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Modeling of gas flow in the cylindrical channels of high-voltage plasma torches with rod electrodes

A M Borovskoy, S D Popov and A V Surov
Institute for Electrophysics and Electric Power RAS, 18 Dvortsovaya embankment, Saint-Petersburg, 191186, Russia

E-mail: borovskoi.alex@mail.ru, sergey_popov1973@mail.ru, alex_surov@mail.ru

Abstract. The article is devoted to the calculation of gas dynamic parameters of gas flow in various areas of low-temperature plasma generator, therefore, target area's grid was built for the simulation of plasma gas flow in channels of studied high-voltage AC plasma torches and calculations of three-dimensional gas flow was made using GAMBIT and FLUENT soft-ware and Spalart-Allmares turbulence model, air flow was simulated in the tangential feed's areas, in the cylindrical channel, in the tapering nozzle chamber and in the mixing chamber of plasma torches and outside (in the environment); thus, 3D-modelling of the cold plasma-forming gas flow was performed in cylindrical channels of studied high-voltage AC plasma torches with rod electrodes for the first time.

The physical characteristics of plasma torches (thermal plasma generators) depend on the arrangement of plasma gas supply and on the interaction nature of the gas flow with electric arcs. Plasma torches with power up to 50 kW with rod electrodes, installed in cylindrical channels [1-3], were developed and tested in IEE RAS; and researches were conducted. As result external characteristics of plasma generators and physical parameters of their torches were determined [4-5]. However, the properties of electric arcs, burning in the cylindrical channels, is not fully understood; therefore an attempt was made to simulate cold gas flow at the first stage of modeling of physical processes in channels of plasma torches. The single-phase two-channel (figure 1 (a)) and three-phase three-channel (figure 1 (b)) high-voltage AC plasma torches appear to be under investigations.


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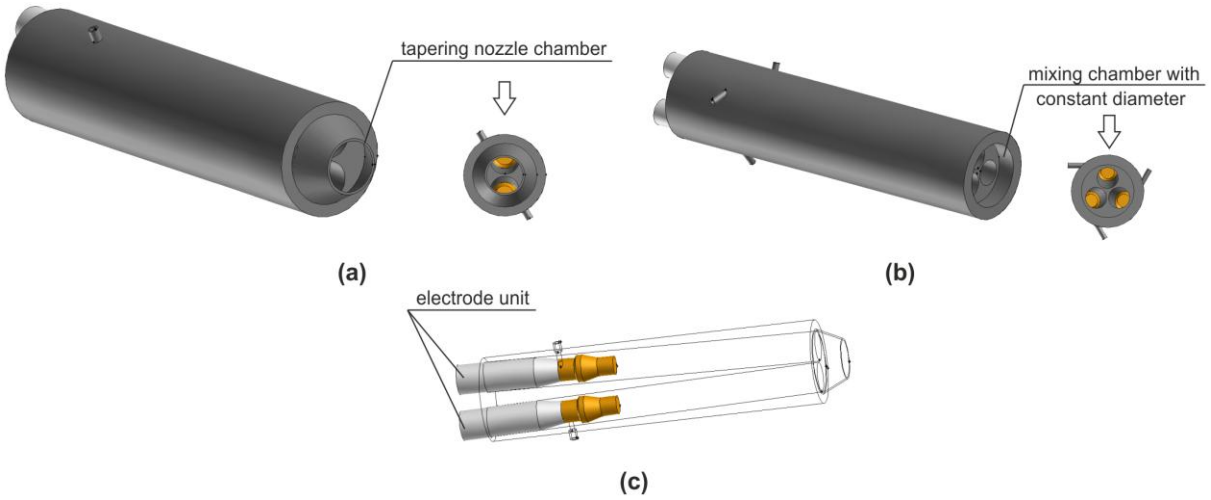


Figure 1. High-voltage AC plasma torches and their electrode units

A two-channel plasma torch has a tapering nozzle chamber (figure 1 (a)) whereas a three-channel plasma torch has a mixing chamber with constant diameter (figure 1 (b)). The investigated plasma torches are identical in design of the electrode sites, but they differ in the geometrical dimensions of channels (figure 1 (c)). The rod electrode, a part of electrode unit of these plasma torches (figure 1 (c)), made in the form of the rotating body, has a common axis with the channel, in which it is installed, and consists of conducting foundation, which is inside the insulator, and of the tip.

