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GASEOUS TRANSPORT PHENOMENA IN RAREFIED CONDITIONS VIA DETERMINISTIC AND STOCHASTIC METHODS WITH APPLICATIONS IN VACUUM AND FUSION ENGINEERING

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In the last two decades, technology is increasingly moving towards micro- and nanoscale levels, by developing miniaturized devices. In addition, vacuum systems and aerosol flows play a critical role in the semiconductor and microelectromechanical systems (MEMS) industry, as well as in some of the most significant large scale scientific and technological achievements, such as particle accelerators and fusion reactors [1,2]. Consequently, the theoretical and computational investigation of gaseous transport phenomena in rarefied conditions is increasingly attracting considerable attention. These phenomena are far from local equilibrium and the molecular theory of gases, as described by kinetic modelling and more specifically by the Boltzmann equation (BE), must be considered.

In the present Ph.D. work, sophisticated deterministic and stochastic kinetic modelling software tools are developed on the basis of the well-established Discrete Velocity Method (DVM) and the Direct Simulation Monte Carlo (DSMC) method, respectively. The developed software tools are first validated in several benchmarks and then, they are implemented to tackle a number of diverse subjects related to gaseous transport phenomena under rarefied conditions.

More specifically, the pressure and temperature driven fully-developed flows in a permeable channel, with uniform injection/suction through the channel walls, are investigated for first time under rarefied conditions, via the exact BE and the Shakhov (S) kinetic model. Furthermore, the ARIADNE code for simulating gas distribution systems of arbitrary complexity under any vacuum conditions is enhanced and benchmarked, providing an excellent agreement with both computational (DSMC, Molflow+) and experimental results [3]. In addition, the capabilities of the ARIADNE code are demonstrated by simulating the ITER primary exhaust system during the so-called burn and dwell phases for various pressure and pumping scenarios. Finally, the 3D DSMC code PROGRESS is appropriately modified in order to simulate the transport of a rigid spherical particle suspended in a rarefied gas. The developed aerosol code is benchmarked, providing an excellent agreement with analytical and computational results for the cases of planar thermophoresis [4], as well as, for translational and rotational Brownian motion [5,6].

The developed s/w tools may be useful in the theoretical investigation of transport phenomena far from local equilibrium, as well as in the design and optimization of devices and systems in gaseous MEMS, vacuum engineering and fusion technology.

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