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Kinetic Modeling of Complex Plasma Equipment

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Kinetics of electrons, ions and neutrals play an important role in industrial plasma systems. These systems are often characterized by complex geometries and require 2D and 3D models of varying resolution for realistic simulations of relevant processes. We will describe hybrid approach to modeling such systems using kinetic models for electrons and hydrodynamic (fluid) models for ion and neutral components. Kinetic modeling of electrons involves numerical solution of the Boltzmann equation or its derivatives. Using two-term spherical harmonics expansion in velocity space, the 6D Boltzmann equation can be reduced to a 4D Fokker-Plank (F-P) equation for the Electron Energy Distribution Function (EEDF), which depends of electron energy and spatial position. This equation can be conveniently solved using total electron energy (kinetic + potential) for a wide range of discharge conditions. Further simplifications are possible in the two extremes. At high gas pressures one can solve local F-P equation for the EEDF as a function of local electric field and plasma composition, and generate Look-Up-Tables (LUTs) for electron transport coefficients and rates of electron induced chemical reactions to be used in fluid models for electrons. The other extreme corresponds to a "nonlocal approach" where the EEDF depend solely on the total energy and does to depend explicitly on spatial position. We will describe the architecture of the F-P solver for electrons in the CFD-ACE+ software package and its application to simulations of low-pressure ICP, CCP, and DC discharges, as well as high-pressure micro-plasmas. The peculiarities of the EEDF formation in these systems, and the importance of nonlocal kinetic effects for the formation of striations, electron heating and macro-plasma parameters will be discussed. We will also discuss the limitations of the F-P approach and our current efforts to develop a full Boltzmann solver for simulations of fast (runaway) electrons and nonlocal electromagnetic phenomena in low-pressure RF discharges.