Fluid Dynamics Analysis of Gas Stream in a Plasma Torch Reactor

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Abstract

Plasma technology has potential applications in a wide range of areas, such as microwave reflectors/absorbers, material processing, sterilization and chemical neutralization. Particular interest has been devoted to atmospheric-pressure plasma sources, devices in which an open cavity expose plasma torch directly to the atmosphere. However, the design of such structures is highly complex, since its optimum arises from the delicate balance of the magnetohydrodynamics variables that govern the physical phenomena. In these devices a gas stream flows through an electrical discharge between pairs of electrodes to produce a plasma torch. The knowledge about the fluid behavior in such systems has a central role, since the stability of the flow in the region of the electrical arc is essential for the development of a well-behaved torch. Furthermore, such analysis has deep impact on the concept of the equipment geometry, allowing for the identification of critical points that contribute to waste of energy. Since the size of the torch depends on the velocity of the gas in the level of the electrodes, frequently highly complex turbulent flow is observed. CFD techniques can be successfully applied to save time and costs in the design of such devices, leading to the optimization of the geometric parameters in the early stage of the project. However, despite the huge potential of the application of numerical methods in this field, few works have been carried out. In this work, a numerical analysis of the gas flow inside a three-dimensional model, based on a plasma torch device previously described in the literature, was carried out in COMSOL Multiphysics® software. The geometry consisted in a cylindrical pre-chamber with 25 mm of diameter and height of 10.5 mm. A nozzle placed on the bottom of the pre-chamber fed the gas stream, with different velocities, ranging from 10 m/s to 50 m/s. Once inside the pre-chamber, the gas stream was allowed to flow through four constrictions, radially equidistant. Those constrictions connected the pre-chamber to another one, also cylindrical with 12 mm of diameter and height of 23 mm, coincident with the top of the pre-chamber, with an annular block of 6.3 mm of diameter in the outlet region. The gas stream was allowed to freely flow inside this compartment, yielding a vorticity pattern, and exit through an open cavity placed on top of the chamber. Reynolds-Averaged Navier-Stokes (RANS) equations were employed to describe the turbulence in this process, through k-ε model. Figures 1-3 show the steady-state velocity profile evaluated on the geometry studied. The results showed that the peak of velocity was obtained at the constrictions that interconnect the two chambers. The flow was, however, equally distributed among the four constrictions. Furthermore, a stabilized rotational upward flow with high velocity was observed in the region of the electrical discharge, indicating the development of a viable torch.

Reference

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

2. 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

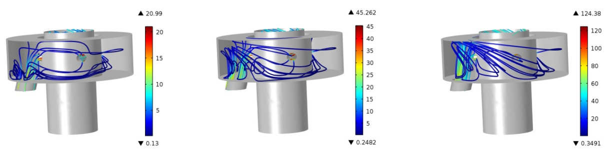

Figure 1: Streamlines for inlet velocities of 10, 20 and 50 m/s.

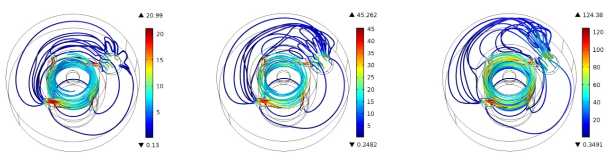

Figure 2: Stable vortice in the outlet of the model, in the region of electrical discharge (inlet velocities of 10, 20 and 50 m/s).

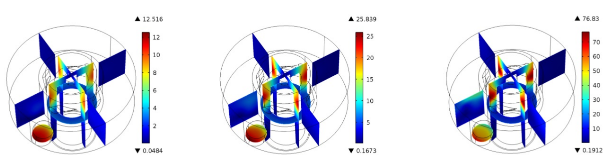

Figure 3: Slices indicating the velocity profile inside the model (inlet velocities of 10, 20 and 50 m/s).