IMPURITY CONTROL STUDIES USING SOL FLOW IN DIII-D*

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Impurity control in the scrape-off-layer (SOL) of a diverted plasma in a high-power density fusion device is essential in obtaining high radiative power fractions in the SOL to protect the divertor surfaces from unacceptable heat loads and material erosion while maintaining acceptably low impurity contamination in the core plasma. A key component of obtaining the necessary impurity control is tailoring of the main ion flow in the SOL such that the frictional drag on the impurities by this flow will be sufficient to preferentially direct the impurities towards the divertor. The tailoring of the main ion flow through strong D_2 gas injection (with flow rates up to 2.5×10^{22} D°/s) and simultaneous divertor exhaust has been an integral part of the DIII–D program since 1994 [1–3]. In recent years, experiments on DIII–D have focused on 1) characterizing main ion and impurity flow in the SOL and divertor region, 2) assessing the effectiveness of using induced deuterium flow in the SOL to improve the divertor retention of seeded impurities both open and closed divertor configurations, and 3) using strong, induced deuterium flow in the SOL simultaneously with strong argon injection to produce a high radiative power fraction in the SOL and divertor plasmas. These experiments have demonstrated that induced SOL flow offers several potential advantages and two primary results have been obtained: 1) induced SOL flow improves impurity enrichment in the divertor plasma in both open and closed divertor configurations with argon enrichment values as high as 17 obtained in the highest flow cases; and 2) plasmas with $P_{rad}^{tot} \big/ P_{input}$ > 80% with a high SOL radiation fraction ($P_{rad}^{SOL} + P_{rad}^{div}$ > 60% of P_{rad}^{tot}) have been obtained in ELMing H–mode plasmas with confinement ~1.8 $\tau_{ITER89P}$, $n_e = 0.6\ n_{e_{GW}}$, and $Z_{eff} < 1.8$ using argon as the seeded impurity.

These studies are motivated by the fact that the most attractive plasma solution from an energy balance standpoint is one in which the dominant portion of the radiation occurs in the SOL and divertor plasma, rather than the core plasma. In this regard, divertor-dominated radiation loss requires the preferential enrichment of impurities in the divertor region to compensate for the reduced volume of the divertor in comparison to the core plasma. One way to influence impurity enrichment is to augment the natural plasma ion flow in the SOL such that a strong target-directed primary ion flow exists throughout the entire radial width of the SOL.

To assess the efficacy of this approach, a series of controlled experiments were first carried out in lower, single-null, attached, ELMing H–mode plasmas to determine the impact of induced SOL flow on trace-level impurity enrichment (defined as ratio of the impurity fraction in the divertor to the impurity fraction in the core) of helium, neon and argon. These

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experiments benefited greatly from an expanded diagnostic set that allows direct measurements of the helium, neon, and argon concentrations in the core, SOL, and divertor plasmas as well as in the exhaust gas. The baseline (i.e., taken without induced SOL flow) enrichment values were found to be different for the various impurities with argon enrichment in the range of 3.0–6.0, neon enrichment in the range 1.0–1.6, and helium enrichment in the range 0.5–0.9. The ranges here primarily result from operation at various density levels, with the largest enrichment values found at the highest density. This set of results is similar to results reported on ASDEX-Upgrade [4], but unlike the ASDEX-Upgrade results, both neon and argon enrichment improved dramatically in the presence of induced SOL flow. Argon enrichment ~17 and neon enrichment ~2.5 was obtained in the strongest flow cases studied. Modeling of these discharges with the b2.5 edge transport code reproduces many of the key aspects of the measured data including the improvement of enrichment with SOL flow. Similar results have been found in experiments using the more closed divertor geometry of the newly installed upper divertor baffle in DIII–D. Although direct measurements of impurity enrichment are not yet possible in upper, single-null plasmas, observations of argon exhaust times in the core plasma of ~300 ms in the presence of strong D_2 flow suggests that the impurity retention (and likewise impurity enrichment) is extremely high in these cases.

Encouraged by these results, recent experiments utilized the “puff and pump” method in combination with divertor fueling of argon to produce H–mode plasmas with high SOL radiation power. The results are promising. Plasmas with H–mode quality confinement (i.e., $\tau/\tau_{ITER89P} > 1.8$) were sustained with steady-state deuterium flow rates up to 2.5×10^{22} D°/s. Upon argon injection into these plasmas, the radiative power increases significantly with P_{rad}/P_{input} increasing from 60% to 80 %. Interestingly, both the core and SOL radiation increase while the divertor radiation does not change, implying that the fraction of power conducted into the divertor that is being radiated is actually increasing during the argon injection phase. Minimal contamination of the core plasma via argon is observed with Z_{eff} increasing from 1.5 to 1.8. The enhanced SOL radiation in this case appears to result from the production of a thick, cold SOL as a result of the strong D_2 injection into the SOL.

Finally, measurements of the flow patterns of both the main ions and intrinsic and seeded impurities have also been made in plasmas with both "natural" flow and induced SOL flow. The flow patterns in the “natural” flow case are complex with flow reversal (i.e., main ion and impurity ion flow directed toward the core plasma) observed on field lines near the separatrix and normal flow towards the plate on field lines outboard of the separatrix. Although induced SOL flow does appear to change the main ion flow characteristics measured by an insertable Mach probe, there are regions where reversed impurity ion flow is still observed.

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