



Enriching Oxygen Content in Air by Nonequilibrium Plasma

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Mechanism of plasma assisted air enrichment

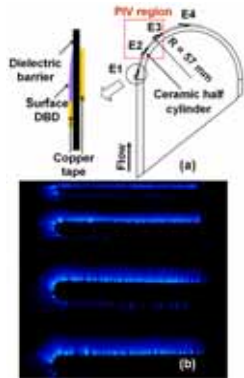
Abstract

This presentation describes an exploratory study of the physics necessary to advance the development of a low power, small scale, air separation unit (ASU) based on non-equilibrium plasma discharges (PD-ASU). In essence, this idea is derived from a results of prior studies that the dominant ionic charge carriers are negative ions of molecular oxygen (O_2^-) during the Dielectric Barrier Discharge (DBD) process in atmospheric pressure air flows, that is, the plasma can selectively apply a body force on oxygen in air. In this poster, we present phase locked PIV studies to demonstrate this selective oxygen transport along with a preliminary effort to find an optimized design of the PD-ASU. The latter part consists of electric field simulation in quiescent air using a commercial software, Multi Physics (COMSOL), and progress towards the development of a prototype separation cell. In addition, we present preliminary measurements of cell separation performance taken using a gas chromatograph. The result shows that the air chemistry is easily changed by as much as $\sim 1\%$. Our ongoing study is aimed at improving the separation performance by further optimizing the current prototype.

Conventional Wisdom of Plasma Based Suction

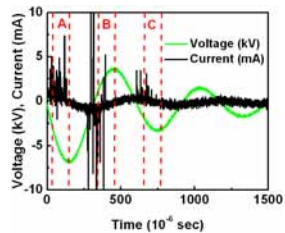
- Ions from nitrogen (typically N_2^+) produced by a plasma discharge play a central role in suction mechanism.
- J. P. Boeuf, Y. Lagmich, Th. Unfer, Th. Callegari, and L. C. Pitchford, *J. Phys. D: Appl. Phys.* 40, 652 (2007).
- G. I. Font and W. L. Morgan, *Contrib. Plasma Phys.* 47, 103 (2007).

Experimental Geometry and Photo of DBD



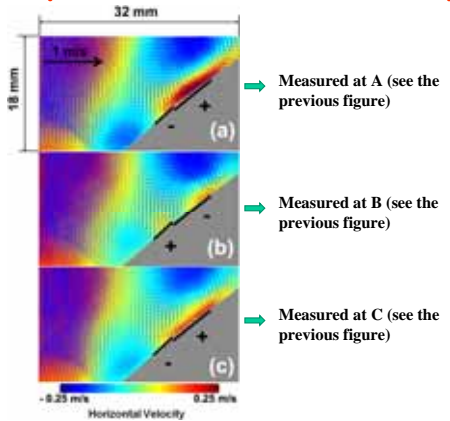
- Speed of freestream air = 0.7 m/s
- DBD voltage = 11 kV p-p
- DBD frequency = 260 Hz
- Dielectric: 520 μ m thick glass fiber dielectric tape.
- Electrode: 90 μ m thick copper electrode foil
- Note: only E2 or E3 is activated for single actuator configuration.

Current & Voltage Profile (Single Electrode Pair)



- Voltage measured at an exposed electrode
- Current measured at a buried electrode
- Asymmetric current profile: Current is higher in forward stroke (when the exposed electrode is negatively biased relative to the buried electrode)

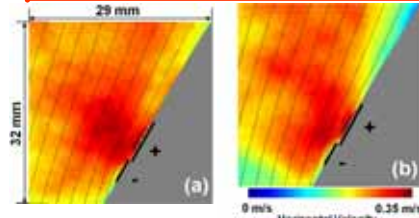
Phase Locked PIV (Single Electrode Pair)



- Measured at A (see the previous figure)
- Measured at B (see the previous figure)
- Measured at C (see the previous figure)

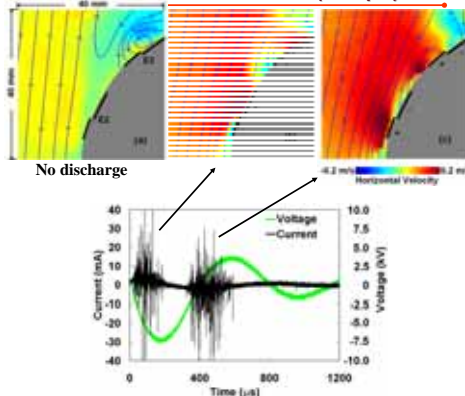
- More significant flow suction in the forward stroke
- Negatively charged species are more important in the flow dynamics.

