PAPER TITLE:

GENERATION OF HYBRID PLASMA OVER A LIQUID LAYER.

Contributors:

1. Professor Tatiana Vasilieva
2. Professor Michael Vasiliev
3. Mfeuter Joseph Tachia – *corresponding author.*

Moscow Institute of Physics and Technology – Russia.

ABSTRACT:

This experimental study investigates the ability of hybrid plasma generation over a special liquid mixture of vaseline and lecithin. The combination of gas discharge plasma and electron beam plasma was used to generate the hybrid plasma. The apparatus used consisted of a radio frequency connected to an electrode disc that was inserted into the liquid mixture placed in a vacuum chamber. The power was set to 25 W and an electron beam plasma was injected into the special liquid mixture to create a plasma cloud under a vacuum chamber environment. The plasma cloud formed uniformly around the liquid layer and was stable during the experiment. After the experiment, the droplets of water on the petri-dish used for the experiment were observed to be more viscous than on the other petri-dish not used. This work suggests that hybrid plasma generation over liquids has potential applications in various fields, including biomedical, surface modification, and environmental remediation. Further research can explore the effects of different liquid properties on the ability to generate hybrid plasma and its potential applications in various fields.

KEY WORDS:

Hybrid plasma, special liquid, gas discharge, electron beam plasma, radio frequency.

INTRODUCTION:

Plasma, the fourth state of matter, has been the focus of numerous scientific studies due to its unique properties and potential applications in various fields such as medicine, energy, and material science, industrial electronics and other research works (Eliezer, 1989; Rezaei et al., 2019). In particular, the generation of plasma in liquid layers has been an area of increasing interest, as it offers a new way to study the behavior of plasma in different environments and provides new opportunities for various applications. Hybrid plasma refers to the combination of two or more types of plasma sources to create a new type of plasma. The concept is based on the idea that combining different plasma sources can lead to new and unique plasma characteristics that can be utilized for specific applications. The ability to generate hybrid plasma over liquid surfaces has gained significant attention in recent years due to its potential applications in various fields (Bruggeman et al., 2016; Rezaei et al., 2019)**.** Hybrid plasma generation over liquids involves the use of a dielectric barrier discharge (DBD) or non-thermal plasma (NTP) to create a plasma in contact with the liquid surface (Bruggeman et al., 2016; Kazemi & Taghvaei, 2021). This method has been widely studied for surface modification, as well as for biomedical applications such as wound healing and cancer treatment (Kyzioł & Kyzioł, 2018; Lee et al., 2011; Васильева et al., n.d.). The generation of plasma over liquids is a complex process influenced by various parameters, including the liquid properties, electrode geometry, applied voltage, and gas flow rate (Kogelschatz, 2004). Several studies have investigated the influence of these parameters on the ability to generate hybrid plasma over liquids (Mariotti et al., 2012; Morabit et al., 2021; Oehmigen et al., 2011). The potential applications of hybrid plasma generation over liquids are vast, and ongoing research continues to explore new possibilities for this technology. Thus, understanding the fundamental mechanisms of plasma generation over liquids is crucial for advancing this field and exploring its full potential. The use of hybrid plasmas with particles of dispersed powders and liquid droplets additives, has been demonstrated in the experimental study by Vasilieva et al (2022). Despite the promising results obtained with hybrid plasma generation over liquids, challenges still exist in the formation of the reaction zone, which is critical to achieving high efficiency and selectivity (Васильева et al., n.d.). Therefore, further investigation is necessary to optimize the design and operation of the hybrid plasma generation over liquids system for various applications. The unique combination of magnetic stirring, vaseline and lecithin, and radio frequency was used in this work to create a stable and uniform plasma cloud in a vacuum chamber environment which can lead to unique and novel phenomena, such as the generation of reactive species and the formation of new materials (Gil et al., 2019; Montie et al., 2000; Васильева et al., n.d.). A magnetic stirrer was used to prepare a special liquid with a mixture of vaseline and lecithin, which was then poured into a spherical petri dish. An electrode disc connected to a radio frequency was inserted into the liquid and the power was set to 25 W. An electron beam plasma was injected into the liquid to create a plasma cloud under the vacuum chamber as a working environment. The results of this study provide new insights into the generation of plasma in liquid layers and the use of mass spectrometry to study its mass composition. This research contributes to the broader field of plasma science and technology by providing a novel method for the generation of plasma in liquid layers and by exploring the behavior and composition of plasma in this unique environment. The findings of this study have important implications for various application including biomedical synthesis, plasma modification and treatments, energy production, environmental protection, and material synthesis.

