9th Asia-Pacific Conference on Plasma Physics, 21-26 Sep, 2025 at Fukuoka

# Cold atmospheric pressure micro-plasma jet in a transverse magnetic field : effect of field induced plasma water activation on seedling growth

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Atmospheric pressure plasma jet (APPJ) are non-equilibrium plasmas that have widely varying electron (~ 6000 K) and ion temperatures (~ 300 K). These plasmas are created in ambient air, and its interaction with the atmosphere leads to formation of reactive oxygen and nitrogen species (RONS), which are quite beneficial and have led to a variety of applications of the jet in areas such as biology, medicine, agriculture, surface processing and environmental remediation. The objective of this study is two-fold, firstly employing optical emission spectroscopy the evolution of plasma and gas parameters such as the electron excitation temperature ($T_{exc}$), electron density ($N_e$), and gas temperature ($T_g$) in the plasma jet are investigated, as a function of applied magnetic field ($B$) that is transverse to the jet propagation. Thereafter, by letting the jet interact with water we create plasma activated water (PAW) at six different values of $B$ in the following range: (i) $B$ = 0 G (ii) $B$ = 0 – 500 G (iii) $B$ = 500 – 1500 G (iv) $B$ = 1500 –2250 G, and (v) $B$ = 2250 – 3250 G. As a special case, (vi) PAW is created at 1470 G, where collisionally broadened ion cyclotron resonance (ICR) for $N_2^+$ ions is expected to occur at an applied frequency $f$ of 80 kHz (for ICR, $f = qB/2\pi M$, $q$ is the ionic charge assumed to be single and $M$ is the mass of the ion $N_2^+$) [1]. The PAW is then applied for investigating seed germination and growth of flowering plants. Zinnia flower seeds which are quick to germinate and thrive in summer weather have been chosen in the experiments. As per the above cases, the seeds are kept in 6 miniature pots in a Seed Starter Tray with controllable Plant Light and with humidity domes, the pots are filled with standard potting soil mix purchased from Trustbasket (item Redsoil). Measured quantities of PAW (10 ml) is regularly applied to each pot over a period of 2 weeks and observations of the soil quality, germination of the seeds, and thereafter growth of saplings is recorded and reported. The soil quality is tested in terms of pH, fertility, temperature, moisture, air humidity, and illumination levels using a soil tester, and the sapling growth is recorded with a ruler scale.

The experimental system (Fig. 1 (a)) consists of a capillary tube with a needle-to-ring electrode configuration [2]. The applied voltage and frequency can be varied in the range of 0.2–4 kV and 70–100 kHz. High voltage is applied to the central needle electrode and the ring electrode is grounded. Helium gas (99.999% purity) is passed through the capillary at 5 lpm using a mass flow controller and the applied voltage is fixed at 1.75 kV pp and $f$ = 80 kHz. The gas breaks down and emerges from the capillary as a fine micro-plasma jet (cf. Fig 1 (a)). A solenoid magnet (Fig. 1 (b)) with a gap of 1 cm between the pole pieces creates the transverse magnetic field, where the jet is placed. Optical emission from the plasma is captured using an UV/VIS optical fiber bundle (SR-OPT-8024) with 19 fibers of 200 μm core diameter and taken to a high-resolution spectrometer (Andor Technologies, Shamrock 750) with 1200 and 1800 lines/mm gratings (0.02 nm resolution). Boltzmann plot method is employed to determine $T_{exc}$, $T_g$, and Stark broadening of the Hydrogen spectral lines namely $H_\alpha$ (656.3 nm) and $H_\beta$ (486.1 nm) are employed to determine $N_e$.

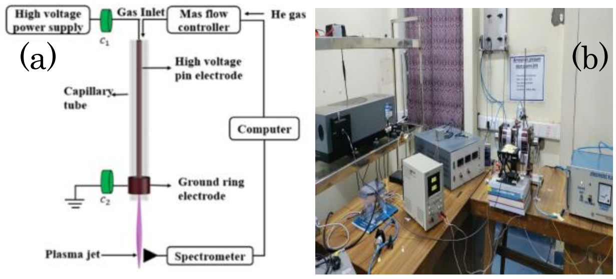


Figure 1 (a) Schematic of the experimental set-up (b) digital photo of the complete set-up with the solenoid.

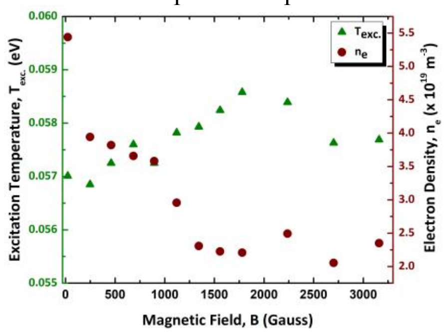


Figure 2 Electron excitation temperature $T_{exc}$ and plasma electron density $N_e$ as a function of magnetic field

Figure 2 shows a plot of $T_{exc}$ and $N_e$ measured as a function of $B$. $T_{exc}$ is seen to decrease at first and then gradually increases after 250 G until about 1750 G and thereafter decreases again. The peak is located near the ICR field of 1450 G. Overall, $N_e$ is seen to decrease with $B$ but the decrease is not monotonic. This observation was also reported in a previous article [1]. The PAW generation is therefore investigated in different ranges of $B$ values in accordance with the changes in $N_e$. Experimental results employing PAW for seed germination, and thereafter growth of saplings will be presented at the conference.

References

[1] K. Barman, et al., Physics of Plasmas, **28**, 123503, (2021)

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