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Electron and ion transport equations in computational weakly-ionized plasmadynamics

Bernard Parent [a,*], Sergey O. Macheret [b,1], Mikhail N. Shneider [b]

[a] Department of Aerospace Engineering, Pusan National University, Busan 609-735, South Korea
[b] Department of Mechanical and Aerospace Engineering, Princeton University, Princeton, NJ 08544-5263, USA

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ABSTRACT

A new set of ion and electron transport equations is proposed to simulate steady or unsteady quasi-neutral or non-neutral multicomponent weakly-ionized plasmas through the drift–diffusion approximation. The proposed set of equations is advantaged over the conventional one by being considerably less stiff in quasi-neutral regions because it can be integrated in conjunction with a potential equation based on Ohm's law rather than Gauss's law. The present approach is advantaged over previous attempts at recasting the system by being applicable to plasmas with several types of positive ions and negative ions and by not requiring changes to the boundary conditions. Several test cases of plasmas enclosed by dielectrics and of glow discharges between electrodes show that the proposed equations yield the same solution as the standard equations but require 10 to 100 times fewer iterations to reach convergence whenever a quasi-neutral region forms. Further, several grid convergence studies indicate that the present approach exhibits a higher resolution (and hence requires fewer nodes to reach a given level of accuracy) when ambipolar diffusion is present. Because the proposed equations are not intrinsically linked to specific discretization or integration schemes and exhibit substantial advantages with no apparent disadvantage, they are generally recommended as a substitute to the fluid models in which the electric field is obtained from Gauss's law as long as the plasma remains weakly-ionized and unmagnetized.

1. Introduction

Weakly-ionized plasmas have recently been the focus of increased attention as a means to improve the capabilities of aircraft. Possible applications of weakly-ionized plasmas that are currently under investigation include (and are not limited to) boundary layer control on fixed and rotating wings using DBD plasma actuators, power generation on board high-speed airbreathing vehicles through MHD generators, or thrust production using MHD accelerators. Numerical simulations of weakly-ionized airflow for aerospace applications have so far been accomplished mostly using a fluid model (i.e. the drift–diffusion approximation) [1–4] because more involved physical models based on kinetic theory require excessive computational resources at the relatively high densities encountered in plasma aerodynamics, although some progress is being made in this area [5].

* Corresponding author.
E-mail addresses: bernparent@gmail.com, parent@pusan.ac.kr (B. Parent).
URL: http://www.bernardparent.com (B. Parent).
[1] Current address: Lockheed Martin Aeronautics Company, 1011 Lockheed Way, Palmdale, California 93599-0160, USA.

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