OBJECTIVES:

The main goal of this work is to study the behavior and characteristics of plasma generated over a given liquid layer using radio frequency and to understand the fundamental mechanisms of plasma-liquid interaction and its application in different fields.

METHODOLOGY:

A mixture of Vaseline and lectithin was used in the experiment, this liquid mixture was selected based on its properties such as viscosity, conductivity, and stability. A vacuum chamber is used to control and prevent external interference and mixture with gases. The pressure inside the chamber was regulated between 0.06 – 0.08 Torr. A spherical electrode disc with a diameter of 8cm was inserted into the liquid mixture and connected to a radio frequency generator which regulated to power rating of 25W. After the application of the radio frequency, the formation of plasma cloud over the liquid mixture was observed.

EXPERIMENTAL DESIGN:

A magnetic stirrer was used to prepare a special liquid with a mixture of vaseline and lecithin, which was then poured into a spherical petri dish – 7. An electrode disc – 8 connected to a radio frequency generator was inserted into the liquid and the power was set to 25 W. An electron gun – 1 was used to generate electron beam – 3 which was directed into the liquid mixture setup to create a plasma cloud under the vacuum chamber – 6 as a working environment. The electron scanning system with the injection window – 4 was used to control the geometry of the electron beam plasma that was directed toward the setup. The pressure meter – 5 was used to measure the pressure in the working chamber – 6 and the mass spectrometer was connected to the injection window….

The figure below illustrates the experimental framework

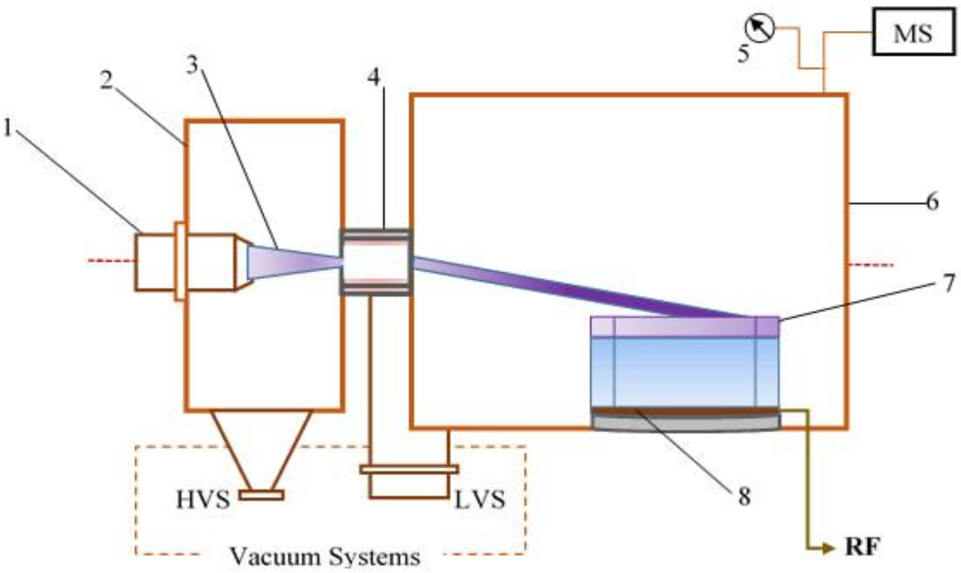

Figure 1: The Experimental Setup for the Generation of Hybrid Plasma over a Liquid Layer.

