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Ambipolar diffusion and drift in computational weakly-ionized plasmadynamics

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A B S T R A C T

Modeling of ambipolar diffusion and drift taking place within a weakly-ionized fluid can lead to some convergence difficulties when the ion conservation equation and the electric field potential equation are solved consecutively. A novel formulation of the ion flow rate is proposed here that reduces the computing effort to reach convergence by a factor of 10 or more. It is shown that by recasting the ion flow rate in terms of drift and ambipolar diffusion components, the sensitivity to the electric field is reduced hence alleviating the stiffness of the system of equations and permitting significantly faster convergence. What makes the method particularly appealing is that (i) it yields faster convergence without affecting the accuracy of the converged solution and (ii) it is not restricted to specific discretization or relaxation schemes and can hence be readily implemented in existing flow solvers. Because it is developed in general form (*i.e.* applicable to a multicomponent plasma in the simultaneous presence of electric current and magnetic and electric fields), the method is notably well-suited to simulate ambipolar diffusion within ionized multi-species flow solvers and is recommended for all flowfields as long as the plasma remains weakly-ionized and quasi-neutral.

1. Introduction

Ambipolar diffusion is a phenomenon that occurs within a plasma when a spatial gradient of the number density of at least one of the charged species is present. The phenomenon is caused by the different charged species having different diffusivities, hence resulting in some of the charged species diffusing more or less rapidly than the others, which would lead to a loss of neutrality of the plasma. A minor loss of neutrality, however, induces an ambipolar electric field which, if the Debye length is sufficiently small, slows down the fast-diffusing species and speeds up the slow-diffusing species in such a way that the plasma remains quasi-neutral.

For a non-magnetized plasma composed of electrons and only one type of positive ions, a straightforward derivation shows that the effect of the ambipolar electric field causes the diffusion coefficient of the ions to be augmented according to the following expression (see for instance Ref. [1, p. 187]):

$$D_{\rm a} = \left(1 + \frac{T_{\rm e}}{T_{\rm i}}\right) D_{\rm i} \tag{1}$$

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