The calculation area's mesh was built for the simulation of plasma gas flow using GAMBIT software, the calculations of the gas flow were made using FLUENT software with Spalart-Allmares turbulence model; the gas density was determined by equation of ideal gas, and its viscosity was calculated by the Sutherland's equation with three ratios; the specific heat capacity, the thermal conductivity and the molar mass of the gas were constant. The mass flow of the plasma working gas was asked in tangential feed's inlet sections, united in one surface; the return flows, the temperature of 293,15 K and normal atmospheric pressure (101325 Pa) were asked on the surfaces of the environment, which were taken into account by the external mesh of GAMBIT software. The air flow was also simulated in the tangential feed's areas, in the cylindrical channel, in the tapering nozzle chamber and in the mixing chamber of plasma torches and outside, that is in the environment.

The contours of gas velocities, such as velocity magnitude, tangential, radial and axial velocity components, were built in the various sections on the longitudinal coordinate (figure 2) at optimum work mode (the gas mass flow of 6 and 10 g/s per all channels for two-channel and for three-channel plasma torches respectively); mass-average velocities were calculated and their dependences on the longitudinal coordinate (profiles of mass-average velocities) were built (figure 3); the gas mass flow was from 3 to 15 g/s and from 5 to 18 g/s for two-channel and for three-channel plasma torches respectively. It was revealed that the velocity takes the maximum value in the section of the channel, nearest to the tangential feed, and the velocity is from 40 to 170 m/s for two-channel plasma torch (figure 3 (c)) and from 40 to 135 m/s for three-channel plasma torch (figure 3 (d)). In the case of maximum velocity the major contribution is introduced by mass-average tangential component equal from 15 to 65 m/s and from 30 to 90 m/s for two-channel and three-channel plasma torches respectively. It is also evident that the minimum value of velocity of the working gas flow is observed in the output section of the channel and is from 1,5 to 8,4 m/s for two-channel plasma torch (figure 3 (c)) and from 1,6 to 5,5 m/s for three-channel plasma torch (figure 3 (d)). In the case of minimum velocity the major contribution is introduced by mass-average axial component equal from 1,2 to 6,2 m/s and from 1,4 to 4,9 m/s for two-channel and three-channel plasma torches respectively.

The contours of velocity magnitude and of axial velocity of plasma gas in the output section of the tapering nozzle chamber of two-channel plasma torch (z = 0,39 m) are presented in figure 2 (a) and in figure 2 (b) respectively; and also the contours of velocity magnitude and of tangential velocity were obtained in the section, nearest to the tangential feed. We have the contours of velocity magnitude and of axial velocity of plasma gas in the output section of the mixing chamber of three-channel plasma torch (z = 0,47 m) in figure 2 (c) and in figure 2 (d) respectively; and also the contours of velocity magnitude and of tangential velocity were obtained in the section, nearest to the tangential feed.

