CAE-Based Design and Optimization of a Plasma Reactor for Hydrocarbon Processing

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Abstract

Plasma reactors can be applied to the conversion of waste, biomass and fuels to synthesis gas (mixture of hydrogen and carbon dioxide) with efficiencies as higher as 90-95% and low energy demand, depending on the design optimization. In particular, a complex process occurs at the electrode, where the interaction of the fluid dynamics, the chemical reactions and the electromagnetic field dictates the stability and performance of the equipment. In this regard, computational resources may be applied in the early phase of conceptual designs and for the analysis of installed devices, allowing for cost and time saving as well as better understanding of the phenomena involved. In this work, a multi-step approach was applied to the investigation of the main physics involved in a rotating gliding arc (RGA) discharge reactor. Initially, COMSOL Multiphysics® was applied to the computational simulation of the fluid flow in a 3D geometry (Figure 1) representing a real equipment operated under similar conditions in lab scale. The CFD Module, particularly the single phase flow physics interface, was used and the velocity and pressure fields were extracted (Figure 2). Nitrogen (N2) and propane (C3H8) were fed to the system at two separated locations and with varying mass flow rate ratios. This data was then used for the calculation of the chemical composition of N2 at the electrode region using the software Chemical Equilibrium with Applications (CEA), provided by Glenn Research Center - NASA (Figure 3a). Additionally, the pressure profile obtained from the fluid flow simulation was used as an input for a home-made MATLAB® code based on Paschen's law to calculate the breakdown voltage at the electrode as a function of the pressure and the gap length (Figure 3b). Finally, 2D simulations were performed in COMSOL Multiphysics using the AC/DC Module and information about the difference of potential and the electric field at the electrode was obtained (Figure 4).

Reference

Edward Koretzky, Spencer P. Kuo, Simulation study of a capacitively coupled plasma torch array, IEEE Transactions on Plasma Science, 29, 5 p. (2001).

Spencer P. Kuo et al., Methods and apparatus for generating a plasma torch, Int. Cl. B23K 9/00, US 6,329,628 B1, Dec. 10 1999, Dec. 11 2001.

Figures used in the abstract

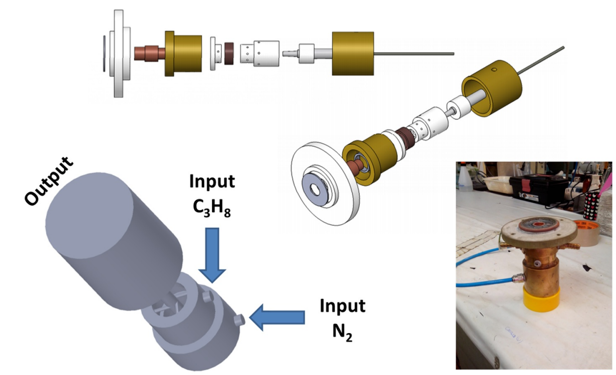

Figure 1: Overview of the rotating gliding arc (RGA) discharge reactor, highlighting the input and output setup, the internal features and the real equipment in lab scale.

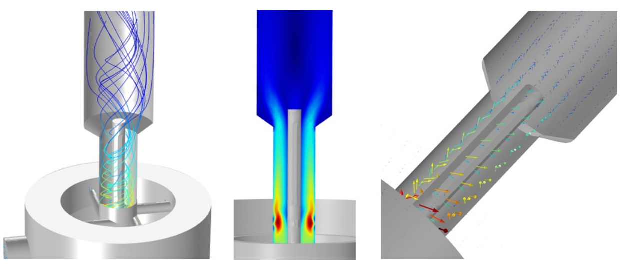

Figure 2: Overview of the fluid flow at the electrode region.

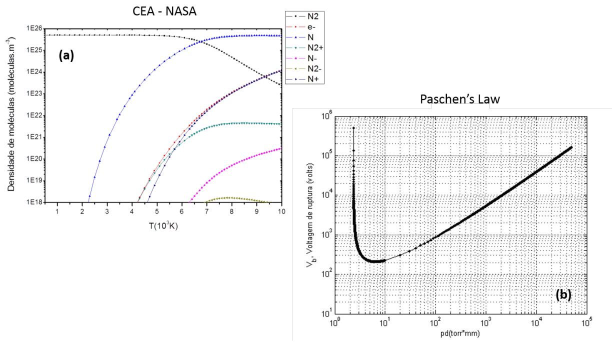

Figure 3: Auxiliary calculations: (a) NASA's CEA (carrier gas composition); (b) Paschen's law (breakdown voltage as a function of pressure and gap length).

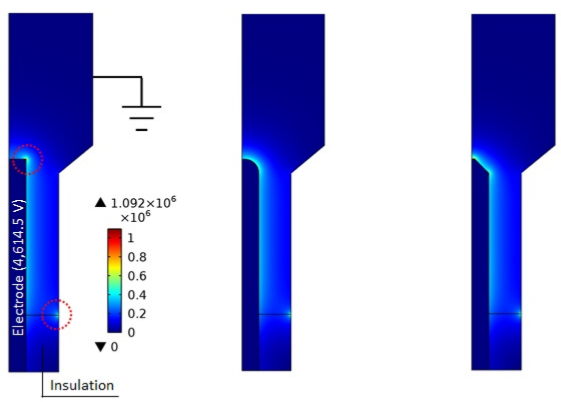

Figure 4: Electric field norm (V/m) at the electrode region.