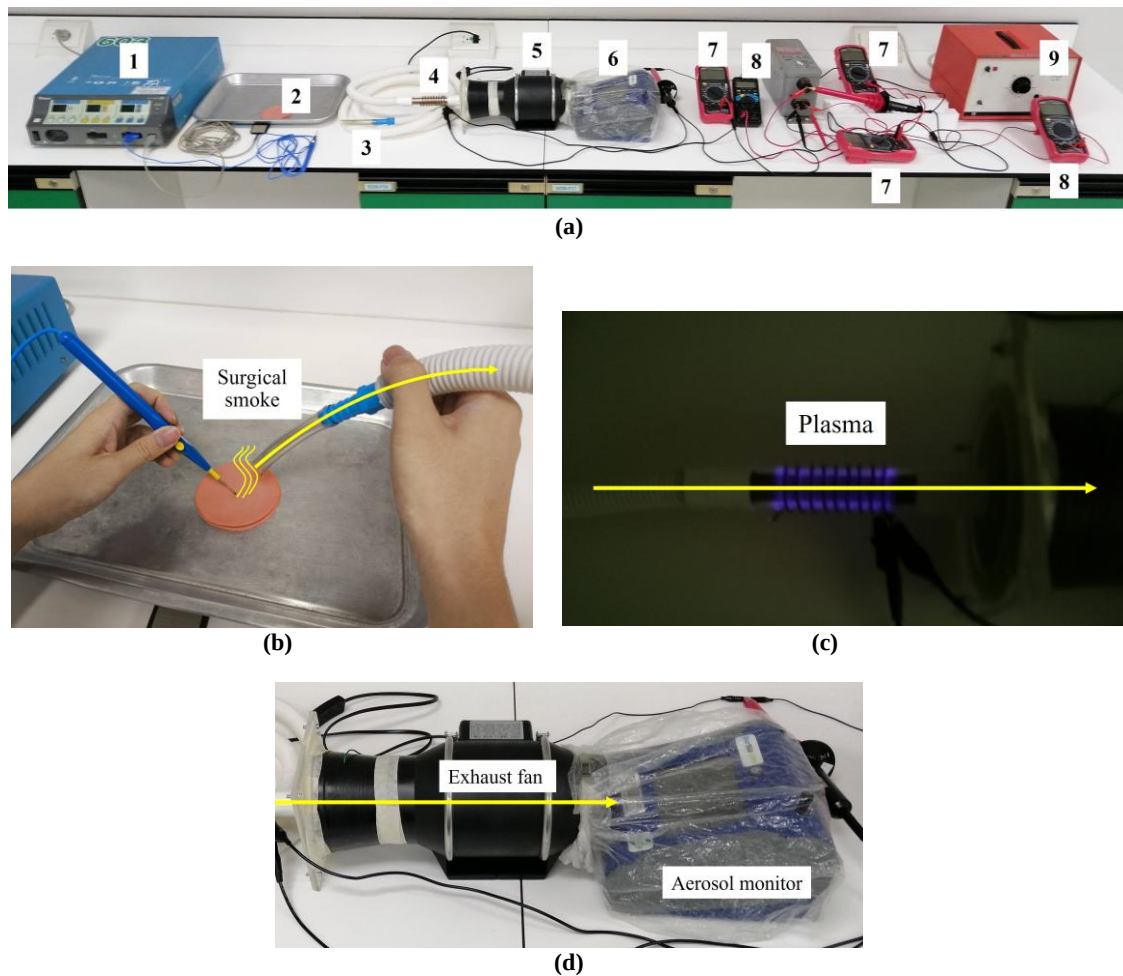


Figure 4. (a) System setup and equipment for trapping smoke from an electrosurgical unit: 1. Electrosurgical unit 2. Pork sample 3. Evacuation tubing 4. Clear acrylic tube with inner and outer electrodes 5. Exhaust fan 6. Aerosol monitor 7. Voltmeter 8. Ammeter, and 9. High-voltage AC power supply.
 (b) Surgical smoke generation during tissue cutting.
 (c) Plasma formation in the DBD system for PM trapping.
 (d) The exhaust fan releases filtered air while the PM concentration is measured by the aerosol monitor

a laboratory environment. The dependent variables of the experiment consisted of: 1. The electric potential drop across the DBD system. 2. The electric current of the DBD system. 3. The PM amount was measured from the aerosol monitor. All the experimental results are shown in the next section. Each experimental condition underwent testing four times to ensure the reliability and consistency of the results.

