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Gas puff fuelling simulation with a combined neutral/HESEL model

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In future magnetic confinement fusion devices, such as ITER, high efficiency fuelling with deep penetration is required for maintaining a sufficient plasma core density. One possible fuelling method is gas puffing, in which neutral molecules are puffed into the scrape-off layer (SOL), where they dissociate, and if the resulting atoms are ionized inside the last closed flux surface (LCFS), they fuel the plasma effectively.

We simulate gas puff fuelling by implementing a module for neutral particles into the HESEL model [1]. The HESEL model is a four-field model based on the Braginskii equations on a 2D drift-plane at the outboard mid-plane, and is capable of describing interchange-driven low frequency turbulence. The domain includes the closed field line edge region as well as the open field line SOL region.

It is investigated to what extend the artificial density source in the HESEL model can be replaced by a more accurate model for the fuelling process by implementing a self consistent dynamical model for the neutral particles. This gives an estimate for the amount of neutrals from gas puffing, which is required to fuel the plasma.

For the fuelling to maintain the amount of plasma particles, the ionization of neutrals inside the LCFS must (on average) balance the integrated flux of plasma across the LCFS, i.e.,

$$\left\langle \int_{\text{edge}} \mathrm{d}V \, nN\langle\sigma_{\text{iz}}v\rangle \right\rangle_t = \left\langle \int_{\text{LCFS}} \mathrm{d}A \, \Gamma_n \right\rangle_t , \tag{1}$$

where n is the electron density, N is the neutral atom density, $\langle\sigma_{\text{iz}}v\rangle$ is the ionization rate coefficient, Γ_n is the particle flux, and $\langle\cdot\rangle_t$ denotes the temporal average. The volume integral on the LHS is over the volume inside LCFS, and the surface integral on the RHS is over the LCFS.

For typical gas puffing rates it is found that the resulting fuelling only accounts for approximately 15-20 % of the required plasma density source. We believe this can be explained by the fact that the domain in the HESEL model is located at the outboard mid-plane, in which area the far highest turbulent flux is concentrated, whereas the gas puffing may reasonably be assumed to be more uniformly distributed across the plasma surface. Thus, accounting for this issue would lead towards a much better balance between the fuelling and the plasma losses through the turbulent flux, which indeed is the dominating loss channel.

References

[1] J. Madsen et al., (2016), submitted to PoP