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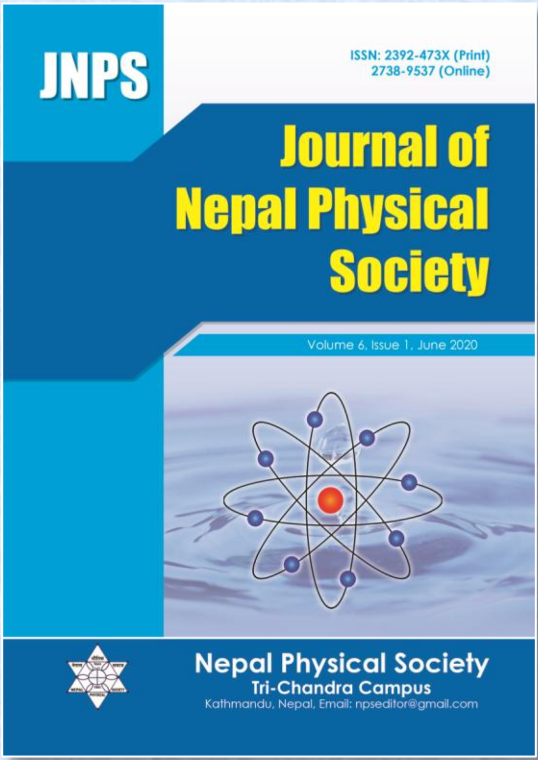

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Measurement of Floating Potential and Ion Concentration in Arc Plasma at Atmospheric Pressure

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Abstract

Arc plasma is generated using low voltage dc power supply for the measurement of plasma parameters such as floating potential and ion-concentration in the plasma seeded with molybdenum. Langmuir moving probe is used in order to measure the probe current at different values of the dc potential applied on the probe. A graph is plotted between the probe current and the probe potential, based on data at the atmospheric pressure, using the experimental set up in the gas discharge chamber for the single probe method. The floating potential is calculated to be 32V, and the average ion-concentration to be 1.43-10^{16}m^{3}.

Keywords: Langmuir Probe, Seeded arc plasma, Floating Potential, Ion- concentration.

1. INTRODUCTION

There is a rapidly growing interest for seeded arc plasma research which promises a wide range of industrial applications. A plasma arc operates on principles similar to an arc-welding machine, where an electrical arc is struck between two electrodes. The plasma arc is enclosed in a chamber. Waste material is fed into the chamber and the intense heat of the plasma breaks down organic molecules (such as oil, solvents, and paint) into their elemental atoms. In a carefully controlled process, these atoms recombine into harmless gases such as carbon dioxide. Solids such as glass and metals are melted to form materials, similar to hardened lava, in which toxic metals are encapsulated. With plasma arc technology there is no burning or incineration and no formation of ash. There are two main types of plasma arc processes known as plasma arc Melter and plasma torch.

Plasma arc Melter have a very high destruction efficiency. They are very robust and they can treat any waste with minimal or no pre-treatment; and they produce a stable waste form. The arc Melter use carbon electrodes to strike an arc in a bath of molten slag. The consumable carbon electrodes are continuously inserted into the chamber, eliminating the need to shut down for electrode replacement or maintenance. The high temperatures produced by the arc convert the organic waste into light organics and primary elements. The plasma arc can be used for organic and inorganic wastes. It is being studied for mixed radioactive waste treatment, because it separates the organic from the inorganic portion of the waste. It is also being studied to reduce explosive compounds and unexploded ordnance in place of traditional technologies, such as open burning and open detonation that produced toxic emissions and hazardous ash. It has also been used to thermally reduce asbestos to a slag that can be disposed of in a municipal landfill.

In plasma torch systems, an arc is struck between a copper electrode and either a bath of molten slag or another electrode of opposite polarity. As with plasma arc systems, plasma torch systems have very high destruction efficiency; they are very robust; and they can treat any waste or medium with minimal or no pre-treatment. The inorganic portion of the waste is retained in a stable, leach-resistant slag. The air pollution control system is larger than for the plasma arc system, due to the need to stabilize torch gas.