Results and Discussion

The first step of this research was to study the relationship between the voltage across

electrodes, the operating voltage, and the current flowing through the DBD system of different types of electrodes; the result is shown in the graph in Figure 5. As a result, the electric current in the circuit began to occur when the operating voltage was between 2 kV and 3 kV, and the current increased steadily with the increasing operating voltage. The x-intercept of each type of electrode is approximately 3 kV at this point. A DBD system using argon gas at atmospheric pressure was found to produce a plasma filament formed from the ionization of argon gas at a breakdown voltage of 2.5 kV (Suyadi and Suseno, 2017). This breakdown voltage is close to this x-intercept point. This point may be a breakdown voltage of this system research

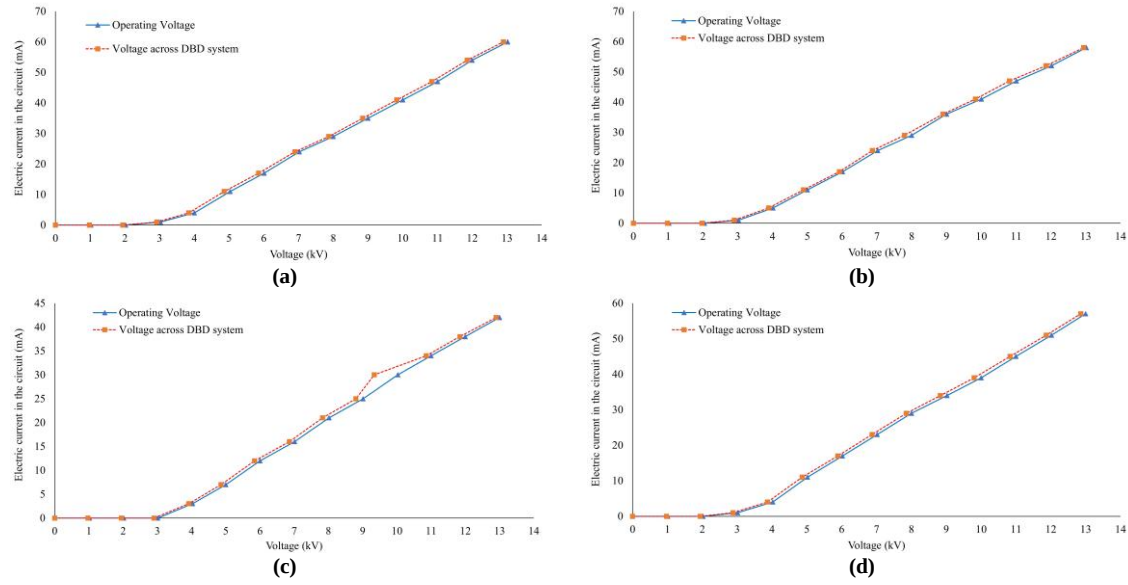


Figure 5. The operating voltage and the current flowing through the DBD system of different types of electrodes: (a) 18 mm-IE, CP (OE); (b) 18 mm-IE, CTC (OE); (c) 10 mm-IE, CP (OE); (d) 10 mm-IE, CTC (OE)

