Investigating the influence of TCV divertor baffles on nitrogen seeded detachment with SOLPS simulations

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SOLPS-ITER simulations are performed to study the influence of baffles on nitrogen seeded detachment in the TCV divertor. Baffled nitrogen seeding is found to lead to lower target temperatures and heat fluxes compared with baffle-only and seeding-only cases. At the same separatrix density the upstream profiles are unaffected by seeding. The presence of baffles raises the neutral compression and yields an increasing nitrogen retention with respect to the seeding rate. While baffled neutral compression is always higher than when unbaffled, the nitrogen retention with baffles surpasses that of unbaffled cases only for sufficiently high seeding levels.

1. Introduction

The divertor targets of magnetic fusion devices are exposed to intense plasma heat fluxes. Material limits of the target require sufficient power dissipation that can be achieved by operating the divertor in the detached regime, characterized by low plasma temperatures in front of the targets and reduced particle fluxes. Detachment is usually induced by increasing the plasma density or injecting sufficient impurities. The improved divertor closure is also believed to facilitate the access to a detached divertor state. Studies of neutral baffling in the tokamak à configuration variable (TCV) have so far concentrated on plasma density ramps.[1, 2] The present work provides predictions that may be compared with baffled nitrogen seeding TCV experiments.

Impurity transport plays a vital role in the seeded detachment and numerous efforts have been made to reveal the determinant underlying mechanisms. Impurities are known to be subject to thermal and friction forces with their force balance determining the impurity leakage. Recent work further suggests that it is the relative position between the stagnation point and the ionization front that essentially regulates the impurity leakage.[3] Adding baffles inevitably complicates the behavior of impurities necessitating additional investigations on possible synergies between baffling and seeding. This is the main goal of the present work, which is

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organized as follows. The simulation model is introduced in Section 2, the simulation results including upstream and target profiles, neutral and impurities behaviors are presented in Section 3 and concluding remarks are given in Section 4.

2. Simulation setup

SOLPS-ITER is a 2D transport code to simulate the scrape-off layer (SOL) for a variety of magnetic fusion devices.[4] It combines the Monte-Carlo neutral transport kinetic model EIRENE and the 2D multi-fluid plasma transport model B2.5, and has been used to predict the divertor performance in ITER and future reactor designs. Here, we simulate the TCV lower single null divertor discharges with a magnetic field of 1.4 T and a plasma current of 250 kA in baffled and unbaffled TCV configurations. The generated grids including the deuterium and nitrogen injection locations for baffled and unbaffled cases are shown in Fig. 1.

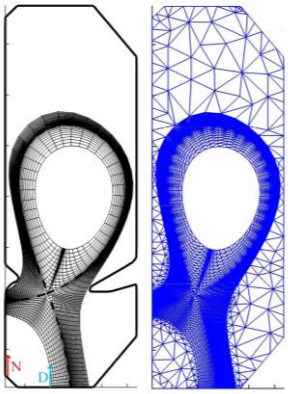

Fig. 1. Employed (a) B2.5 grid for baffled cases and (b) EIRENE grid for unbaffled cases.

The simulated plasma species are deuterium, carbon and nitrogen, and the reactions include ionization, charge exchange, dissociation, recombination, elastic collisions and excitation. Nitrogen is injected in atomic form as the dissociation mean free path of molecular nitrogen is short. Note, that the recent studies highlighted a stronger importance of plasma-molecule interaction with systematic errors in some of the included reaction cross sections.[5] Here, the outer midplane separatrix density is fixed at $n_{e,sep}$ =1.5 × 10^{19} m^{-3}, the N seeding rate ranges from zero to 8 × 10^{20} atom s^{-1} and the D_2 fueling rate from 2.5 × 10^{20} molecule s^{-1} to 1.5 × 10^{21} molecule s^{-1}. Recycling coefficients are set to 0.99 for deuterium, 0 for carbon, 1.0 for neutral nitrogen, and 0.3 for nitrogen ion. The chemical sputtering yield of carbon is set to 3.5%. Transport coefficients are set as $D_{\perp} = 0.2\ m^2 s^{-1}$ and $\chi_{\perp,e} = \chi_{\perp,i} = 1.0\ m^2 s^{-1}$. These choices are based on previous simulations of Ohmically heated TCV plasma discharges as they match the experimental measurements such as Thomson scattering and the divertor spectrometer system.[6, 7]

3. Simulations of baffled and unbaffled seeding

At constant $n_{e,sep}$ baffles decrease the neutral density in the main chamber, reducing ionization inside the last-closed-flux-surface and, hence, lower the density gradient inside the separatrix, whereas neither baffles nor seeding have a significant effect upon the upstream SOL profiles, Fig. 2(a). At the outer target, both baffling and seeding result in a reduction of the heat flux q_{ot}. Unbaffled seeding achieves q_{ot} reduction with a drop of both target temperature $T_{e,ot}$ and particle flux Γ_{ot}, whereas baffled seeding shows a larger T_{ot} reduction (compared with unbaffled seeding) to compensate for the higher Γ_{ot} (not shown here) from the higher neutral and electron densities in the divertor region, Fig. 2(b)-(d). The baffled, strongly seeded, case results in the lowest target temperature and heat flux.