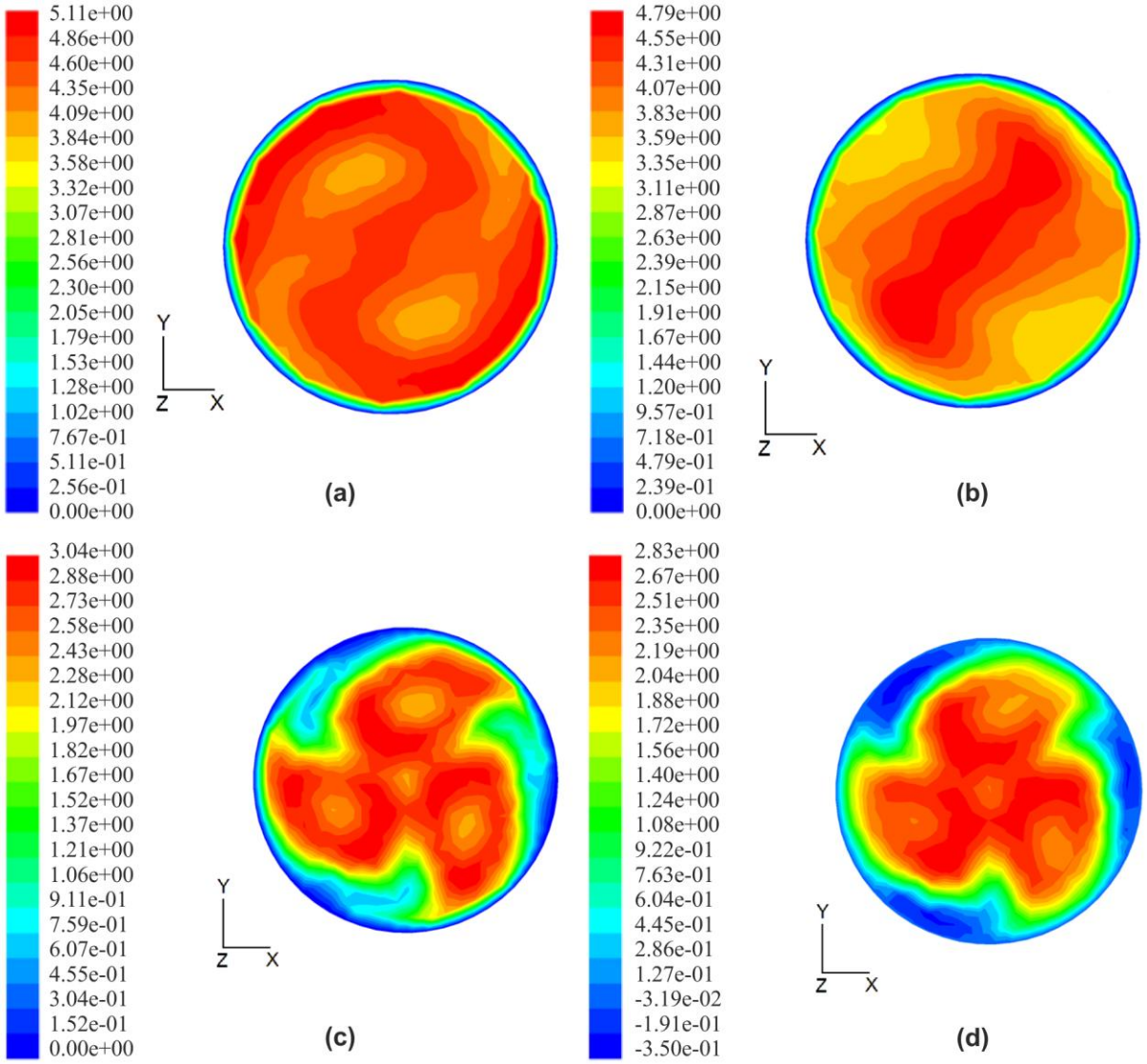


Figure 2. The contours of gas velocities in the sections of the tapering nozzle chamber and in the mixing chamber of plasma torches at optimum work mode

The profiles of mass-average velocity magnitude and of all components of plasma gas at optimum work mode in the channels of two-channel and of three-channel plasma torches are presented in figure 3 (a) and in figure 3 (b) respectively. We have the profiles of mass-average velocity magnitude of plasma gas at various work modes in the channels of two-channel and of three-channel plasma torches in figure 3 (c) and in figure 3 (d) respectively.

