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Plasma wall interaction in long duration plasmas on ST
STにおける長時間維持プラズマのプラズマ・壁相互作用

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Steady state operation of spherical tokamaks is one of the key objectives in realizing cost-effective fusion power plants and establishing steady power and particle balance are indispensable. Plasma-wall interaction (PWI) plays an essential role in the balance. Fuel recycling is a key to resolve complexity of PWI. Modeling to combine global balance with post-mortem analysis is required for a quantitative discussion and QUEST-wall model is established. The model indicates solution and recombination play a dominant role in the growth of fuel recycling rate during discharges.

1. Introduction

Spherical tokamaks (STs) have a capability to realize cost-effective fusion power plants because of their compactness and high β stability. Steady state operation (SSO) of STs is one of the key objectives and establishing steady power and particle balance are indispensable. ST magnetic geometry gives an inherently large figure of merit P/R, and leads to higher divertor heat fluxes, raising concerns over divertor operation in the proposed ST-based fusion power plant concepts [1], where P is the input power and R is the major radius. Substantial experimental work has been carried out on heat load studies during ELM on MAST [2-4], power accountability study on NSTX [5], partial detached divertor [6] and well-structured magnetic geometry [7, 8]. Therefore, power accountability studies on long duration ST yield an important information on conceptional design of ST-based future fusion power plants.

While, ST research activities have not focused on particle balances yet. The world record for plasma duration for tokamaks of more than 5 h was achieved in TRIAM-1M [9], where an accurate power balance of the discharge was investigated [10]; a particle balance was also studied in regard to global particle balance [11]. The result indicates that even when the power balance of the discharge seems to be complete, the global particle balance was not in a steady state [11]. Indeed, the longest duration plasma was terminated unpredictably, one reason being a slight shift in particle balance, due to uncontrollability of fuel recycling. Thus, to understand particle balance is still important in establishing SSO. Plasma-wall interaction (PWI) plays an essential role in their balances. Fuel recycling is a key to resolve complexity of PWI.

2. PWI effects on core plasma

Many ways of wall-conditioning have been developed to control wall behavior and one of the most effective ways is lithium (Li) conditioning done in NSTX [12]. Lower collisionality has been obtained in H-mode plasmas via Li conditioning of plasma facing components (PFCs). An increase in energy confinement time, τ_E, has been reported shown in Fig. 1. The ν_e^* scaling is provided by the gyrokinetic simulation, which gives the dependence of electron thermal transport on electron collisionality, ν_{ei}, is examined for plasmas with different underlying microinstabilites. Reduction of fuel recycling due to Li conditioning plays an essential role in improvement of core plasma transport.

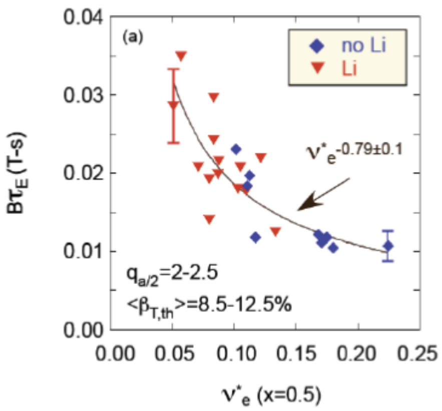

Fig. 1. $B_T\tau_E$ as the function of ν_e^* [12].

Density behavior related on fuel recycling was observed in long duration discharge on QUEST, which is a medium size of ST and has a capability to make a SSO. Recently, a series of more than 10 minutes discharges has obtained with non-inductive microwave current drive technique. The density was controlled in a feedback manner of H_α signal and a lower threshold value was decided to puff predetermined quantity of hydrogen molecule as fuel gas. The response of electron density to the fuel puffing is gradually modified with plasma duration shown in Fig. 2. The duration between higher density and return has clear relation to amount of wall-stored fuel particle, which indicates fuel recycling plays an intrinsic role in the phenomena.

These results suggest that fuel recycling is a key to resolve complexity of PWI.

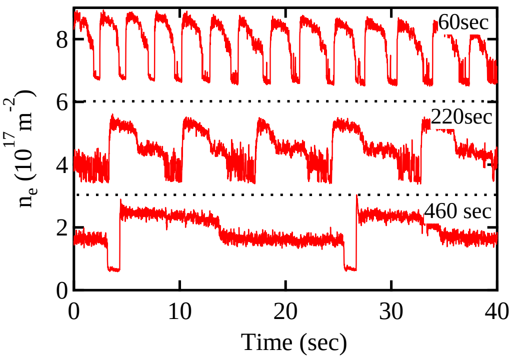

Fig. 2. Density response on gas puffing in a long duration discharge. The elapsed time from the beginning of the discharge shows in each sub-figure.

3. Investigation of fuel recycling

Global fuel balance has been investigated in many devices and many of the post-mortem analyses are also applied to specimens exposed to plasmas. Their investigations into the quantitative consistency of each measurement are still lacking. Inherently, any post-mortem analysis shows only local information. Therefore, the results obtained are difficult to apply directly to global fuel balance. This indicates that modeling to combine both activities is required for a quantitative discussion and QUEST-wall model [13] is established.

Based on the D_2^+ implantation experiments, the QUEST-wall model is devised that included prescriptions for describing several physical processes, such as reflection, diffusion, solution, recombination, trapping, and plasma induced desorption that would occur in the QUEST wall. Clear evolutions of R_{rec} are reconstructed by the model in Fig. 3, where R_{rec} is defined as a ratio of the out-going flux to in-coming flux of H on the wall. The model can reconstruct the growth of R_{rec} and the time evolution of R_{rec} for a 100 nm thick layer and a H flux of 0.2×10^{18} H/m^2/s is the most suitable for the experiment. The model indicates solution and recombination play a dominant role in the growth of R_{rec}.

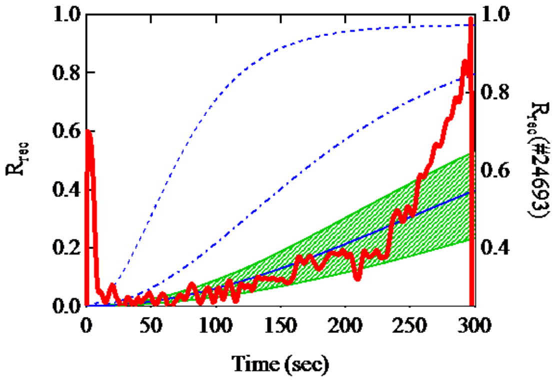

Fig. 3. Time evolutions of R_{rec} are calculated based on the QUEST-wall model. The solid, dotted, and dashed-dotted lines correspond to the cases of 100, 50, and 20 nm at H flux = 2 x 10^{17} H /m^2/s. The hatched area shows the region of H flux from 1 to 3 x 10^{17} H/m^2 in the case of 100 nm. The thick solid line show the experimental result.

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