RESULTS:

Hybrid plasma was generated over liquids by combining an electron beam plasma and gas discharge plasma. An electrode disc was connected to a radio frequency source with a liquid electrode discharge which involves using a liquid as one of the electrodes. Electron beam was incident on a spot on the liquid and was evenly distributed uniformly over the liquid layer. The scanning beam electron was used. Electron beam was directed to move over the liquid with various diameter in a circular pattern with the use of electron beam controller.

The experimental results were observed and are as presented below.

Figure 1

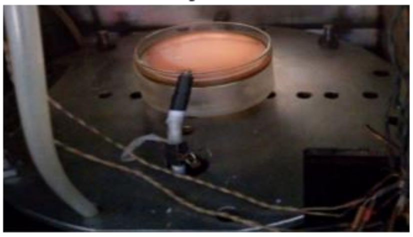

Figure 2

Figure 3

Figure 4

Figure 5

Figure 6

Fig.1: Mixture of the special liquid placed in vacuum chamber at pressure around (0.06 – 0.08 Torr).

Fig.2: Radio frequency connected to the spherical electrode disc inserted into the liquid mixture with an EBP incident on the liquid mixture.

Fig.3: Hybrid plasma generation over the liquid layer after 5mins.

Fig.4, Fig.5 and Fig.6 illustrates the increasing formation of uniform and stable hybrid plasma over the liquid layer at the radio frequency power rating of 25W. The plasma cloud started to form over the liquid and as the power was gradually increased to a peak power of 25 W, the plasma cloud became more uniform and stable. At approximately 15 minutes, the plasma cloud had stabilized and produced a pink-colored cloud over the liquid mixture as shown in the figures above.

DISCUSSION:

The work explored the potential applications of hybrid plasma generation over liquids surface. Plasma is an ionized gas that has been widely used in surface modification, sterilization, and other biomedical applications (Chu et al., 2002; Gomathi et al., 2008). The use of hybrid plasma generation over liquids involves introducing liquid droplets or films into the plasma, resulting in a liquid-phase plasma that can be used for various applications. The purpose of this experiment was to investigate the ability of hybrid plasma generation over a mixture of vaseline and lecithin as the special liquid. The mixture was placed in a vacuum chamber to prevent external interference and to control the pressure. The vacuum pumps were used to reduce the pressure to 0.06-0.08 Torr, creating a favorable environment for plasma formation. A round electrode disc of 8 cm diameter was inserted into the liquid mixture and was connected to a 300 KHz radio frequency with a power rating of 25 W as shown in figure 1. After a period of 5 minutes, the plasma cloud started to form over the liquid (from figure 2 and figure 3) and as the power was gradually increased to a peak power of 25 W, the plasma cloud became more uniform and stable. After approximately 15 minutes, the plasma cloud had stabilized and produced a pink-colored cloud over the liquid mixture, this is illustrated in figures 4, 5 and 6 respectively. The results of this experiment demonstrate the successful generation of hybrid plasma over a liquid mixture using radio frequency and highlight the importance of controlling pressure in the vacuum chamber for effective plasma formation. However, further studies may be necessary to investigate the stability of the plasma cloud and its potential applications. Several studies have investigated the effectiveness of this technique and the factors that influence its ability to generate plasma and are consistent with the results obtained in this work. The various approaches for generating plasma over liquids, including electrical discharge, laser-induced breakdown, and electrolysis also highlight the importance of liquid properties such as viscosity, surface tension, and conductivity in determining the efficiency of plasma generation (Bruggeman et al., 2021; Kierzkowska-Pawlak et al., 2019; Siow et al., 2006). The potential of hybrid plasma generation over liquids for biomedical applications such as sterilization and wound healing has been an area of research and some results proofed that this technique could efficiently generate plasma and produce reactive oxygen species that could kill bacteria and promote cell proliferation (Arora et al., 2014; Heinlin et al., 2011; Lee et al., 2011; Misra et al., 2021; Rezaei et al., 2018). In summary, hybrid plasma generation over liquids shows promise for various applications, including surface modification and biomedical fields. The effectiveness of this technique and its ability to generate plasma are influenced by factors such as liquid properties and the type of plasma generation method used. Further research is needed to fully understand the potential of this emerging technique. There are several physics laws that provides the basis for this work, which include the laws of thermodynamics, electrodynamics, and plasma physics. The first law of thermodynamics states that energy cannot be created or destroyed, but can be converted from one form to another. In the case of plasma generation, electrical energy is converted into thermal energy, resulting in the ionization of gas molecules and the production of plasma. The second law of thermodynamics states that entropy tends to increase over time, which is also applicable in plasma generation since plasma is a highly disordered state of matter. Electrodynamics is the study of the interactions between charged particles and electromagnetic fields. In hybrid plasma generation, the electromagnetic field is used to ionize the gas molecules and generate plasma. The plasma interacts with the liquid droplets or films, resulting in chemical reactions and other modifications to the surface or material being treated. Plasma physics is the study of the behavior of ionized gases and the plasma state of matter. The physics of plasma is crucial to the understanding of plasma generation and its applications. For instance, the type of plasma generated depends on the gas pressure, power input, and other parameters. The behavior of the plasma and its interactions with the liquid droplets or films also depend on the plasma parameters and the properties of the liquid. In summary, the potential applications of hybrid plasma generation over liquids for surface modification and biomedical purposes involve the use of fundamental physics laws, including the laws of thermodynamics, electrodynamics, and plasma physics (Adamovich et al., 2022; Conrad et al., 1987; Conrads & Schmidt, 2000). These laws are crucial to the understanding of plasma generation and its applications, as well as the behavior of the plasma and its interactions with the liquid droplets or films.