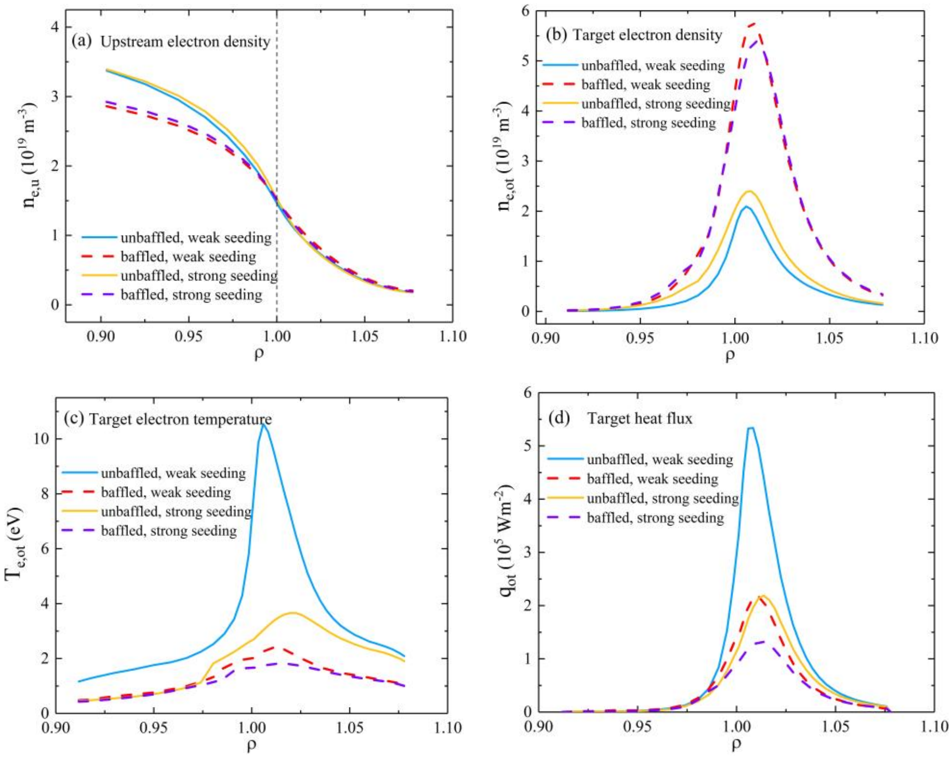

Fig. 2. Upstream and outer target profiles. Weak and strong seeding rates are 2×10^{20} s^{-1} and 8×10^{20} s^{-1}.

The neutral compression characterizes the neutral distribution and is here defined as the ratio of mean neutral density in the divertor region to that in the main chamber, $C_D = \frac{\langle n_n \rangle_{divertor}}{\langle n_n \rangle_{main\ chamber}}$, with total neutral density $n_n = 2n_{D2} + n_D$. The baffles lead to a large increase in C_D and the compression can be further increased through nitrogen seeding, Fig. 3(a). The definition of nitrogen retention is similar to C_D except that both neutral and ionized states are considered: $R_N = \frac{\langle n_N \rangle_{divertor}}{\langle n_N \rangle_{main\ chamber}}$. R_N decreases with the seeding rate without baffles as the nitrogen ionization front moves further away from the nitrogen stagnation point. With baffles, retention increases with seeding rate but its value surpasses the unbaffled R_N only at high seeding levels. For low seeding level the nitrogen reflection by the baffles is insufficient to compensate for increased nitrogen leakage from the lower temperature baffled divertor. The competition of receding nitrogen ionization front and neutral nitrogen reflection by the baffles determines the increasing trend of R_N with respect to the seeding rate, with the latter dominating at high seeding levels.

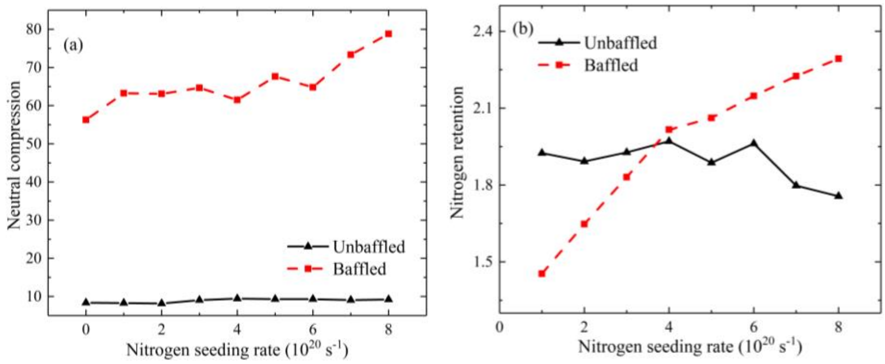

Fig. 3. Nitrogen seeding rate scanning of (a) neutral compression (b) nitrogen retention

4. Conclusions

The baffled, nitrogen seeded detachment in TCV is investigated with SOLPS-ITER simulations. It is found that the baffled nitrogen seeding leads to lowest target temperatures and heat fluxes compared with seeding-only and baffles-only cases. Baffles also improve neutral compression and nitrogen retention at high seeding levels. The synergies of baffling and nitrogen seeding are thus predicted to achieve deeper detachment.

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