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# Physics of Neutral Gas Jet Interaction with Magnetized Plasmas

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Neutral gas-plasma interaction is a fundamental problem which is widely studied in astrophysics, space plasmas, low temperature plasma, nuclear fusion physics, etc. Throughout the solar system and universe, plasmas are embedded in a background neutral gas and interact with it. Plasma and neutral interactions have a wide range, such as i) ion drag and “flywheel” effects in collision-dominated ionospheres; ii) charge-exchange reactions in the rarefied plasmas of magnetospheres and stellar winds; iii) dust-plasma interactions in cometary atmospheres; iv) plasma and neutral interactions in pulse-modulated radio-frequency glow discharge; v) gas fueling, helium pumping, neutral beam heating, and plasma wall interaction in MCF.

One of the most important applications of plasma-neutral interaction is to utilize the fusion energy in magnetic confinement plasma. The interaction of neutral atoms with plasma ions and electrons in the edge plasma has been found to have an important effect on density limits, the L-H transition, plasma fueling and other phenomena. Density control and fuel retention are two critical issues for future fusion devices with long pulse and high performance of plasma discharge. Active fuelling is a useful method to maintain the plasma density. It is critical to understand the physics and transport dynamics during the plasma fuelling process. There are many key issues influencing fuelling particle transport those are not well understood, such as interactions between fuelling particles (deuterium and tritium) and the pre-injection plasma, loss rates of fuelling particles via complex collision atomic and molecular reactions (i.e. ablation, dissociation, ionization, charge exchange), and influence of the plasma density rise along the injection path on fuelling particle propagation.

The modeling of gas fuelling problems includes four major particle species (i.e. hydrogen molecules, atoms, ions and electrons) and dominant reactions. Consistent with the different species of particles, the equations in the physical model can be divided into those for molecules, atoms, and plasma transport. Transport of molecules and atoms are treated separately. Plasma and neutral interactions involve the transfer of charge, momentum, and energy in ion-neutral and electron-neutral collisions. Thus, a seven field fluid model of gas jet fueling, which couples plasma density, heat, and momentum transport equations together with neutrals density and momentum transport equations of both molecules and atoms, is obtained by reduction of the Braginskii equations with source and sink terms due to plasma and neutral interactions. The behavior of neutral atoms and molecules in tokamak geometry has been investigated with a newly developed 3D neutral transport module called *trans-neut*[1], within the original BOUT++ boundary plasma turbulence framework. During gas fueling, neutral molecules and atoms penetrate continuously and the propagating front of molecules stagnates due to balance of the molecule dissociation rate with the molecule injection rate. Both positive and negative parallel ion velocities are driven near gas jet fueling region due to parallel pressure gradient, which drives convection for parallel plasma density transport. The poloidal propagation of plasma density blobs (i.e., source) and ion temperature holes (i.e., sink) has been observed. The simulations of mean profile variations during fueling have been compared and validated with experiment results which are semi-quantitatively consistent well with each other[2].

We have further studied neutral penetration depth with varying fueling intensities[3,4]. The molecular transport processes, during gas jet fueling with various injection velocities and densities, are simulated and the final results compared for predictions of penetration depth and the fueling efficiency. The key observations are: i) the penetration depth of gas jet fueling obviously increases with the increase of the injection velocity; ii) the penetration depth does not vary much due to the dramatic increase of the dissociation rate, once the fueling injection density exceeds a critical value; iii) with the same injection flux of gas jet fueling, the larger the injection velocity, the deeper the molecules penetrate into the plasma. Thus, our simulation results suggest an effective method to achieve a better penetration depth and fueling efficiency during gas jet fueling, by injecting molecules at a larger radial injection velocity and at a critical molecule injection density.

References

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