CONCLUSION:

The experiment demonstrated the ability to generate hybrid plasma with a stable cloud over the mixture of vaseline and lecithin. The choice of using this specific mixture was due to its ability to remain in its liquid form under low pressure conditions, which was achieved by conducting the experiment in a vacuum chamber. The observation of increased viscosity in droplets of water after the experiment suggests the potential for this process to be used in processing biomedical materials to improve their viscosity for various applications. Overall, the results provide valuable insight into the feasibility of hybrid plasma generation over liquid layers and open up avenues for further exploration in this field. With continued exploration and development, this technology could offer significant benefits for a variety of fields, from healthcare to manufacturing and beyond. The use of hybrid plasma generation over liquids involves introducing liquid droplets or films into the plasma, resulting in a liquid-phase plasma that can be used for various applications. the potential applications of hybrid plasma generation over liquids for surface modification and biomedical purposes involve the use of fundamental physics laws, including the laws of thermodynamics, electrodynamics, and plasma physics (Adamovich et al., 2022; Conrad et al., 1987). These laws are crucial to the understanding of plasma generation and its applications, as well as the behavior of the plasma and its interactions with the liquid droplets or films. In conclusion, this work has explored the potential applications of hybrid plasma generation over liquids for surface modification and biomedical purposes. Based on the literature review and analysis of existing research, it is evident that this technology holds great promise for a wide range of applications, including sterilization, wound healing, drug delivery, and surface modification (Bruggeman et al., 2021; T. Vasilieva, 2012; T. Vasilieva & Lysenko, 2007). However, further research is needed to fully understand the physics and mechanisms underlying hybrid plasma generation over liquids and to optimize the technology for specific applications. Factors such as the properties of the liquid, the type of plasma used, and the specific application must be carefully considered in the design and implementation of hybrid plasma systems.

Declaration of conflict of interests:

The authors declare no conflict of interests.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work, the authors used some AI tools (ChatGPT, Scispace Bolts, and Quillbot AI) for the purpose of paraphrasing, grammatical checks, and better presentation of the original ideas generally. After using these tools/services, the authors reviewed and edited the content to ensure the original ideas is retain as desired and takes full responsibility for the content of the publication.

REFERENCES:

Adamovich, I., Agarwal, S., Ahedo, E., Alves, L. L., Baalrud, S., Babaeva, N., Bogaerts, A., Bourdon, A., Bruggeman, P. J., & Canal, C. (2022). The 2022 Plasma Roadmap: low temperature plasma science and technology. *Journal of Physics D: Applied Physics*, *55*(37), 373001.

Arora, V., Nikhil, V., Suri, N. K., & Arora, P. (2014). Cold atmospheric plasma (CAP) in dentistry. *Dentistry*, *4*(1), 1.

