Modelling of heat flow and electromagnetic phenomena in a non transferred plasma torch

S.S.Likitha[1,*], L.G. Westerberg[1], H.O.Åkerstedt[1], H.Wiinikka[2], A.Sepman[2]

[1]Division of Fluid and Experimental Mechanics, Luleå Uniersity of Technology, SE-971 87 Luleå
[2]RISE Energy Technology Center, Industrigatan 1, SE-941 38 Piteå, Sweden

1 Introduction

Plasma torches are used in a wide number of applications such as the processing of materials and the energy industry. They have also become an attractive alternative to fossil fuel-driven burners as heat sources in the process industry. The available torches (burners) today are however small in comparison to many industrial fossil fuel-driven burners, leading to a need of a proper understanding of the dynamics when scaling up the plasma torch power. As a first step, it is important to understand effect of different parameters on the formation and development of plasma jet inside a plasma torch. In this paper the dynamics inside a non transferred plasma torch is modelled numerically, using COMSOL Multiphysics and the Equilibrium Discharge Interface (EDI). Different velocities, swirl numbers and input current conditions are considered.

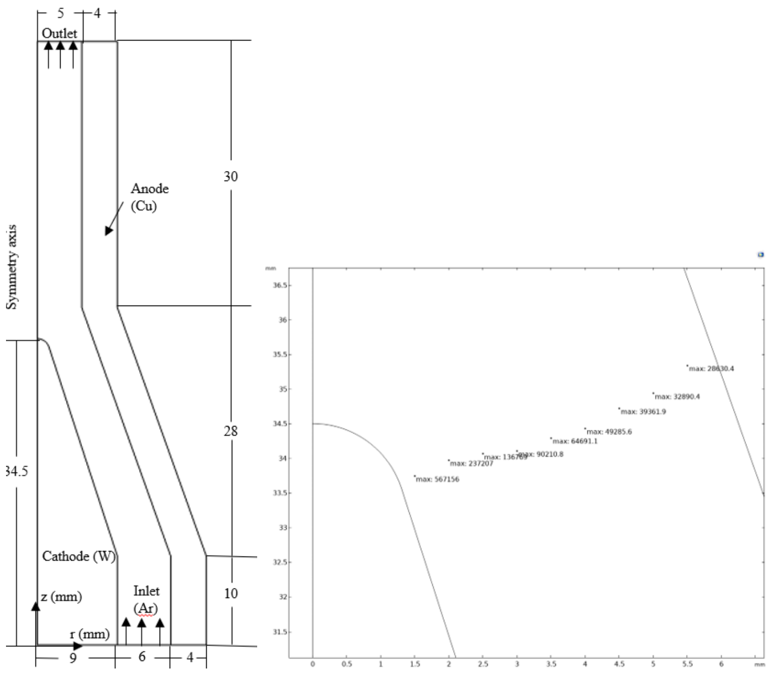
2 Numerical model

High-intensity DC arcs present in actual geometry can be considered to meet the conditions for partially or complete local thermodynamic equilibrium (LTE) [1]. For length scales of the order of the dimensions provided by the geometry, the flowing medium can be treated as a continuous fluid. This in turn yield that the MHD equations can be used [2]. In COMSOL, the Equilibrium Discharge (thermal plasma) Interface model is essentially an MHD model with some further modelling facilities and assumptions[1] which lead to a set of simplified MHD equations (Ref. [3], p. 222).

Figure 1 shows the geometry considered. Here Argon is injected through the marked inlet integrating the Copper anode and Tungsten cathode. The analysis is carried out for different inlet velocities. The top boundary is a pressure outlet with ambient (atmospheric) pressure. The electrode boundaries are defined as walls with given electric current and magnetic properties. The cathode tip is also defined with a 3500 K temperature for thermionic emissions. Finally, the heat

*Corresponding author. E-mail address: likitha.siddanathi@ltu.se. Telephone: +46 920 491000

[1]Namely: Fully ionized plasma, LTE, Newtonian flow, laminar- and quasi-incompressible flow, no viscous dissipation or pressure work, negligible displacement current, magnetic Reynolds number $<< 1$, optically thin plasma



(a) (b)

Figure 1: Computational domain (a) and arc orientation for stationary flow (b).

transfer coefficient and external temperature of anode are defined as $10^4\ \mathrm{W/m^2K}$ and 500 K respectively. The computational grid is created with 83,162 free triangular elements without boundary layers. The average element quality is 0.95 which indicates a higher mesh element quality. The simulations are carried out at steady state condition using a stationary solver and a fully coupled solver.

3 Results and discussion

3.1 Influence of inlet velocities

A case study is conducted to understand the influence of inlet velocity on the flow temperature and velocity in the plasma torch. Figure 2 shows the velocity and temperature variations along the center line stretching from the cathode tip to the outlet.Near the cathode tip the flow interacts with the arc discharge and undergoes Joule heating, leading to ionization of the gas and plasma formation, thus resulting in high temperature and increased velocity. The plots also explain that when the inlet flow is turbulent the distribution of velocity towards the outlet is more steady, whereas in laminar case the decrease in velocity is rapid. This statement also is supported by Deng et al. [4] who have done similar work using laminar and turbulent inflows. Further, the temperature distribution is interesting, as near the cathode tip the maximum temperature is the same for all the velocity cases as the current input and cathode tip temperature is same for all the cases. However, as the flow approaches the outlet the temperature is rapidly decreased for the laminar velocity cases. The residence time of plasma gases in the case of laminar flows is longer than that of turbulent flows thus leading to fast energy transfer.