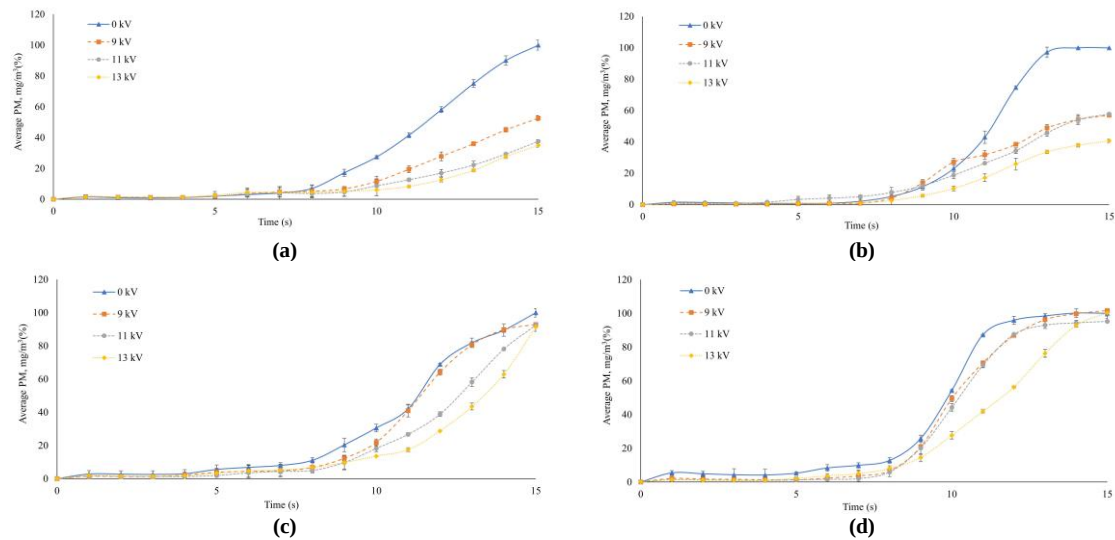


Figure 6. The relationship between plasma induction potentials at 9 kV, 11 kV, and 13 kV and the average PM percentage measured by the aerosol monitor from 0 s to 15 s for each inner and outer electrode type: (a) 18 mm-IE, CP (OE); (b) 18 mm-IE, CTC (OE); (c) 10 mm-IE, CP (OE); (d) 10 mm-IE, CTC (OE)

that causes the air ions to start breaking into plasma. However, this study selected an operating voltage of 9 kV, the lowest potential at which the researchers can observe plasma. When comparing the electric potential across the electrodes with the operating voltage, it was found that the operating voltage is greater than the potential across the electrodes, which is one of the causes of this loss of energy to the resistance in the circuit.

Next, the relationship between operating voltage and the average PM amount of smoke flowing through each type of electrode measured by the aerosol monitor was considered. The smoke was generated by cutting the tissue sample with an electrosurgical unit for 15 sec. However, the aerosol monitor has a limitation that can measure the average PM amount up to 150 mg/m^3 . Therefore, this experiment only measured the PM amount up to

the highest average PM value of 150 mg/m^3 . The experiment found that the size of the electric potential affected the aerosol monitor's measurement of the average PM amount. The percentage of average PM amount decreased due to increased electric potential. The 18 mm copper tube inner electrode had a higher percentage of average PM amount than the 10 mm copper tube inner electrode. The copper plate outer electrode had a higher percentage of average PM than the copper tube coil outer electrode. It was found that the 18 mm copper tube (inner electrode) and copper plate (outer electrode) were the inner and outer electrodes with the highest percentage of average PM amount reduction. This is shown in the graph in Figure 6.

The electric potential increases, causing the electric force and the amount of air that breaks into plasma to increase (Suyadi and Suseno, 2017; Tangjitsomboon *et al.*, 2021), which results in the PM particles having more electrical properties. The PM particles are, therefore, subjected to more electrical force, causing the average PM percentage measured to decrease.

When comparing the average PM percentage measured using inner electrodes of different sizes, it was found that the 18 mm copper tube inner electrode has a smaller gap between the inner electrode and the clear acrylic tube than the 10 mm copper tube inner electrode, resulting in a larger electric field size but a lower air flow rate, resulting in a lower average PM percentage measured.

In addition, it was found that the average PM percentage measured from the plate-type outer electrode was lower than the spiral type, which is because the plate-type outer electrode provides a more uniform electric field compared to the spiral type, which provides an inconsistent electric field between the inner electrode and the spiral, resulting in an inconsistent electric field, resulting in an inconsistent plasma formation. Therefore, some PM particles do not change their electrical properties due to the inconsistent interaction between the PM particles and the plasma. The inconsistent electric field results in an inconsistent electric force, which is one of the reasons why the average PM content percentage measured in the plate-type outer electrode case was lower than that in the spiral type, as shown in Figure 7 and Table 1.

However, from the experimental results, it was found that the mass of smoke generated from cutting attached to the surface of the inner electrode and clear acrylic tube of the big copper tube was less than that of the small copper tube because the 18 mm inner electrode had a smaller gap between the inner electrode and the clear acrylic tube than the 10 mm inner electrode, resulting in a lower air flow rate.

As a result, the mass of smoke generated from cutting attached to the inner electrode's surface and the big copper tube's clear acrylic tube was less, as shown in Figure 8 and Table 2.

