On the influence of radiative transfer method in computer simulation of hybrid-stabilized electric arc

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Numerical investigation of properties and processes in the worldwide unique type of thermal plasma generator with combined stabilization of electric arc by argon flow and water vortex, the so called hybrid-stabilized arc, has been carried out. In the hybrid arc two arcs in series are used: The first one is a short gas stabilized argon arc with adjustable gas flow rate. This arc creates a cathode for the second arc stabilized by water vortex. Parameters of the generated thermal plasma jet and plasma composition can be controlled by a change of parameters of both arcs and by conditions of their interaction. At present, this arc has been used for plasma spraying using metallic or ceramic powders injected into the plasma jet, as well as for the pyrolysis of waste (biomass) with production of syngas which seems to be promising environmentally friendly application of thermal plasma jets.

The aim of this paper is a numerical study of the influence of radiative transfer method on processes and parameters in the discharge and near-outlet regions of the hybrid-stabilized arc. In the numerical simulation we assume one-fluid, two-dimensional, axisymmetric, unsteady, compressible and turbulent plasma flow with homogeneous mixing of water and argon species. The complete set of conservation equations for density, velocity, energy and electric potential includes temperature- and pressure-dependent transport and thermodynamic properties.

Two radiation methods are implemented in the energy equation as energy losses from the argon-water plasma: the net emission coefficients for the arc radius of ~ 3 mm, and the partial characteristics method, both of them as functions of temperature, pressure and argon molar content in the plasma mixture. Continuous radiation due to photorecombination and "bremsstrahlung" processes has been included in the calculation as well as discrete radiation consisting of thousands of spectral lines together with O_2, H_2, OH and H_2O molecular bands. Broadening mechanisms of atomic and ionic spectral lines due to Doppler, resonance and Stark effects have been considered. The net emission coefficients method used here is a special case of the partial characteristics method with zero partial sink.

For time integration of the conservative equations we use LU-SGS method coupled with Newtonian iterative method. To resolve compressible phenomena, convective term is calculated using 3rd order MUSCL type TVD scheme. For electric potential we chose TDMA algorithm enforced with the block correction method. Large Eddy Simulation with the Smagorinsky subgrid-scale model is applied to capture possible turbulent behavior.

Results carried out for currents 300-600 A and for argon mass flow rates 22.5-40 slm proved that:

(a) Reabsorption of radiation within the discharge chamber ranges between 31-45 %, it decreases with current and slightly decreases with argon mass flow rate.

(b) The partial characteristics method gives somewhat lower temperatures but in most cases higher outlet velocities and the Mach numbers compared to the net emission coefficients. It was also confirmed that the net emission coefficients method provides somewhat better agreement with experiments as regards the radial temperature profiles 2 mm downstream from the nozzle exit - maximum relative difference between the calculated and experimental temperature profiles is lower than 5 % for the net emission coefficients, and below 10 % for the partial characteristics.

(c) Divergence of radiation flux obtained by the net emission coefficients method is, compared to the partial characteristics, higher in major part of the discharge volume for 500 and 600 A, for other currents it is lower in the axial region and higher in arc fringes.

(d) Relative difference between the two radiation methods for fluid, thermal and electrical characteristics is below 15 % at the axis of the discharge near the outlet nozzle.