Measurement of Plasma Parameters [1, 2] is of immense importance for plasma processing [3-5]**.**

It is also known as cold plasma of higher density, or low temperature plasma. However, its temperature is high enough to get the probe melted in a fraction of second when placed in it. The probe is, therefore, kept moving through the arc. Experimental data for the molybdenum seeded arc plasma is obtained at the atmospheric pressure using the experimental set up in the low-cost vacuum chamber [6]. Plasma parameters such as floating potential (V_F) and ion-concentration (n_i) are calculated using Langmuir Probe [5, 7-11]. Single probe method is used in this study to measure these plasma parameters in the arc plasma, seeded with molybdenum.

2. THEORY

Basic equations [12, 13] for Langmuir probe (single probe method) are as follows:

$$I_e = \exp\,(eV / kT_e) \quad \text{......} \quad (1)$$

For $V = 0$, $I_e = (I_e)_r$ and so we can write

$$n_e = \frac{(I_e)_r}{eA}\left(\frac{2\pi m_e}{kT_e}\right)^{1/2} \quad \text{......} \quad (2)$$

$$n_i = \frac{2.5 I_i}{e\,A}\left(\frac{m_i}{2kT_e}\right)^{1/2} \quad \text{......} \quad (3)$$

Here I_e denotes the electrons current. I_i is the current due to ions, n_e the electron-concentration, n_i the ion-concentration, e the charge on each electron, A the surface area of the probe, k the Boltzmann's constant, T_e the electron's temperature, m_e the mass of an electron, m_i the mass of an ion, and V the probe potential.

Equation (1) is used for measuring the electron temperature (T_e) by drawing a tangent to the curve of *ln I* versus *V* of the probe. Once the electron temperature is found, one can obtain the electron density using equation (2). The ion-concentration is found using equation (3) for a particular value of ion-current. After calculating various ion-concentrations for different values of ion-current, the average ion-concentration in the arc plasma can be determined. For a sufficiently negative probe potential, a stage comes when the drawn electron current just cancels the ion current. This takes place when $V = V_s$. Here, V_s represents the space potential. Langmuir probe method is useful for study of a plasma of moderate density.

3. EXPERIMENTAL SET UP

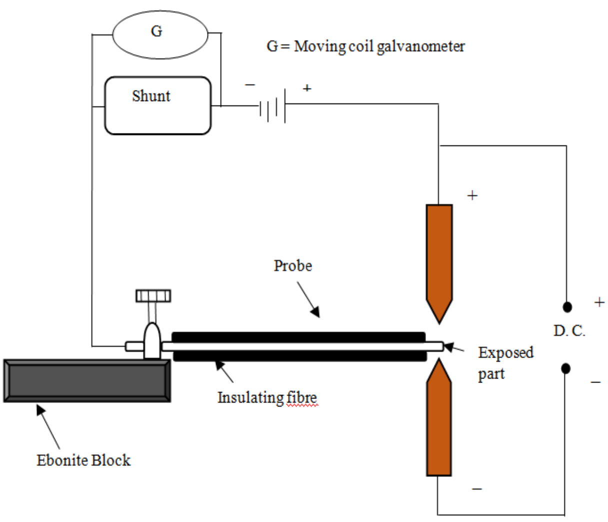

Figure 1: *Schematic Diagram for Single Probe Method*

Figure (1) shows the schematic diagram of the experimental set up for the single probe method in the low-cost chamber. A burning arc behaves like a dynamic plasma medium. The cylindrical probe wire of tungsten is supported on an ebonite base. The major portion of the probe is covered with insulating fiber leaving only a small part at its front uncovered (uninsulated). The probe is made to move through the arc.

