Study of nitrogen seeded plasma in JET in preparation of JT-60SA

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Introduction

JT-60SA has the mission to support the ITER experiment and to investigate the possible plasma scenarios in view of DEMO. According to ITER limits, the maximum allowable heat loads on divertor target is $q_{t.max}$ =10 MW/m^2 [1] in steady state, while a lower value of 5 MW/m^2 in DEMO is foreseen. In JT-60SA one of the main goals is the exploration of the feasibility of integrated scenarios, where high core plasma performances must be compatible with high radiative divertor in long pulse discharges. As predicted in [2] and in [3] the injection of external impurity is unavoidable in case of a full metallic W wall to ensure safe operations of the tokamak. However, the possibility to work with high radiating fraction has been extensively demonstrated in various experiments in devices equipped with metal wall with injection of external impurity – e.g. with nitrogen and neon in JET ITER-Like Wall and ASDEX Upgrade [4].

In this paper we present the analysis of a JET-ILW H-mode nitrogen seeded plasma used as the reference point for the validation of the SOLPS-ITER code [5] and for the study of the divertor conditions in JT-60SA equipped with full W-wall. The numerical results in terms of upstream and target conditions will be compared with the experiment.

Modeling setup and JET experimental overview

The ultimate goal of the proposed analysis is the assessment of the SOL and divertor conditions by means of SOLPS-ITER in the transition to full metal W wall in JT-60SA [6]. Possible puffing strategies will be investigated in order to guarantee safe operations of the machine in terms of maximum heat flux $q_{t.peak}$ and stable detached divertor conditions. As a starting point in the analysis, we take into account the Scenario 3 of JT-60SA, the vertical Lower Single Null fully inductive high density scenario [6]. The parameters characterizing the plasma scenario are given in Tab. 1. It is the least demanding in terms of power exhaust

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[1] See the author list of E. Joffrin et al., to be published in Nucl. Fusion Special Issue, overview and summary reports from the 27th Fusion Energy Conference (Ahmedabad, India, Oct. 2018)

Table 1: Main plasma parameters in JET and JT-60SA [6].

	B_T	I_p	P_{add} (P_{SOL})	κ_x	δ_x	n_e	$\Lambda_{q,Eich}$
	[T]	[MA]	[MW]	-	-	[10^{19} m $^{-3}$]	[mm]
JET	2.7	2.5	20 (12.5)	1.72	0.4	10	1.7
JT60SA	2.25	5.5	30	1.86	0.5	10	1.4

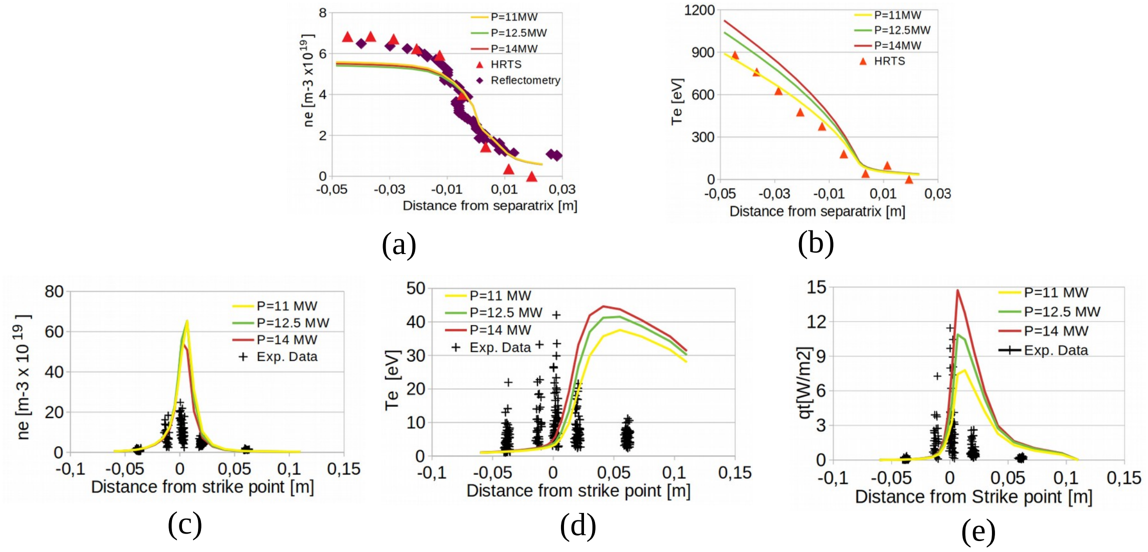
compared to the others since of the high density operation.