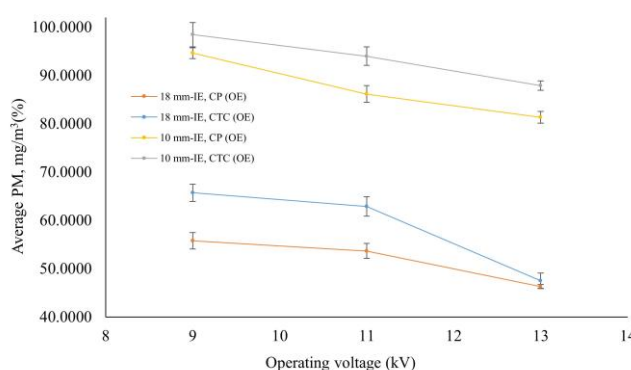


Figure 7. The relationship of average PM percentage at operating voltages (9 kV, 11 kV, and 13 kV) obtained using each electrode type

Table 1. Average PM percentage at operating voltages (9 kV, 11 kV, and 13 kV) for each electrode type

Inner and Outer electrodes	Average PM percentage (%)			
	0 kV	9 kV	11 kV	13 kV
18 mm-IE, CP (OE)	100.00	55.78	53.66	46.32
18 mm-IE, CTC (OE)	100.00	65.70	62.87	47.49
10 mm-IE, CP (OE)	100.00	94.60	86.13	81.33
10 mm-IE, CTC (OE)	100.00	98.43	93.98	87.89

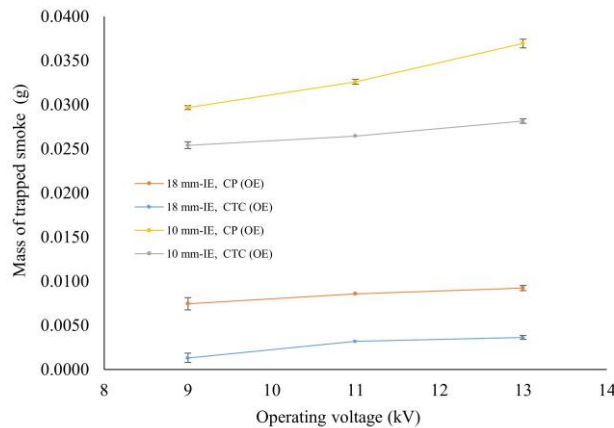


Figure 8. The relationship between the mass of trapped smoke on various inner electrodes and clear acrylic tubes at operating voltages (9 kV, 11 kV, and 13 kV)

Table 2. Mass of trapped smoke on various inner electrodes and clear acrylic tube at operating voltages (9 kV, 11 kV, and 13 kV)

Operating voltage (kV)	Mass of trapped smoke on the inner electrode and clear acrylic tube (g)			
	18 mm-IE, CP (OE)	18 mm-IE, CTC (OE)	10 mm-IE, CP (OE)	10 mm-IE, CTC (OE)
0	0.0056	0.0006	0.0281	0.0233
9	0.0075	0.0013	0.0297	0.0254
11	0.0086	0.0032	0.0326	0.0265
13	0.0092	0.0036	0.0369	0.0282

From the experimental results, the performance of the DBD system in capturing PM depends on the electrode design and the generated electric field. However, aside from its efficiency in reducing PM, other factors, such as cost and energy consumption, must also be considered.

The DBD system demonstrates promising results in trapping surgical smoke. However, it is important to address concerns regarding its cost and energy consumption compared to alternative methods like nanofiber filters. Nanofiber filters are generally considered a lower-cost option upfront. Most studies have focused on improving the performance of traditional filtration systems through advancements in material composition, structural design, and fabrication techniques to enhance filtration efficiency while minimizing airflow resistance (Liu *et al.*, 2020; Ma *et al.*, 2023).

Despite their effectiveness, these systems still suffer from filter clogging and require regular maintenance. Their efficiency can degrade rapidly with use, requiring frequent replacements. This issue leads to increased long-term costs and waste generation.

DBD systems, on the other hand, have higher initial costs due to the power supply and electrode configuration. However, they offer the potential for

a longer operational lifespan and reduced filter replacement costs. Regarding energy consumption, DBD systems require significant energy to generate and sustain the plasma. Optimization of the electrode design and power supply is crucial to minimize energy consumption and improve the overall efficiency of the system.

