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Investigating Plasma Jets Behavior using Axisymmetric Lattice Boltzmann Model under Temperature Dependent Viscosity

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Abstract. This study aims to investigate turbulent plasma flow using the lattice Boltzmann (LB) method. A double population model D2Q9-D2Q4 is employed to calculate the plasma velocity and temperature fields. Along with the calculation process a conversion procedure is made between the LB and the physical unit systems, so that thermo-physical properties variation is fully accounted for and the convergence is checked in physical space. The configuration domain and the boundary condition treatment are selected based on the most cited studies in order to illustrate a realistic situation. The jet morphology analysis gives credible results by comparison with commonly published works. It was demonstrated also that accounting for the substrate as wall boundary condition modify greatly the flow and temperature structures with may affect absolutely the particles behavior during its in-flight in the hot gas.

AMS subject classifications: 35Q20, 35Q30, 76F65, 80M25, 81T80, 82D10, 82C80, 82C70

Key words: LB method, axisymmetric model, temperature dependent viscosity, turbulence, plasma jets.

1 Introduction

Surfaces coating by plasma spraying is an important manufacturing process with many industrial applications. In the last several decades, numerical modeling of plasma spraying processes has met with considerable attention [1–3]. That is in order to well understand the complex phenomena the plasma spray involves, for economic constraints and to well predict the plasma-inflight-particles exchanges since this affects directly the coating formability and microstructure. Plasma jets have been very successful in many

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applications such as spraying, cutting, welding,$\cdots$. The excellent choice of high performance plasma gases and spraying materials has been the subject of several experimental and numerical efforts. An excellent choice will be the response of efficient numerical studies and the results of experimental tests. However, plasma jets are high temperature flows (>8000K); therefore, all diffusion parameters involved in conservation equations are temperature dependent.

This study deals with the investigation of plasma jets using an axisymmetric LB thermal model. We use in the following the axisymmetric formulation based on the J. G. Zhou's model [4].

2 Mathematical considerations

In conventional CFD methods, the conservation equations of macroscopic quantities are discretized to generally up-to second order, which leads to complex algebraic equations. However, in lattice Boltzmann method, the fluid consists of fictive particles that move in consecutive collision – streaming processes over a discrete lattice mesh. Due to its particulate nature, this approach has met with particular interest from researchers and has become a powerful tool in CFD modeling. In other side, jet flows form an important field for scientific research and industrial applications. The jet flows presents some specificity related to its discharging behaviour, in addition to the complexities of treating the boundary conditions for numerical studies. Plasma jets fall into this category and a special treatment is needed due to the high temperature (>8000K) and high velocity fields.

2.1 Continuum governing equations

The continuity, momentum and energy equations governing an incompressible axisymmetric plasma jet flow in (z,r) coordinates are written in tensorial form as follows in the Eq. (2.1):

$$\begin{cases} \partial_j u_j = -u_r/r, \\ \partial_t u_i + u_j \partial_j \partial u_i = -\partial_i p/\rho + v\big(\partial_j^2 u_i + \partial_r u_i/r - u_i \delta_{ir}/r^2\big), \\ \partial_t \theta + u_j \partial_j \theta = \alpha\big(\partial_j^2 \theta + \partial_r \theta/r\big), \end{cases} \tag{2.1}$$

where t is the time, (u_r,u_z) are the radial and axial velocity components, ρ is the fluid density, θ is the dimensionless gas temperature, v is the kinetic viscosity, α is the thermal diffusivity, p is the pressure and δ_{ir} is the Kronecker delta symbol.

2.2 Lattice Boltzmann approach

The lattice Boltzmann (LB) method was proposed a decade ago [5–7] and has been developed to offer an alternative numerical tool to conventional Computational Fluid Dynamics (CFD) for simulating fluid flows. The LB classical collision model (BGK) was