Bracht, V., Gembus, J.-L., Bibinov, N., & Awakowicz, P. (2023). Surface modifications of aluminium and aluminium oxide induced by a treatment with a He-plasma jet and plasma electrolytic oxidation. *Journal of Physics D: Applied Physics*, *56*(16), 165201.

Bruggeman, P. J., Bogaerts, A., Pouvesle, J. M., Robert, E., & Szili, E. J. (2021). Plasma–liquid interactions. *Journal of Applied Physics*, *130*(20).

Bruggeman, P. J., Kushner, M. J., Locke, B. R., Gardeniers, J. G. E., Graham, W. G., Graves, D. B., Hofman-Caris, R., Maric, D., Reid, J. P., & Ceriani, E. (2016). Plasma–liquid interactions: a review and roadmap. *Plasma Sources Science and Technology*, *25*(5), 053002.

Chu, P. K., Chen, J. Y., Wang, L. P., & Huang, N. (2002). Plasma-surface modification of biomaterials. *Materials Science and Engineering: R: Reports*, *36*(5–6), 143–206.

Conrad, J. R., Radtke, J. L., Dodd, R. A., Worzala, F. J., & Tran, N. C. (1987). Plasma source ion-implantation technique for surface modification of materials. *Journal of Applied Physics*, *62*(11), 4591–4596.

Conrads, H., & Schmidt, M. (2000). Plasma generation and plasma sources. *Plasma Sources Science and Technology*, *9*(4), 441.

Eliezer, S. (1989). *The fourth state of matter*.

Gil, B., Rogala, Z., & Dorosz, P. (2019). Pool Boiling Heat Transfer Coefficient of Low-Pressure Glow Plasma Treated Water at Atmospheric and Reduced Pressure. *Energies*, *13*(1), 69.

Gomathi, N., Sureshkumar, A., & Neogi, S. (2008). RF plasma-treated polymers for biomedical applications. *Current Science*, 1478–1486.

Heinlin, J., Isbary, G., Stolz, W., Morfill, G., Landthaler, M., Shimizu, T., Steffes, B., Nosenko, T., Zimmermann, J. L., & Karrer, S. (2011). Plasma applications in medicine with a special focus on dermatology. *Journal of the European Academy of Dermatology and Venereology*, *25*(1), 1–11.

Johnson, W. L. (1996). Electrostatically-shielded inductively-coupled RF plasma sources. *High Density Plasma Sources. NY: Noyes Publications*, 100–114.

Kazemi, M., & Taghvaei, H. (2021). A novel multi array dielectric barrier discharge plasma gas diffuser for wastewater treatment: The role of reactive species. *Separation and Purification Technology*, *260*, 118236.

Kierzkowska-Pawlak, H., Tyczkowski, J., Jarota, A., & Abramczyk, H. (2019). Hydrogen production in liquid water by femtosecond laser-induced plasma. *Applied Energy*, *247*, 24–31.

Kogelschatz, U. (2004). Atmospheric-pressure plasma technology. *Plasma Physics and Controlled Fusion*, *46*(12B), B63.

Kyzioł, A., & Kyzioł, K. (2018). Surface functionalization with biopolymers via plasma-assisted surface grafting and plasma-induced graft polymerization—materials for biomedical applications. In *Biopolymer grafting* (pp. 115–151). Elsevier.

Lee, H. W., Park, G. Y., Seo, Y. S., Im, Y. H., Shim, S. B., & Lee, H. J. (2011). Modelling of atmospheric pressure plasmas for biomedical applications. *Journal of Physics D: Applied Physics*, *44*(5), 053001.

Mariotti, D., Patel, J., Švrček, V., & Maguire, P. (2012). Plasma–liquid interactions at atmospheric pressure for nanomaterials synthesis and surface engineering. *Plasma Processes and Polymers*, *9*(11-12), 1074–1085.

Matveev, I. B., Ardelyan, N. V, Bychkov, V. L., Bychkov, D. V, & Kosmachevskii, K. V. (2013). Plasma assisted combustion, gasification and pollution control. *Int. Plasma Technol. Center*, *1*, 1–28.