PIV in Oxygen/Nitrogen Enriched Air (Single)



- 31 % oxygen in air
- 83 % nitrogen in air
- Oxygen is more important in controlling the flow.

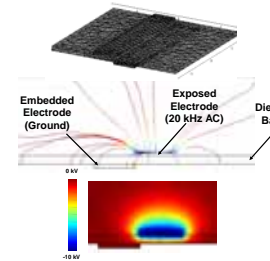
Cross-talk between Pairs (Multiple)



- Near-symmetric discharge current: an evidence of the cross-talk between adjacent discharge pairs.

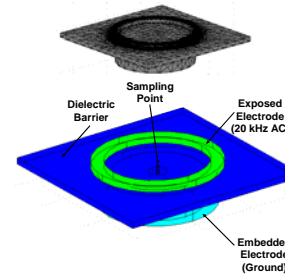
Design optimization of PD-ASU

Conventional DBD Cell



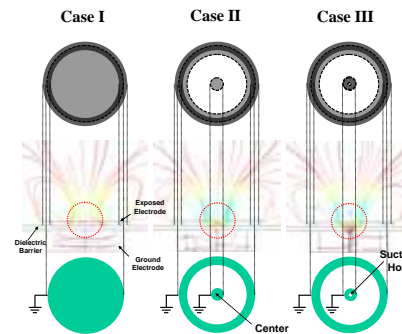
- It is difficult to collect negative (oxygen) ion using the straight-line plasma cell.

Concentric DBD Cell



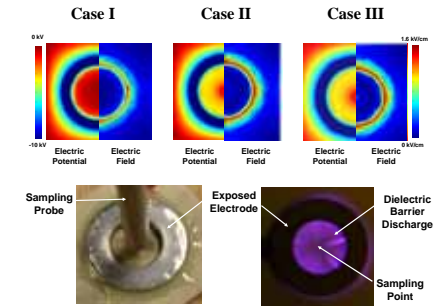
- Concentric plasma cell configuration provides stagnation point at the center.
- It is convenient to collect negative ions at the sampling point.

Design Optimization

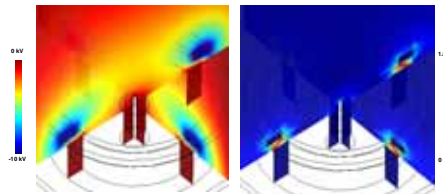


- Ground (embedded) electrode is modified to guide electric field toward the center of the cell.
- Case III is the most effective configuration pulling negative ion toward the suction hole.

Electric Potential/Field on a Dielectric Barrier

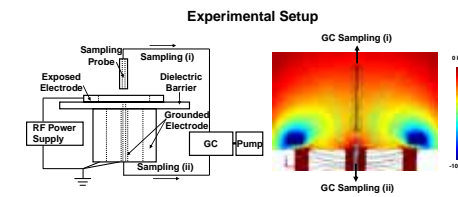


Case III



- Outer rim of the ground electrode causes strong electric field producing plasma discharge.
- Center core guides electric field toward the center.

Gas Chromatography (GC) Analysis



- Oxygen concentration is decreased by approximately 1.1 % when sampled above the center of the cell (sampling (i)).
- Oxygen concentration is decreased by approximately 0.2 % when sampled by the hole through the center core (sampling (ii)).
- Ozone production and negative oxygen ion attraction to the core would cause the concentration difference: ozone production consumes oxygen and the electric field pulls oxygen ion toward the center core (sampling (ii)).

Conclusion and Future Work

- Negative ion (oxygen ion) is mostly responsible for plasma induced flow near the surface of dielectric barrier discharges in air.
- The PD-ASU design is optimized to collect negative ions effectively using a preliminary electric field simulation.
- Oxygen concentration decreases at the center of the concentric plasma source.
- Further design modification is required (e.g. multi-stage plasma separators).
- Electron energy and plasma frequency will be optimized to produce more oxygen negative ions.