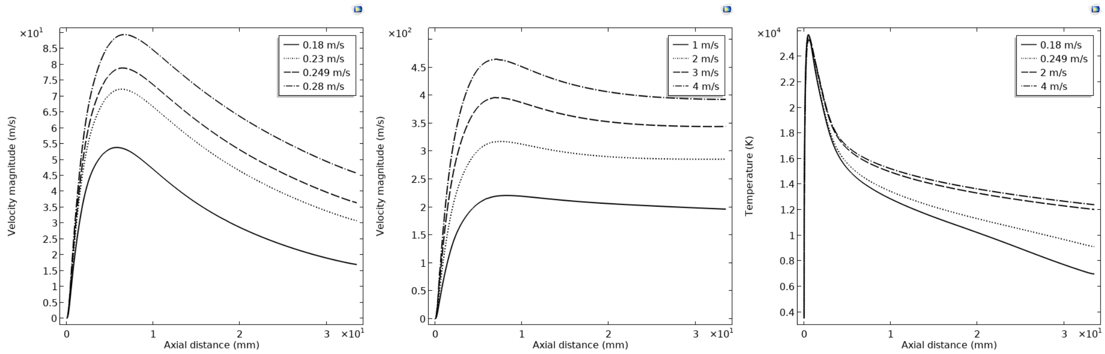


Figure 2: (a) Velocity variation when inlet flow is laminar (left) (b) Velocity variation when inlet flow is Turbulent (middle) (c) Temperature variation for laminar and turbulent velocity cases (right)

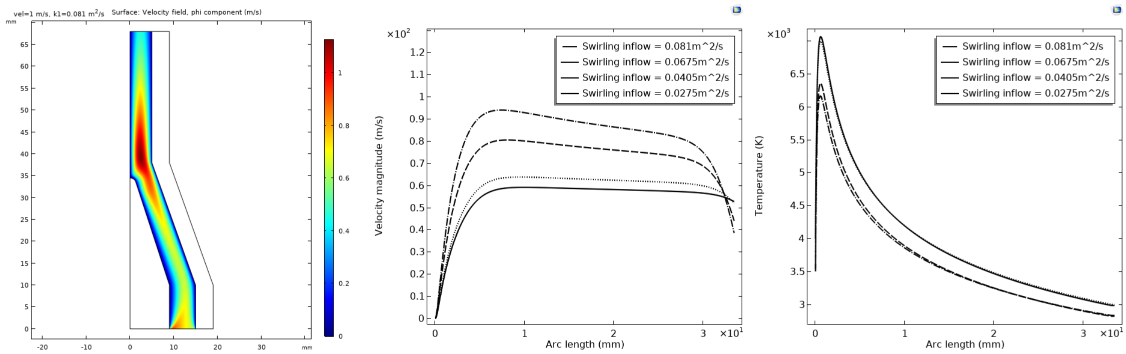


Figure 3: Temperature and velocity variations with respect to swirl flow

3.2 Influence of swirl flow

The high temperature inside a plasma torch leads to anode erosion. The use of Swirling flow can control the erosion as it creates a vortex in the discharge tube and stabilizes the torch flame in the center. Figure 3 shows the temperature and velocity distribution in the plasma torch for different swirl flows. It is observed that an increase in swirl increases the velocity across the plasma torch and decreases the temperature. This trend is also observed by Felipini and Pimenta [5].

3.3 Arc orientation

Klinger et al. [6] states that the plasma arc is formed at the shortest distance between the cathode and anode. This conclusion is confirmed by identifying the peak-current values between the cathod and anode; see Fig. 1b showing the location of the peak values. The arc orientation is then obtained by connecting the dots. For the present stationary case the arc root position is mainly unaffected by the flow velocity and current. The dynamics of the arc location is to be further studied in transient models. The literature states that the velocity also affects the arc length. To investigate this further the movement of electrons from the cathode tip, species modeling and/or a two-fluid model should be developed - something which is reserved for future work.

4 Concluding remarks

In present study, the plasma formation in a non transferred plasma torch is numerically modelled using COMSOL Multiphysics and its Equilibrium Discharge Interface. A steady-state analysis is carried out on a 2D axi-symmetric geometry comprised of a Tungsten cathode, Copper anode, and Argon as working gas. The influence of inlet velocity and swirl flow is studied for different cases. The orientation of the arc is also obtained. It was observed that that velocity has a limited effect on the temperature of plasma jet. The effect of swirling flow could only be observed for high swirling conditions. Finally the arc formed is confirmed to travel the shortest distance between the cathode and anode.

Acknowledgement

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