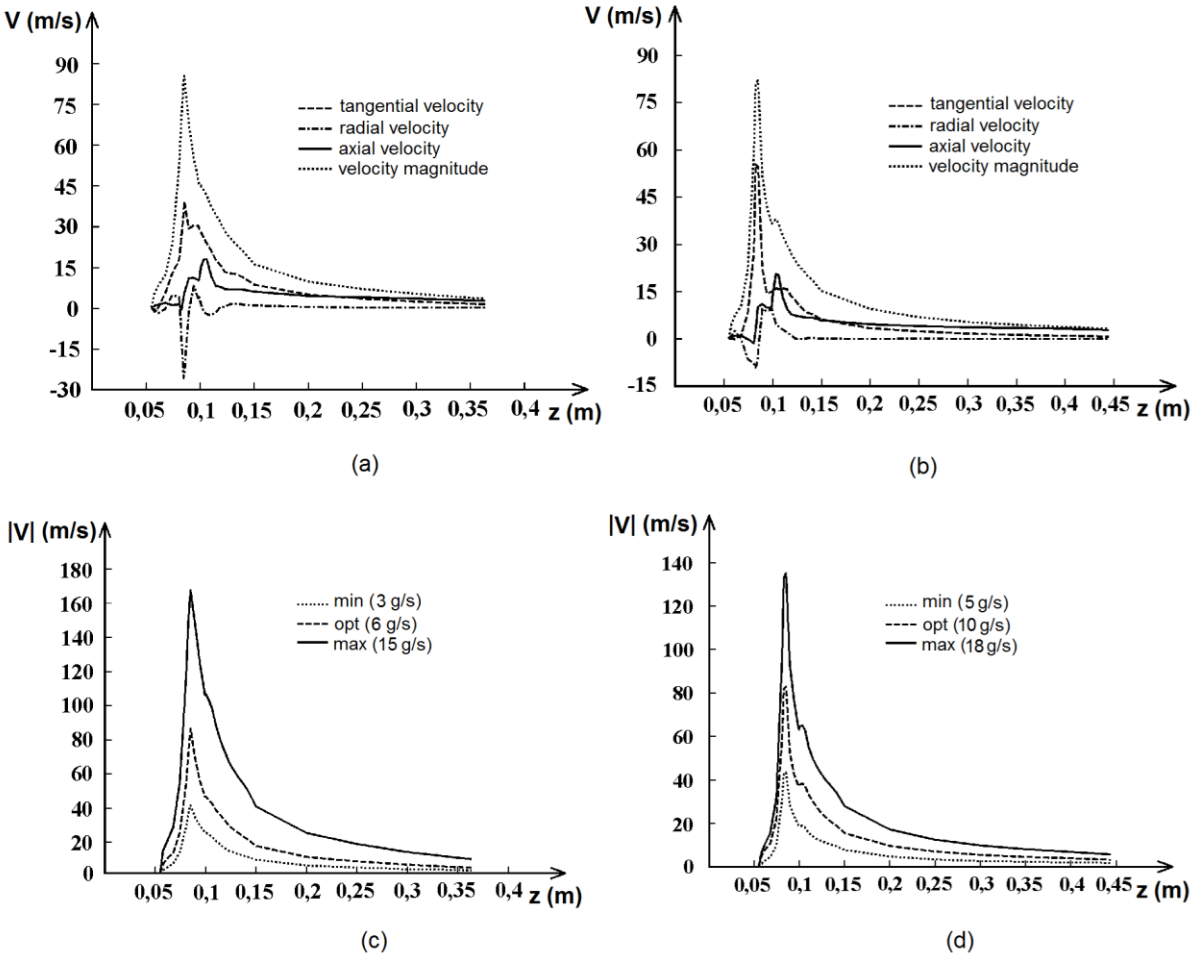


Figure 3. The profiles of mass-average velocities of working gas in the channels of plasma torches

The results of the research show the significant decrease of the mass-average velocity of gas flow in the channels of the investigated plasma torches during movement to exit and outside (in the environment), i.e. from the tapering nozzle chamber of two-channel plasma torch (figure 4 (a) for the gas mass flow of 6 g/s per all channels) and from the mixing chamber of three-channel plasma torch (figure 4 (b) for the gas mass flow of 10 g/s per all channels). The velocity takes the maximum value in the initial section of the tapering nozzle chamber and of the mixing chamber and data vary from 1,5 to 8,2 m/s for two-channel plasma torch (figure 4 (c)) and from 1,6 to 5,5 m/s for three-channel plasma torch (figure 4 (d)). In the case of maximum velocity the major contribution is introduced by mass-average axial component equal from 1,2 to 6,3 m/s and from 1,4 to 4,9 m/s for two-channel and three-channel plasma torches respectively.

The profiles of mass-average velocity magnitude and of all components of plasma gas at optimum work mode in the tapering nozzle chamber of two-channel plasma torch, in the mixing chamber of three-channel plasma torch and in the environment are presented in figure 4 (a) and in figure 4 (b) respectively. We have the profiles of mass-average velocity magnitude of plasma gas at various work modes in the tapering nozzle chamber of two-channel plasma torch, in the mixing chamber of three-channel plasma torch and in the environment in figure 4 (c) and in figure 4 (d) respectively.