Beyond cost and energy considerations, comparisons with other existing technologies highlight the strengths of the DBD system. Several studies have explored different approaches to surgical smoke management. ESP has been investigated for its ability to remove PM from the air (Xu *et al.*, 2016; Tian *et al.*, 2023). They offer greater versatility and higher efficiency in trapping various particulate sizes. However, ESP systems can be bulky and require high voltage, posing safety concerns in the operating room environment.

Our DBD plasma system offers a unique approach to surgical smoke management by utilizing ionized gas to charge and capture airborne particles. Compared to other DBD systems (Huang *et al.*, 2016; Tangjitsomboon *et al.*, 2021), which also demonstrate PM trapping efficiency, our system achieves efficient PM capture under conditions similar to commercial portable smoke evacuation systems commonly used in operating

rooms. This distinction sets our system apart from other DBD systems.

Moreover, developing our DBD system presents a promising way to reduce PM from surgical smoke. While there are some concerns regarding cost and energy consumption compared to nanofiber filters, its effectiveness and long-term potential make it a viable option. Our DBD system can also be integrated with existing smoke evacuation systems to enhance efficiency, improve smoke capture, and extend filter lifespan. By providing a practical solution to reduce pollution and improve safety in operating rooms, this research highlights the potential of DBD plasma technology in creating safer surgical environments for medical personnel.

Conclusions

This research aims to trap smoke from electrosurgical unit cutting using a DBD system developed with different inner and outer electrodes.

The plasma of this system was generated by the ionization of air with a high-voltage electric potential between the inner and outer electrodes. Charged particles in the plasma, including electrons and ions, interact with PM particles from surgical smoke, resulting in changes in the charge properties of PM, causing PM to be trapped by the DBD system. In this research, PM from smoke was generated using the electrosurgical unit in cutting mode with a power of 40 watts for 15 sec, which acted on the surface of the pork sample. The initial operating voltage used in the research was 9 kV, the lowest electric potential at which plasma could be observed. The operating voltage was increased by 2 kV at a time until the maximum voltage of 13 kV, which was the limitation of the machine. The amount of PM was measured using an aerosol monitor.

The experimental results revealed several critical insights into the relationship between the electric potential, electrode configuration, and the efficiency of PM trapping. It was observed that increasing the electric potential between the electrodes led to a significant reduction in the average amount of PM measured. This improvement in trapping efficiency was attributed to enhanced interactions between PM particles and plasma particles. Specifically, the more substantial electric potential increased the electric force acting on PM particles, which changed their electrical properties due to their interaction with plasma.

The configuration and dimensions of the electrodes played a pivotal role in determining the effectiveness of the DBD system. The inner

electrode's diameter significantly influenced the gap length between the inner and outer electrodes, affecting the electric field strength. A smaller gap length resulted in a stronger electric field directly proportional to the electric force responsible for trapping PM. In this study, inner electrodes with larger diameters demonstrated superior performance due to their ability to create a more robust electric field.

The outer electrode's design and material were also critical in optimizing PM trapping efficiency. The copper plate used as the outer electrode outperformed the copper tube coil primarily because the copper plate generated a uniformly distributed electric field. This uniformity ensured consistent plasma formation across the entire surface of the electrode, allowing for more effective interaction between plasma particles and PM. In contrast, the copper tube coil produced a less consistent electric field, leading to uneven plasma distribution and reduced PM trapping efficiency.

Based on these findings, the study concluded that combining the largest diameter inner electrode and a copper plate outer electrode was the most effective configuration for trapping PM in the DBD system. This optimized setup can be a foundation for further enhancements in surgical smoke evacuation technologies.

In the following endeavor, the PM trapping efficiency will be improved by developing other types of electrodes and further applying the developed system to enhance the efficiency of surgical smoke trapping in conjunction with other commercial portable smoke evacuation systems.

Acknowledgements

The authors would like to thank the Faculty of Science and Health Technology, Navamindradhiraj University, Thailand, for supporting laboratories and equipment, and the College of Industrial Technology, King Mongkut's University of Technology North Bangkok, Thailand, and the Department of Physics, Faculty of Science, Chulalongkorn University, Thailand, for providing instruments and equipment.

