Model for plasma jet-driven magneto-inertial fusion

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Synopsis Mathematical models are developed to model the implosion dynamics for plasma jets-magnetized target system [1-9]. Transport (diffusion, thermal, radiative) processes of atoms, ions, electrons, molecules, photons in a strong magnetic field are taken into account.

We assume that the plasma is quasi-neutral, and use the average ion model to determine Z_i (when it is assumed that all ions of chemical components "i" have the same value Z_i at each point in the computational domain). This can be justified if the distribution of the different degree of ionization is sufficiently narrow.

The average ion charge Z_i (t) can change over time and we can use the formula:

$$\frac{DZ_i}{Dt} = Z_i\left(\nu_I - \nu_{Ph} - \nu_{T.R}\right).$$

The following inelastic processes (electron impact ionization ν_I, photorecombination ν_{Ph} and triple recombination $\nu_{T.R}$) in the one-component case are taken into consideration in calculation:

$$\nu_I = 10^{-7} n_i \left[\frac{I_H}{I(Z_i)}\right]^{3/2} \exp\left[-\frac{I(Z_i)}{kT_e}\right]\left[\frac{I(Z_i)}{kT_e}\right]^{1/2}\left[1+\frac{I(Z_i)}{kT_e}\right]^{-1}$$

$$\nu_{Ph} = 6\times\lambda\times10^{-14} n_i \left[\frac{I(Z_i)}{I_H}\right]^{1/2}\left[\frac{I(Z_i)}{kT_e}\right]^{3/2}\left[1+\frac{I(Z_i)}{kT_e}\right]^{-1}$$

$$\nu_{T.R} = 3{,}3\times10^{-31} Z_i n_i^2 \left[\frac{I_H}{I(Z_i)}\right]^{3/2}\left[\frac{I_H}{kT_e}\right]^{3/2}\left[\frac{I(Z_i)}{kT_e}\right]^{1/2}\left[1+\frac{I(Z_i)}{kT_e}\right]^{-1}$$

where $I_H = 13{,}6$ eV is the ionization potential of hydrogen, $I(Z_i)$ is the ionization energy of the average ion, T_e is the electron temperature (K), $\lambda = 1\div5$, $n_e = Z_i n_i$, $n_i = \rho/M_i$ are electron and ion densities (cm^{-3}).

It is known, that plasma dynamical processes are strongly affected by irradiation, if plasma temperature achieve 1 eV. In that case, the gas dynamic fields of thermal physical variables may be calculated only with taking into account the radiation fields. In this work the radiation transfer equation is used in the form of multi-group diffusion approach:

$$\frac{1}{J}\frac{\partial\left(Jq_{i\xi}\right)}{\partial\xi} + \frac{1}{J}\frac{\partial\left(Jq_{i\eta}\right)}{\partial\eta} + \chi_i c U_i = 4\chi_i\sigma_i T^4,$$

$$\frac{c}{3}\frac{\partial U_i}{\partial\xi} + \chi_i q_{i\xi} = 0, \quad \frac{c}{3}\frac{\partial U_i}{\partial\eta} + \chi_i q_{i\eta} = 0,$$

where $U_i(y, z, t)$ is the radiation power density in i-th spectral group, χ_i is the spectral absorption coefficient. Besides of the method mentioned above, the discrete ordinates method has been used in the work, which gets an opportunity to solve the radiation transfer equation on tetrahedral non–structured mesh. Modified alternatively triangular three-layered iterative scheme is applied for the solution of radiation transport equations, where the time step selected via conjugate directions method.

The turbulent viscous coefficient $\mu_\Sigma^{r,z}$ is calculated by using of the Bussinesk hypothesis, when effective viscous is $\mu_\Sigma^{r,z} = \mu_m^{r,z} + \mu_t$, where $\mu_m^{r,z}$ is a molecular viscosity coefficient, taking into account the atomic-molecular collision processes and the presence of a magnetic field in the plasma, and μ_t is a turbulent one, determined from two-parameter turbulence model (Coakley model). The mathematical model and test results are presented and discussed.

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