Preliminary Characterization of NO_x Abatement by Atmospheric Pressure Dielectric-Barrier Discharge Plasma

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Abstract: This work presents preliminary computational and experimental results evaluating conventional Dielectric-Barrier Discharge (DBD) and membrane DBD (mDBD) reactors for NO_x (NO and NO_2) abatement. Experimental results using the DBD reactor show NO_x abatement rates of up to 100% at an energy cost of 1.0 g_{NOx}/kWh. Modeling results indicate that the mDBD reactor may improve the energy efficiency of DBD-based NO_x abatement.

1. Introduction

Carbon-free fuels, such as hydrogen-ammonia (H_2/NH_3) blends, are key for decarbonizing internal combustion engines. However, the combustion of these novel fuels can result in higher NO_x (i.e., NO and NO_2) emissions [1,2], which should be avoided [3]. DBD plasma devices, capable of generating highly reactive species and responding rapidly, are appealing for NO_x abatement, particularly in treating emissions from compression ignition engines [4], such as large stationary engines operating under dynamic loads with a higher tolerance to energy costs.

The use of a porous dielectric membrane may enhance the performance of DBD reactors. This work presents preliminary computational and experimental evaluation of a membrane DBD (mDBD) reactor for NO_x abatement.

2. Methods

The mDBD reactor (Fig. 1a) generates plasma within a 2 mm gap between two dielectric layers. The powered electrode is hollow and perforated, and it is surrounded by a porous dielectric membrane to allow radial gas transport. The reactor allows 3 modes of operation: (regular) DBD, pure mDBD, and hybrid, with annular and radial flows.

The mDBD plasma reactor is evaluated under operation with a 22 kHz high-voltage power supply and a working gas mixture of 975 ppm NO and 1095 ppm NO_2 in N_2, simulating combustion exhaust from a H_2/NH_3 fuel blend under lean-to-stoichiometric conditions [2]. Performance of the reactor comprises thermo-fluid computational model simulations and evaluations across varying power (70-200 W) and flowrate (1-3 slpm) conditions through electrical diagnostics, optical spectroscopy, and FT-IR spectroscopy.

3. Results and Discussion

A thermo-fluid computational model evaluates the mDBD reactor's performance under varying operating modes. Representative results (Fig. 1b) for a 1 slpm flow rate with the heat source off reveal significant changes in the characteristic gas transport time for the three operating modes: 0.29 s for DBD (all flow through the annular inter-dielectric barriers gap), 0.57 s for pure mDBD (all flow passing radially through the membrane), and 0.38 s for the hybrid mode (half the flow through the membrane).

Experimental results of the reactor operating in the DBD operation mode (Fig. 1c) show complete NO_x abatement at low flow rates (0.5 and 1 slpm) and over 90% abatement at

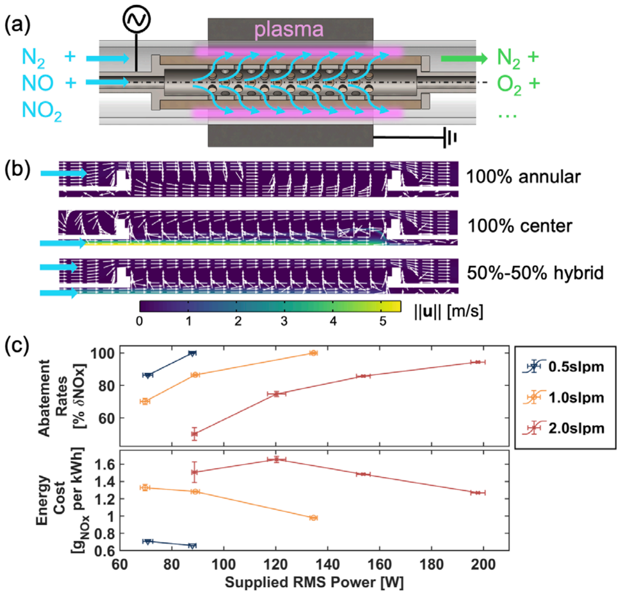

Fig. 1. (a) mDBD reactor, (b) computational thermo-fluid model results for the reactor operating in 3 different modes, and (c) NO_x abatement efficiencies in DBD mode.

2 slpm. The highest abatement energy efficiency of 1.6 grams of NO_x per kWh was observed at a flow rate of 2 slpm with approximately 120 W of power input.

4. Conclusion

This study presents preliminary thermo-fluid modelling and experimental results on NO_x abatement using DBD and mDBD reactors. DBD reactor experiments achieved up to 100% NO_x abatement but with high energy consumption. Thermo-fluid modelling of the mDBD reactor indicates an extended characteristic passing time compared to the DBD reactor that may enhance NO_x abatement performance.

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