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[REGULAR POSTER TWIN] Advances in understanding power exhaust physics with the new, baffled TCV divertor

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Introduction – Achieving safe power and particle exhaust compatible with a high-performance core plasma is one of the main challenges towards commercial fusion power. Currently, the most promising solution is to operate a diverted tokamak in detached conditions with high divertor neutral pressure, high volumetric power dissipation, and a strong temperature and pressure gradient along the magnetic field towards the target plates [1]. Access and performance of detachment strongly depend on the divertor plate and wall geometry and the ability to confine neutrals and impurities to the divertor region. Important additional benefits such as reduced plasma and impurity density thresholds for detachment and/or passive stabilisation of the detachment front are expected from non-conventional divertor magnetic geometries.
Validation of current models and an improved understanding of the different mechanisms involved require experiments that separate magnetic topology from neutral trapping through wall geometry. To meet these needs, removable neutral baffling structures were installed on the Tokamak à Configuration Variable (TCV) [2] and a first experimental campaign was completed. Combined with the extreme magnetic shaping capabilities and substantial upgrades in heating power and divertor diagnostics, TCV now provides a unique testbed to disentangle the effects of magnetic topology from neutral effects and to validate state-of-the-art simulation tools.

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Divertor closure and detachment threshold – The results of recent Ohmic L-mode density ramp experiments in a Single Null reference shape (β=250kA), comparing operation with and without the new baffles, confirm the main SOLPS-ITER predictions of how the baffles change divertor performance: a) an increase in divertor neutral pressure by a factor 2-5 for the same upstream conditions; and b) a R_t 30% reduction of the upstream density threshold for detachment (Fig. 1). To further increase divertor closure and possibly detachment access, the position of the plasma with respect to the baffles was varied. This revealed that the reference baffle location, chosen based on modelling, is already close to the optimum; shifting the plasma closer to the baffles resulted in a substantial recycling flux from the baffles and a drop in divertor neutral pressure. In all these plasmas, the divertor neutral pressure is found to be a good parameter to describe the divertor state, with detachment starting at I_p 0.15 Pa, irrespective of the upstream density, divertor closure, and fuelling location.
Detailed SOLPS-ITER drift simulations of these plasmas have been carried out and results are being compared with an extensive set of measurements, including two-dimensional profiles of density, temperature, parallel flow, and plasma potential measured across the entire outer divertor leg with a *reciprocating divertor probe array* housing 12 Mach probes. This comparison reveals a qualitative agreement between the simulated and measured target currents and their variation with density and drift direction. The experiments also confirm the model prediction of a negative potential well near the X-point in reversed field, and quantitatively match the predicted change in neutral pressure and detachment threshold with the baffles. The reasons for remaining differences with modelling are being investigated and benchmarked with simulations from the SolEdge2D-EIRENE code.

Detachment in H-mode plasmas – Even stronger effects of the baffles are observed in H-mode experiments. The L-H power threshold is reduced substantially with the baffles and, for a given upstream density and level of neutral beam heating power, pedestal pressure and stored energy increase by $\sim$30%. The operational window for H-mode detachment also increased strongly with the added baffles: In Type-I ELMy H-mode plasmas at 170kA and with 1MW of neural beam heating, the outer target is close to detachment between ELMs, with target electron temperatures in the range of 5eV, rather than $\sim$20eV as in comparable unbaffled cases. Seeding nitrogen as impurity results in a larger than three-fold reduction of the outer target ion saturation current. This clear detached divertor state is corroborated by the inter-ELM CIII emission front receding smoothly up the divertor leg to the X-point, with no indications for a bifurcation-like transition as on other devices [3].

Divertor closure and alternative divertors – The compatibility of the new TCV baffles with a large range of alternative divertor geometries has been demonstrated experimentally, including Super-X, Snowflake, and X-Divertor geometries, and experimental and theoretical studies shed light on the separate effect of divertor

closure and magnetic topology. In particular, recent SOLPS-ITER simulations [4] reproduce previous TCV Super-X results without baffles [5]. The modelling further reveals that the effect of a large strike-point major radius $\sim$ (the main Super-X property) can be counteracted by a simultaneous change in divertor neutral trapping. Both, strong baffling and a fixed poloidal incidence angle $\sim$ of the divertor leg, were required in the simulations to equalise neutral trapping between different geometries and to recover the expected detachment threshold reduction at large R_t [4]. Motivated by this, β and R_t were varied in experiments with baffles from 0.62-1.05m and 50R_t-130β, respectively (examples in Fig. 1). This reveals a strong dependence of the detachment threshold on $^\circ$ for $^\circ$>90β, yet a relatively weak dependence on β and unexpected changes in target profile shapes with $^\circ$, suggesting an importance of drift or turbulence effects.
Ongoing work is assessing the reliability of edge transport codes to reproduce these experimentally identified dependencies on magnetic topology and wall geometry and how they may extrapolate to higher power conditions. These investigations help to better understand the different effects which play a role for detachment and divertor-core compatibility and will allow for more reliable predictions for future devices.

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