References

- Abu-Rafea, B., Vilos, G.A., Al-Obeed, O., AlSheikh, A., Vilos, A.G., and Al-Mandeel, H. (2011). Monopolar electrosurgery through single-port laparoscopy: A potential hidden hazard for bowel burns. *Journal of Minimally Invasive Gynecology*, 18(6):734-740. <https://doi.org/10.1016/j.jmig.2011.07.015>
- Alqadi, G.O. and Saxena, A.K. (2020). Smoke and particulate filters in endoscopic surgery reviewed during COVID-19

- pandemic. *Journal of Pediatric Endoscopic Surgery*, 2:61-67. <https://doi.org/10.1007/s42804-020-00060-y>
- Ata, E.C., Senturk, G.E., Saygi, H.I., Ulukan, M.O., Ugurlucan, M., Erkanli, K., Beyaz, M.O., Yildiz, E. (2022). Identifying the optimal monopolar electrocautery output power in pedicular internal thoracic artery harvesting: 20 or 40 watts? *Cardiovascular Journal of Africa*, 33(5):243-247. <https://doi.org/10.5830/CVJA-2022-005>
- Casey, V.J., Martin, C., Curtin, P., Buckley, K., and McNamara, L.M. (2021). Comparison of surgical smoke generated during electrosurgery with aerosolized particulates from ultrasonic and high-speed cutting. *Annals of Biomedical Engineering*, 49(2):560-472. <https://doi.org/10.1007/s10439-020-02587-w>
- Chou, Y.-C., Tung, T.-C., Wu, P.W., Lin, B.-R., and Lai, S.-L. (2024). Protective effect of a novel smoke evacuation device during laparoscopic surgery: An experimental proof-of-concept study. *Journal of the Formosan Medical Association*, p. 1-8. <https://doi.org/10.1016/j.jfma.2024.12.023>
- Dennis, V. (2022). Needed Practice change: surgical smoke evacuation. *AORN Journal*, 116:103-105. <https://doi.org/10.1002/aorn.13756>
- Dixon, K., Dasgupta, P., and Vasdev, N. (2023). A systematic review of the harmful effects of surgical smoke inhalation on operating room personnel. *Health Sciences Review*, 6:100077. <https://doi.org/10.1016/j.hsr.2023.100077>
- El-Sayed, M.M. and Saridogan, E. (2020). Principles and safe use of electrosurgery in minimally invasive surgery. In: *Minimally Invasive Surgery in Gynecological Practice: Practical Examples in Gynecology*. Saridoğan, E., Kilic, G., and Ertan, K. (Ed.), Berlin, Boston: De Gruyter, p. 38-49. <https://doi.org/10.1515/9783110535204-004>
- Esenkaya, D. and İyigün, E. (2024). The effect of surgical smoke on operating room workers, attitudes towards risks, and the implementation of preventive measures. *Perioperative Care and Operating Room Management*, 37:100442. <https://doi.org/10.1016/j.pcorn.2024.100442>
- Gioutsos, K., Nguyen, T.L., Biber, U., Enderle, M.D., Koss, A., and Kocher, G.J. (2022). Surgical smoke: modern mobile smoke evacuation systems improve occupational safety in the operating theatre. *Interdisciplinary CardioVascular and Thoracic Surgery (ICVTS)*, 34(5):775-782. <https://doi.org/10.1093/icvts/ivac024>
- Huang, X., Guo, F., Chen, J., Wang, S., Hu, Z., Wang, L., Chen, Z., and Liu, M. (2016). Investigation of the arrayed dielectric barrier discharge reactor for PM2.5 removal in air. *IEEE Transactions on Plasma Science*, 44(8):1341-1348. <https://doi.org/10.1109/TPS.2016.2580538>
- Jena, A., Jain, S., Sundaram, S., Singh, A.K., Chandnani, S., and Rath, P. (2023). Electrosurgical unit in GI endoscopy: the proper settings for practice. *Expert Review of Gastroenterology and Hepatology*, 17(8):825-835. <https://doi.org/10.1080/17474124.2023.2242243>
- Kahramansoy, N. (2024). Surgical smoke: a matter of hygiene, toxicology, and occupational health. *GMS Hygiene and Infection Control*, 19:1-12. <https://doi.org/10.3205/dgkh000469>
- Kattoor, A.J. and Iyer, V. (2024). Electrosurgery in Structural Heart Interventions. *Cardiology Clinics*, 42(3):339-350. <https://doi.org/10.1016/j.ccl.2024.02.020>
