LETTER TO THE EDITOR

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Effect of gas flow rate on breakdown voltage in a rotating gliding arc reactor

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Abstract: Understanding breakdown phenomena in rotating gliding arc discharge (RGA) is of interest to tailor them for specific applications. This work revealed that the breakdown voltage in a RGA reactor was not dictated by collisional effects i.e., change in flow rate. The observation was consistent for both the discharge gas medium argon and nitrogen. The collisional effect variation was implemented by varying the operating flow rates i.e., 5 SLPM which is transitional in nature, and 50 SLPM which is turbulent in nature having localized micro-eddies. The observation also indicated failure of Paschen law in RGA having shortest gap between the electrodes of order of mm, operated under atmospheric pressure conditions. Collisional ineffectiveness indicates possibility of streamer formation which needs to be further investigated in future. This work marks preliminary and important step towards understanding the breakdown phenomena in atmospheric RGAs operated under different flow regimes such as laminar/transitional and turbulent.

Letter

Rotating gliding arc discharges have been extensively studied for its chemical applications [1,2]. The working principle of RGAs is similar to that of conventional gliding arc discharges (GAD) made of planar diverging electrodes i.e., an arc strikes at the shortest gap between the electrodes when sufficient electric field is given to create breakdown; after initial breakdown, the arc is pushed by the gas downstream thereby elongating the arc [3]. In GADs, it is the jet gas flow that pushes the arc, whereas in RGAs it is the gas vortex achieved by tangential gas inlets which pushes the arc or rotates the arc to be more specific. The rotation can be additionally supported by external magnets. In a gas vortex driven RGA, the pressure field inside the reactor increases radially from rotational axis towards the wall [4]. Further, the pressure field distribution pattern changes along the flow direction (axial) and is a major function of flow nature. Turbulent flow conditions in RGAs will have localized effects of turbulent micro eddies and it is hypothesized that gas flow rate affects the breakdown voltage (V_b). The verification of this hypothesis using a systematic study is reported in this paper. To the best of the authors knowledge, the reported work and understanding on RGA is novel.

Figure 1 shows the schematic of the RGA reactor, measurement setup and the electrode configuration. The electrode configuration made of aluminium consisted of a high voltage flat ring powered by AC 20 kHz source PVM500-4000 supplied by M/s Information Unlimited, and a grounded inclined ring. Throughout the work, position of the electrodes was fixed, and the shortest gap was fixed to ≈3 mm. The hypothesis was verified for argon and nitrogen gas, operated at varying flow rates 5 and 50 SLPM controlled by mass flow controller (M/s Alicat Scientific). In previous work, authors have already verified that the flow nature of 5 SLPM and 50 SLPM in this RGA is transitional and turbulent, respectively, for both argon and nitrogen [4]. For this reason, these two flow rates are sufficient to change the collisional dynamics inside the reactor. The feed gas enters the reactor through three tangential entry holes forming gas vortex. As mentioned earlier, once the arc is initiated due to breakdown, it is rotated by the gas vortex and elongated by the geometrical orientation of the electrodes during its rotation (see 3D view in figure 1). Further details on reactor and working of electrode configuration can be seen in earlier work of authors [1,4,5]. The discussion in this work is limited to the breakdown voltage without discussing the rotation of the arc in this RGA.

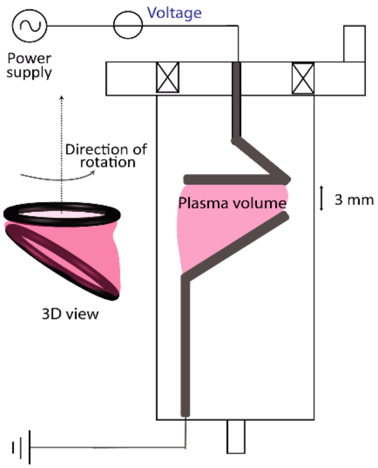

Figure 1. Schematic of the reactor, electrode configuration and measurement setup.

Figure 2 shows the voltage waveform measured during the event of breakdown in nitrogen gas operated at 5 SLPM. As it can be seen in figure 2, the voltage between the electrodes was increased gradually by monitoring the voltage signals (probe Tektronix P6015A) in the oscilloscope (TBS 2074 Tektronix). When the supplied voltage was sufficient for the breakdown, a drop in the voltage was observed indicating that the arc had stricken. The ramped-up voltage peak before the drop during breakdown was considered as V_b. This was repeated at least thrice for each operating condition. In figure 2, the plasma discharge sustained after the initial breakdown can be seen indicated by "plasma on", where the rotational cycles of the arc was captured as periodic pattern in voltage waveform.

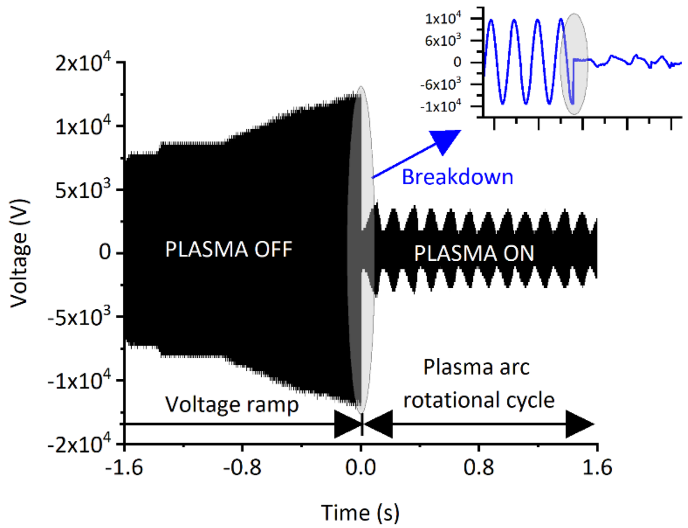

Figure 2. **Voltage waveform showing the breakdown event in nitrogen gas operated at 5 SLPM, having shortest gap between electrodes of 3mm.**