Table 1: Specifications of the Probe and Electrodes

Probe material: *Platinum*
Length of the probe = 0.18mm
Average radius of the probe = 0.55mm
Surface area of the probe (A) = 1.57-$10^{6}$$m^{2}$
Average diameter of the arc = 8.25-10^{3}m
Average velocity of the probe = 20.0-10^{3}mm s^{1}
Passage time of the probe through the arc = 0.46s
Diameter of *copper-electrodes* = 5.51mm

4. RESULTS AND DISCUSSION

In the present experiment, diagnostics are performed using cylindrical Langmuir probe. Single-probe measurements are carried out in the region of molybdenum seeded arc plasma between two electrodes.

Table 2: Variation of probe current with probe potential

Probe Potential in volts (*V*)	*ln I*
0	7.798
-3	7.633
-6	7.565
-9	7.298
-12	6.129
-15	6.883
-18	6.665
-21	6.287
-24	5.883
-27	5.167
-30	1.889
-33	-1.467
-36	-2.954
-39	-3.667
-42	-3.789
-45	-3.876
-48	-3.933
-51	-3.998
-54	-3.987
-57	-3.998
-60	-3.998

At large negative values of *V* almost all the electrons are repelled, and we have an ion sheath and saturated ion current. There are two points of asymmetry between ion saturation and electron saturation due to their mass differences, which causes the disparity in the absolute magnitude of the currents. Since the ion and electron temperatures are usually unequal, and it turns out that sheath formation which is considerably different when the colder species are collected than that of when hotter species are collected.

Figure (2) shows the typical I-V characteristics of Langmuir probe in molybdenum sealed arc plasma where the lower portion of the curve represents ion-current saturation and that of the upper portion of the curve represents electron-current saturation.

In the present research work, the Langmuir probe is biased from 0 to -60V to drag ions so that its concentration can be characterized. In this technique, *I-V* characteristic is depicted which is a fundamental part of diagnosis of plasma parameters such as electron temperature, electron density, ion temperature, ion density and so on. There is slow and non-uniform decrease in probe current as the probe voltage is changed from 0 to -27V. From -27V to -33V, the probe current rapidly decreases at uniform rate, as indicated by straight line part of the curve and the current becomes zero at -32V which is the floating potential of this arc plasma. The current decreases slowly with the change in probe voltage in the range from at -36V to at -48V. The probe current becomes almost constant as the probe potential is changed in the range from -50V to -60V. It is obvious from Fig. 2 that the floating potential in the arc plasma is found to be -32V.

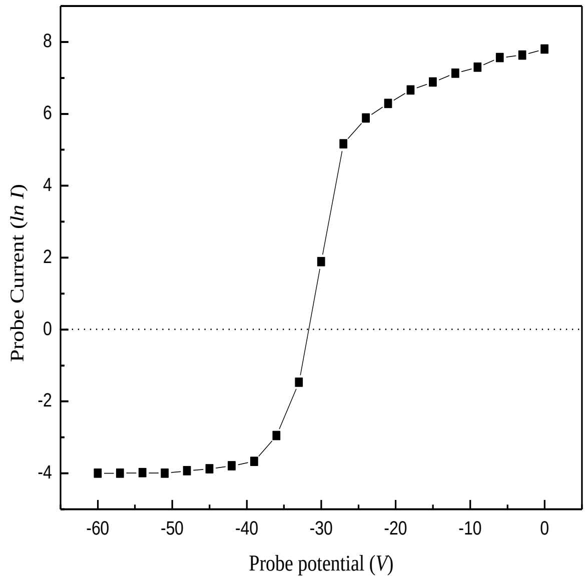

Figure 2: *I-V Characteristics for single probe method in molybdenum -seeded arc plasma*

Table 3: Calculation for Ion-concentration

Maximum Ion-Current (micro-ampere)	**Maximum Ion-Concentration (No. of ions per cubic meter)**
3.998	$1.19\text{-}10^{16}$ (minimum ion-concentration)

The maximum ion-concentration (Table 3) for ion-current of magnitude 3.998-A is $1.19\text{-}10^{16}$ m^3 and the average ion-concentration is $1.43\text{-}10^{16} m^3$ in seeded arc plasma at atmospheric pressure.

