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Two-phases hybrid model for neutral gas transport in Soledge2D-EIRENE

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Neutral particles play a key role in addressing the power exhaust challenge in magnetically confined fusion devices. The presence of neutral gas, together with impurities, allows reaching tolerable plasma temperature in front of the divertor targets, and helps reducing peak heat fluxes through power spreading. In fact, the neutral gas pressure in the divertor is often considered to be a key control parameter for divertor conditions. The Knudsen number of the hydrogen isotopes atom gas flow, defined as the ratio of the mean free path to a plasma gradient length, is much larger than one in most of the device. As a result, neutrals have generally been treated kinetically for the last 35 years. In view of the geometrical complexity, of the numerous species and reaction channels that have to be taken into account, the available solvers rely on a Monte Carlo approach. In next generation devices, simulations show the formation of high collisionality regions of limited spatial extent in the divertor, where particles tracked by the Monte Carlo code can get effectively trapped, undergoing a large number of collisions before being ionized or escaping. This has the effect of considerably slowing down simulations and can be a major hurdle for scoping/design studies. In these high collisionality regions, the neutral gas is expected to behave like a fluid, with a Maxwellian distribution, and using a hybrid kinetic/fluid model is tempting, as done in other applications (e.g. atmosphere re-entry). Two main classes of models have been developed in the literature, namely micro/macro approaches and domain decomposition models. The former solves for kinetic corrections over the whole domain and the later introduces boundaries between kinetic and fluid regions. In practice both approaches introduce modelling errors. The approach based on domain decomposition requires setting up criteria to decide whether a region is kinetic or fluid. In this contribution, we show that the two-phase hybrid model proposed in Ref. [1] can be understood as a particular type of domain decomposition approach. The model has been implemented for atoms in Soledge2d-EIRENE [2], and essentially consists in introducing artificial reaction channels, with condensation terminating trajectories entering into highly collisional regions. EIRENE thus calculates a source of fluid atoms, which is transferred to a neutral fluid code. In low collisionality regions, fluid atoms evaporate into kinetic atoms. The latter are treated as a volumetric source in the neutral fluid code. Here we take a closer look at the sensitivity of the solution obtained in pure deuterium ITER cases on the model parameters: i) form of the criteria defining fluid regions ii) sharpness of the transition layer, ii) amplitude of the condensation/evaporation rates. Modelling errors are assessed by comparison to pure kinetic calculations, and the computational gain is estimated for each case. These gains would ease the contribution of plasma edge modelling to the divertor design process.

[1] C. F. F. Karney, D. P. Stotler and B. J. Braams, Contrib. Plasma Phys. 38, 319 (1998).
[2] M. Valentinuzzi et al., Nuclear Materials and Energy 18, 41 (2019).

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