Figure 3 shows V_b obtained for nitrogen and argon operated at 5 and 50 SLPM, having shortest gap between the electrodes as 3 mm. For nitrogen, the measured V_b is 11375 ± 591 V (5 SLPM) and 11917 ± 186 V (50 SLPM). For argon, the measured V_b is 3000 ± 294 V (5 SLPM) and 2933 ± 306 V (50 SLPM). Table 1 shows the electric field at the point of breakdown, calculated using the measured V_b and the gap i.e., 3 mm as the length. For nitrogen, the electric field is of the order of ≈ 4 MVm^{-1}, and for argon it is ≈1 MVm^{-1}. As expected, results show that nitrogen required high electric field for its breakdown unlike argon.

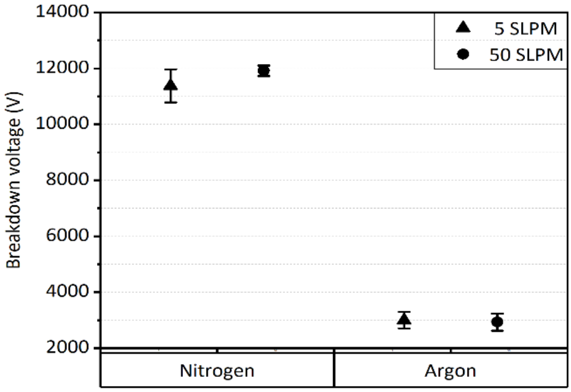

Figure 3. **Breakdown voltage for argon and nitrogen RGA at 5 and 50 SLPM, for the shortest gap of 3 mm between the electrodes.**

Table 1. Electric field required for the breakdown at the operation conditions in this work, having gap of 3 mm.

Gas	Flow rate (LPM)	Electric field (MV/m)
Nitrogen	5	3.79 ± 0.2
Nitrogen	50	3.97 ± 0.06
Argon	5	1.00 ± 0.1
Argon	50	0.98 ± 0.1

For nitrogen discharge, the average V_b increased by 542 V when flow rate was changed from 5 SLPM to 50 SLPM. However, for argon, there was no significant change in the average. To verify the true effect of flow rate and the gas on V_b, ANOVA analysis was performed on the average V_b obtained for the operating conditions studied in this work. Table 2 shows the ANOVA analysis results. The notations used in table 2 are standard self-explanatory abbreviations used in ANOVA. The results revealed that V_b is affected only by the change of gas as expected (F > F crit), whereas the change in flow rate is ineffective.

Table 2. ANOVA results for average breakdown voltage obtained at different flow rates and gas.

Source of Variation	SS	df	MS	F	P-value	F crit
Flow rate	56406	1	56406	1	1	161
Gas	75327934	1	75327934	814	0	161
Error	92517	1	92517			
Total	75476858	3				

The results indicate that the flow nature such as transitional or turbulent which tend to alter the flow collisional dynamics inside the reactor has no effect in V_b. In other words, collisional effects do not dictate breakdown in RGA. Further it indicates that the classical Paschen law used to calculate V_b fails in RGA, corroborated by the report of Amanda et al. [6] on conditions such as high pressures and large gap distances. Further, under such conditions, it is suspected that the electron avalanche causes high space charge field, resulting in streamer formation.

Based on these observations in this work, authors present preliminary understanding that the breakdown phenomena in RGA have streamer formation, and do not follow Paschen law. Further investigation involving sophisticated high-speed imaging of good spatial and temporal resolution is required to confirm the streamer formation, which will be a study for future.

References

[1] J. Ananthanarasimhan, R. K. Gangwar, P. Leelesh, P. S. N. S. R. Srikar, A. M. Shivapuji, L. Rao, Estimation of electron density and temperature in an argon rotating gliding arc using optical and electrical measurements, Journal of Applied Physics, 129 (2021) 223301. https://doi.org/10.1063/5.0044014

[2] J. Martin-del-Campo, S. Coulombe, J. Kopyscinski, Influence of Operating Parameters on Plasma-Assisted Dry Reforming of Methane in a Rotating Gliding Arc Reactor, Plasma Chemistry and Plasma Processing, 40 (2020) 857–881.

[3] A. Fridman, (2008) Plasma Chemistry, Cambridge University Press, Cambridge, UK.

[4] J. Ananthanarasimhan, R. Lakshminarayana, M. S. Anand, S. Dasappa, Influence of gas dynamics on arc dynamics and the discharge power of a rotating gliding arc, Plasma Sources Science and Technology, 28 (2019) 085012.

[5] J. Ananthanarasimhan, A. M. Shivapuji, P. Leelesh, L. Rao, Effect of Gas Dynamics on Discharge Modes and Plasma Chemistry in Rotating Gliding Arc Reactor, IEEE Transactions on Plasma Science, 49 (2021) 502–506

[6] A. M. Loveless, A. L. Garner, A universal theory for gas breakdown from microscale to the classical Paschen law, Physics of Plasmas, 24 (2017) 113522. https://doi.org/10.1063/1.5004654

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Conflict of interest: NIL

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