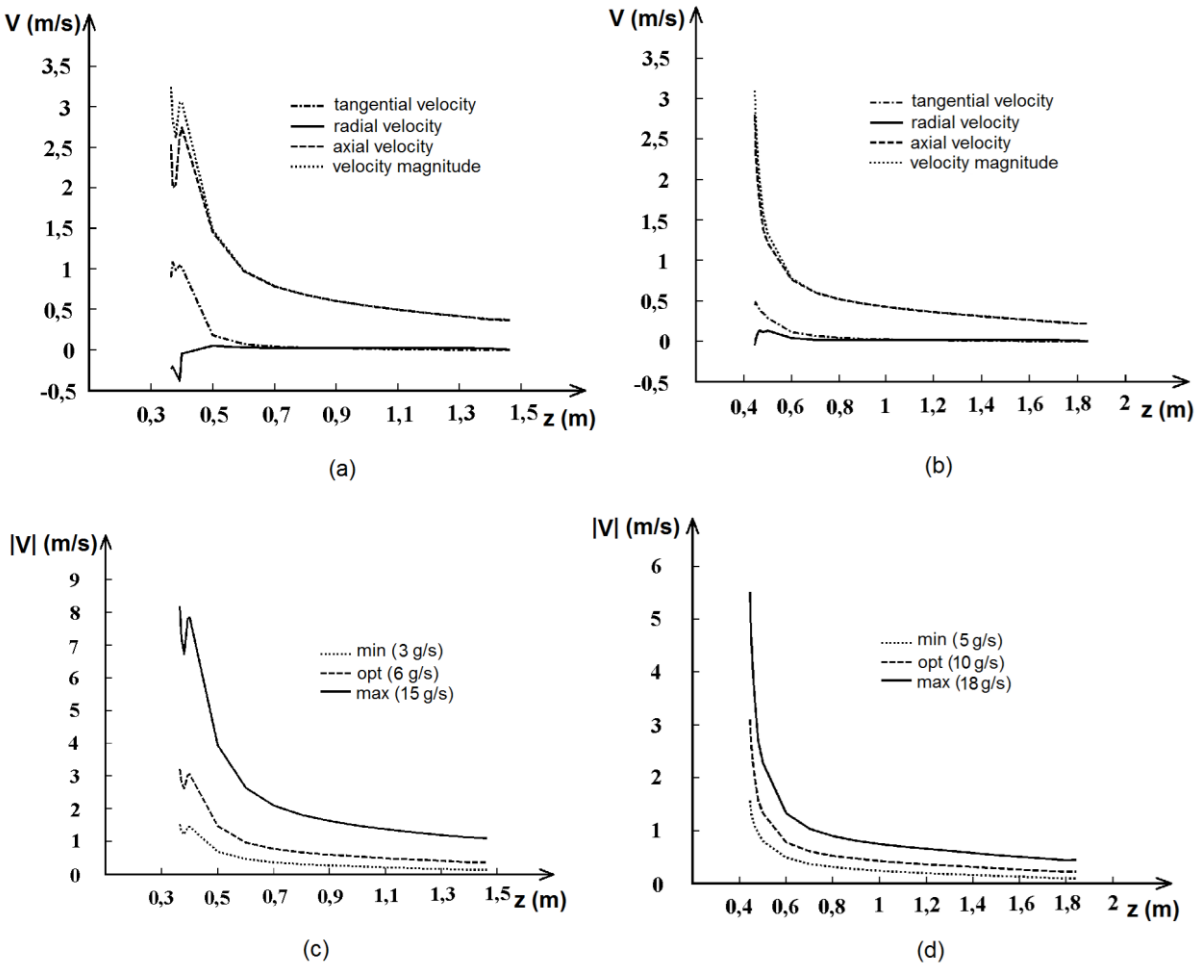


Figure 4. The profiles of mass-average velocities of working gas in the tapering nozzle chamber of two-channel plasma torch, in the mixing chamber of three-channel plasma torch and outside

Conclusion

Thus the contours of parameters of the cold gas flow were calculated in the channels and in the nozzle or in the mixing chamber of high-voltage AC plasma torches with the rod electrodes, as well as velocity profiles of the gas stream were built. It leads to further researches and improvements of the model: the burning of an arc in the channel must be taken into account and the parameters of working high-voltage AC plasma torches will be calculated; also the experimental data, obtained from a testing of this plasma torches with varying mass flow of plasma gas and power, will be used for agreement of the calculating models.

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