Misra, N., Bhatt, S., Arefi-Khonsari, F., & Kumar, V. (2021). State of the art in nonthermal plasma processing for biomedical applications: Can it help fight viral pandemics like COVID-19? *Plasma Processes and Polymers*, *18*(7), 2000215.

Montie, T. C., Kelly-Wintenberg, K., & Roth, J. R. (2000). An overview of research using the one atmosphere uniform glow discharge plasma (OAUGDP) for sterilization of surfaces and materials. *IEEE Transactions on Plasma Science*, *28*(1), 41–50.

Morabit, Y., Hasan, M. I., Whalley, R. D., Robert, E., Modic, M., & Walsh, J. L. (2021). A review of the gas and liquid phase interactions in low-temperature plasma jets used for biomedical applications. *The European Physical Journal D*, *75*, 1–26.

Oehmigen, K., Hoder, T., Wilke, C., Brandenburg, R., Hahnel, M., Weltmann, K.-D., & von Woedtke, T. (2011). Volume effects of atmospheric-pressure plasma in liquids. *IEEE Transactions on Plasma Science*, *39*(11), 2646–2647.

Rezaei, F., Nikiforov, A., Morent, R., & De Geyter, N. (2018). Plasma modification of poly lactic acid solutions to generate high quality electrospun PLA nanofibers. *Scientific Reports*, *8*(1), 2241.

Rezaei, F., Vanraes, P., Nikiforov, A., Morent, R., & De Geyter, N. (2019). Applications of plasma-liquid systems: A review. *Materials*, *12*(17), 2751.

Samal, S. (2017). Thermal plasma technology: The prospective future in material processing. *Journal of Cleaner Production*, *142*, 3131–3150.

Siow, K. S., Britcher, L., Kumar, S., & Griesser, H. J. (2006). Plasma methods for the generation of chemically reactive surfaces for biomolecule immobilization and cell colonization-a review. *Plasma Processes and Polymers*, *3*(6-7), 392–418.

Vakatov, V. P., Vasiliev, M. V, Velikodny, V. Y., Voznesenky, E. N., Volkov, V. A., Zuev, A. P., Korotees, A. S., Meshkov, M. A., Onufriev, A. T., Paveliev, A. A., Rakolov, Yu. G., Safarov, R. A., Sechenov, V. A., Son, E. E., Starikovskaya, S. M., Starikovsky, A. Y., Tchenko, B. K., Shirokov, N. N., & Shcherbina, Yu. A. (2006). *Laboratory Practice on Gas Dynamics, Hydrodynamics and Physical Mechanics* (E. E. Sona, Ed.).

Vasilieva, T. (2012). *Bio-medical applications of the electron-beam plasma*. InTech Rijeka, Croatia.

Vasilieva, T., & Lysenko, S. (2007). Factors responsible for biomaterials modification in the electron-beam plasma. *Journal of Physics: Conference Series*, *63*(1). https://doi.org/10.1088/1742-6596/63/1/012033

Vasilieva, T. M., & Bayandina, D. V. (2010). An experimental complex for studying the operation of beam-plasma reactors for biomedical applications. *Instruments and Experimental Techniques*, *53*, 288–295.

Zhdanok, S. A. (2008). Nonequilibrium processes and their applications. *Applied Thermal Engineering*, *28*(4), 254–260.

Васильева, Т. М., Vasilieva, T. M., Vasiliev, M. N., Tachia, J. M., & Singh, U. K. (n.d.). *ПУЧКОВО-ПЛАЗМЕННЫЕ РЕАКТОРЫ ФОРВАКУУМНОГО ДАВЛЕНИЯ С ГЕТЕРОФАЗНЫМ РЕАКЦИОННЫМ ОБЪЕМОМ: ПРОБЛЕМЫ ФОРМИРОВАНИЯ РЕАКЦИОННОГО ОБЪЕМА FOREVACUUM PRESSURE BEAM-PLASMA REACTORS WITH HETEROPHASIC REACTION VOLUME: PROBLEMS OF THE REACTION ZONE FORMATION*.