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 nonequilibrium plasma discharges (PD-ASUs). In essence, this idea is derived from a recent study that the dominant ion species are negative ions of molecular oxygen (O₂⁻) during the Dielectric Barrier Discharge (DBD) process in atmospheric pressure air flows. Since the plasma can selectively apply a body force on oxygen in air, 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 a preliminary field simulation in quasi-steady 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 ~1%. Our ongoing study is aimed at improving the separation performance further, optimizing the current prototype.

Conventional Wisdom of Plasma Based Suction

• Ions from nitrogen (typically N⁺) produced by a plasma discharge play a central role in suction mechanism.


Experimental Geometry and Photo of DBD

PIV in Oxygen/Nitrogen Enriched Air (Single)

• Speed of freestream air = 0.7 m/s
• DBD voltage = 11 kV p-p
• DBD frequency = 260 Hz
• Dielectric: 520 µm thick glass fiber dielectric tape
• Electrode: 90 µm 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)

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

More significant flow suction in the forward stroke

• Negatively charged species are more important in the flow dynamics.

Conventional DBD Cell

 measured at A (see the previous figure)

Concentric plasma cell configuration provides stagnation point at the center.

It is convenient to collect negative ions at the sampling point.

Phase Locked PIV (Single Electrode Pair)

Measured at B (see the previous figure)

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

Exposed Electrode (Ground)

Gas Chromatography (GC) Analysis

• Concentric plasma cell configuration provides stagnation point at the center.

• It is convenient to collect negative ions at the sampling point.

Cross-talk between Pairs (Multiple)

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 (suction (ii)).

Design Optimization

Case I

• No discharge

• Oxygen concentration is decreased by approximately 0.2 % when sampled near the surface of dielectric barrier discharge.

• Cross-talk between adjacent discharge pairs.

Electric Potential/Field on a Dielectric Barrier

Case I

• Concentric DBD Cell

• Electric Field

• Electric Potential

Note: only E2 or E3 is activated for single actuator configuration.

Case II

• Exposed Electrode (GND)

Design Optimization

Case III

Oxygen concentration is decreased by approximately 1.1 % when sampled near the center of the cell (sampling (ii)).

• Oxygen concentration is decreased by approximately 0.2 % when sampled near the suction hole.

• Oxygen 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 discharge.

• 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.

Note: only E2 or E3 is activated for single actuator configuration.