In order to “calibrate” the transport coefficients we refer to the to shot number 85419 at time t = 18 s, a stationary nitrogen seeded ELMy H-mode 2.7 T, 2.5 MA high triangularity plasma [7]. The main parameters are given in Tab. 1. By comparing the parameters of plasma scenarios in JET and JT-60SA, we can see that they are quite close in terms of plasma shape and λ_q – as extrapolated with the Eich scaling [8]. The input power used in the simulation is given by P_{SOL} =12.5 MW - obtained from the tomographic reconstruction of the core radiation based on the line integrated foil bolometer channels – lower than the one in JT-60SA. In the experiment, the Deuterium is puffed from the inner target with a feed forward fuelling of Γ_D= 2.8 x 10^{22} el/s while the nitrogen puff Γ_N= 2.0 x 10^{22} el/s is in the Private field region (PFR). In the JET computation the location of the nitrogen puff is located as in experiment whilst the deuterium puff is placed in the inner divertor base region in the PFR. The puffing rate of the latter is feedback controlled by imposing a separatrix density $n_{e,sep}$ = 3 x 10^{19} m^{-3} while nitrogen is puffed with a feed forward fuelling.

Results of the validation

Since we are studying an H-mode confined plasma, the cross field transport coefficients D and Χ are adjusted to fit the experimental upstream profiles of n_e and T_e. In the divertor plasma below the X-point the value of the heat conductivity and particle diffusivity are kept radially constant and equal to D=0.5 m^2/s and Χ=0.6 m^2/s.

Fig. 1 shows the results in terms of upstream and downstream quantities. The outboard midplane profiles of n_e and T_e obtained in the simulations are compared with High Resolution Thomson scattering (HRTS) and reflectometry data of the 85419 JET discharge at t= 18 s. These signals are radially shifted in the outward direction by 1.8 cm because of the uncertainty on the equilibrium reconstruction and such that the measured separatrix density is about 100 eV. Three different power levels are taken into account P_{SOL}= 11, 12.5 and 14 MW due to the uncertainty in the assessment of $P_{rad,core}$. The upstream n_e profile is reproduced (Fig. 1(a)) in the near SOL region, while we get an underestimated value in the pedestal top. An overestimation of the temperature is observed in the temperature for the 3



(a) (b)

(c) (d) (e)

Figure 1: Upstream profiles of n_e (a) and T_e (b) compared with HRTS (red trianlges) and reflectometry (purple diamonds) data of the JPN 85419 at t = 18s mapped on the outer miplane . Outer target profiles of n_e (c), T_e (d) and q_t (e) as a function of the strike point distance compared with the Langmuir probes data in the inter ELMs periods in the time interval t=57.9 - 58.1 s. Three different input power levels are shown P_{SOL}=11 (yellow), 12.5(green) and 14(red) MW.

power levels. These discrepancies are mailnly related to the chosen core value of D and Χ.

The results in terms of outer target n_e, T_e and q_t are shown in Fig. 1 (c), (d) and (e), respectively. The experimental data of the Langmuir probes are taken in the inter ELM periods in the time interval t = 57.9 - 58.1 s and are shown with black crosses. We can observe an overestimation of both n_e and q_t. This behaviuor can be probably related with the low radiated power level in the SOL and divertor region. Indeed, 10% of the imput power is radiated in the numerical simulations (P_{rad}~ 1MW) compared to the P_{rad}= 6 MW in the experiment. Further investigation to confirm this hypothesis is foreseen by increasing the nitrogen puffing rate. Currently, low nitrogen puffing of Γ_N = 1 x10^{17} N/s has been setup because of code instabilities with higher puffing rates whose reason is still under investigation. We get a high value of the power decay length λ_q= 4mm - obtained as in [9]. As a consequence, the q_t profile is more spread than in the experiment. In addition, there is a shift of the electron temperature peak outwards due to the V shaped divertor geometry because of the recycling of the Deuterium molecules in the direction of the separatrix [10].

Ongoing and future work

An optimization procedure on the defnition of the D, Χ is currently ongoing on JET. A good fit in case of pure deuterium case has been obtained (Fig. 2) and the nitrogen simulations are currently at an early stage. The value of the near SOL heat diffusivity has been reduced

(a) (b)

Figure 2: Upstream profiles of n_e (a) and T_e (b) with the new set D, χ compared with HRTS (red trianlges) and reflectometry (purple diamonds) data of the JPN 85419 at t = 18s mapped on the outer miplane .

in order to get shorter power decay length (λ_q = 2.5 mm).

An initial study on JT-60SA has been started by considering the first set of transport coefficients used for JET and P_{SOL}= 20MW, where $P_{rad,core}$ = 10 MW by W has been subtracted from P_{add} in accordance to [2]. In the numerical simulations the density boundary condition is adjusted to get the desired $n_{e,sep.}$ We get a λ_q much higher than the one given in Tab. 1 and the peak heat fluxes remain low - below 10 MW/m^2 in pure deuterium case. By considering the new set of transport coefficients we have obtained acceptable results in terms of both λ_q= 1.5 mm and heat loads onto the outer target with $q_{t,peak}$~20 MW/m^2. Therefore, the next step is the injection of nitrogen and the study of the possible operational wondows in terms of allowable $q_{t,peak}$, P_{rad} and upstream separatrix n_e by varying the Γ_D and Γ_N puffing rates.

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