- Kaya, U. and Yildiz, K. (2024). Not invisible but existing danger surgical smoke: A literature review. *Türkiye Klinikleri Journal of Nursing Sciences*, 16(2):577-581. <https://doi.org/10.5336/nurses.2023-99065>
- Kocher, G.J., Dorn, P., Hutterli, M., Koss, A. (2022). Electrocautery smoke exposure and smoke evacuation in thoracic surgery: A prospective randomized study. *British Journal of Surgery*. 109(Supplement_3):znac185.005. <https://doi.org/10.1093/bjs/znac185.005>
- Liu, Y., Qian X, Zhang H, Liang W, Zou C, Cui Y. (2020). Preparing micro/nano-fibrous filters for effective PM 2.5 under low filtration resistance. *Chemical Engineering Science*, 217:115523. <https://doi.org/10.1016/j.ces.2020.115523>
- Ma, W., Qi, H., Zhang, Y., Lin, M., Qiu, Y., and Zhang, C. (2023). Fabrication of laminated micro/nano filter and its application for inhalable PM removal. *Polymers*, 15(6):1459. <https://doi.org/10.3390/polym15061459>
- Merajikhah, A., Imani, B., Khazaei, S., and Bouraghi, H. (2022). Impact of surgical smoke on the surgical team and operating room nurses and its reduction strategies: A systematic review. *Iranian Journal of Public Health*, 51(1):27-36. <https://doi.org/10.18502/ijph.v51i1.8289>
- Soysal, G.E., İlce, A., Lakestani, S., Sit, M., and Avcioğlu, F. (2023). Comparison of the effects of surgical smoke on the air quality and on the physical symptoms of operating room staff. *Biological Research For Nursing*, 25(3):444-453. <https://doi.org/10.1177/10998004221151157>
- Suyadi, Nur, M., and Suseno, J. (2017). Analysis of electric circuit model on atmospheric pressure Dielectric Barrier Discharge (DBD) plasma. *International Journal of Innovative Research in Advanced Engineering (IJIRAE)*, 6(4):1-9. <https://doi.org/10.7910/DVN/YNDPEP>
- Swerdlow, B.N. (2020). Surgical smoke and the anesthesia provider. *Journal of Anesthesia*, 34(4):575-584. <https://doi.org/10.1007/s00540-020-02775-x>
- Tangjitsomboon, P., Ngamrungraj, D., and Mongkolnavin, R. (2021) Effect of electric potential across electrodes for trapping joss smoke particles in DBD plasma atmospheric pressure. *Journal of Physics: Conference Series*, 2145:012020. <https://doi.org/10.1088/1742-6596/2145/1/012020>
- Tian, E., Gao, Y., and Mo, J. (2023). Experimental studies on electrostatic-force strengthened particulate matter filtration for built environments: Progress and perspectives. *Building and Environment*, 228:109782. <https://doi.org/10.1016/j.buildenv.2022.109782>
- Wong, B., Hakimi, A., and Elghobashi, S. (2020). Smoke evacuator use with ultra-low particulate air filtration in rhinoplasty and sinus surgery. *Facial Plastic Surgery and Aesthetic Medicine*, 22(6):404-405. <https://doi.org/10.1089/fpsam.2020.0434>
- Xu, Y., Liu, X., Zhang, Y., Sun, W., Zhou, Z., Xu, M., Pan, S., and Gao, X. (2016). Field measurements on the emission and removal of PM2.5 from coal-fired power stations: 3. direct comparison on the pm removal efficiency of electrostatic precipitators and fabric filters. *Energy & Fuels*, 30(7):5930-5936. <https://doi.org/10.1021/acs.energyfuels.6b00425>
- Yu, H. (2024). The research on the effect of temperature of electro-surgical unit to surgical smoke distribution in theatre-in vitro and simulation study. *PLoS One*, 19(3):e0299369. <https://doi.org/10.1371/journal.pone.0299369>
- Zhou, Y.-z., Wang, C.-q., Zhou, M.-h., Li, Z.-y., Chen, D., Lian, A.-l, and Yong, M. (2023). Surgical smoke: A hidden killer in the operating room. *Asian Journal of Surgery*. 46(9):3447-3454. <https://doi.org/10.1016/j.asjsur.2023.03.066>