5. CONCLUSIONS

Langmuir single probe method is successfully used for measuring plasma parameters (floating potential and ion-concentration) in a molybdenum seeded arc plasma. This piece of study is expected to provide a new perspective for the industrial applications such as plasma processing, plasma torch of high efficiency, efficient arc lamps, etc.

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REFERENCES

[1] Pulinets, M. S., Kirpichev, I. P. and Antonova, E. E. Variations in Plasma Parameters and Magnetic Field upon Magnetopause Crossing at the Main Phase Maximum of the Magnetic Storm of November 14, 2012. *Geomagnetizm and Aeronomiy*, **56**, 673–681 (2016).

[2] Mishra, L. N., Shibata, K., Ito H., Yugami, N., Nishida, Y. Characteristics of electron Cyclotron resonance plasma Generated in a rectangular wave guide by high power Microwave. *Review of Scientific Instruments*, **75**, 84-89 (2004).

[3] Conrads, H. and Schmidt, M. Plasma generation and plasma sources. *Plasma Sources Science Technology*, **9**, 441–454 (2000).

[4] Ben Salem, D., Carton, O., Fakhouri, H., Pulpytel J. and Arefi□Khonsari, F. Deposition of water stable plasma polymerized acrylic acid/MBA organic coatings by atmospheric pressure air plasma jet. *Plasma Processes and Polymers,* **11**, 269-278 (2014).

[5] Robert, B.L., and Brian, E. B. Recommended Practice for Use of Langmuir Probes in Electric Propulsion Testing. *Journal of Propulsion and Power*, **33**, 566-581 (2017).

[6] Jha, V. K., Mishra, L. N. and Narayan B. Development of a Low-Cost Vacuum Chamber for the Experimental study of plasma parameters in a seeded arc plasma. *International Journal of Latest Engineering and Management Research*, **3**, 13-18 (2018).

[7] Dejarnac, R. P., Stangeby, C., Goldston, R. J., Gauthier, E., Horacek, J., Hron, M., Kocan, M., Komm, M., Panek, R, Pitts R. A. and Vondracek, P. Understanding narrow SOL power flux component in COMPASS limiter plasmas by use of Langmuir Probes. *Journal of Nuclear Materials*, **463**, 381-384 (2015).

[8] Sinha, R. P., Prasad, B. M. K., Bhagat, M. and Narayan, B. A study of Arc Plasma Using a Moving Langmuir Probe. *Indian Journal of Pure & Applied Physics*, **26**: 20-21 (1988).

[9] Rakhimova, T. V., Braginsky, O. V., Ivanov, V. V., Kim, T. K., Kong, J. T., Kovalev, A. S., Lopaev, D. V., Mankelevich, Y. A., Proshina, O. V. and Vasilieva A. N. Experimental and Theoretical Study of RF Plasma at Low and High Frequency. *IEEE Transaction on Plasma Science*, **34**, 867-877 (2006).

[10] Doggett, B., and Lunney, J.G., Langmuir probe characterization of laser ablation plasmas, *Journal of Applied Physics,* **105**, 033306 (2009).

[11] Mishra, L. N., Shibata, K., Ito H., Yugami, N., Nishida, Y. Pulsed Corona Discharge as a Source of Hydrogen and Carbon Nanotube Production, *IEEE Transaction on Plasma Science,* **32**, 1727-1733 (2004).

[12] Boyd, T. J. M. and Sanderson, J. J. Plasma dynamics, *Thomas Nelson Sons, London,* UK (1969).

[13] Thakur, G., Khanal, R., & Narayan, B. Characterization of Arc Plasma by Movable Single and Double Langmuir Probes, *Fusion Science and Technology*, **75**, 324-329 (2019).