# Time dependent boundary conditions (BCs) during ELMs

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## Introduction

Detailed understanding of the tokamak Scrape-Off Layer (SOL) and the plasma-surface interaction is critically important for the lifetime of the fusion devices. Because of the complex structure of the SOL, quantitative descriptions are possible only via numerical modelling, except in the very simplest cases. Usual tools for the SOL study are the fluid codes (for example SOLPS-ITER [1, 2, 3]), where a number of kinetic effects are implemented "manually". These effects represent the boundary conditions in regions of plasma-surface interaction and the limiting expressions for the parallel heat flux and viscosity. During the transient process such as Edge Localized Modes (ELMs) these kinetic models are no longer appropriate [4]. In this work the set of the boundary condititons and limiting factors are called kinetic factors (KF). The aim of the present work is to study the behavior of the KF during the parallel transport in the SOL. The simulated plasma parameters are typical of the ITER SOL without neutrals and impurities.

The KF investigated here appear as [5, 2, 3]:

1. boundary conditions for the ion parallel speed and particle energy fluxes at the plasma sheath entrance

$$M = \frac{V_{\parallel}^{i}}{C_s}; \quad \gamma^{e,i} = \frac{Q_{sh}^{e,i}}{\Gamma^{e,i} \cdot T^{e,i}}; \quad \varphi = \frac{e\Delta\phi}{T^e}; \tag{1}$$

2. particle heat flux and ion viscosity expressions used in fluid codes

$$q_{\parallel} = \left(\frac{1}{q_{SH}} + \frac{1}{\alpha q_{FS}}\right)^{-1} \quad \pi_{\parallel} = \left(\frac{1}{\pi_{\parallel}^{Br}} + \frac{1}{bnT}\right)^{-1}; \tag{2}$$

where M, $C_s = \sqrt{\frac{Te+\delta_i T_i}{m_i}}$, $\gamma^{e,i}$, $\Gamma^{e,i}$ and $\varphi$ are the Mach number, the ion-sound speed, the electron and ion sheath heat transmission factor, the electron and ion fluxes to the divertor, and the normalized potential drop, respectively. $m_{e,i}$ and $T_{e,i}$ are electron and ion masses and electron and ion temperature. Here $\delta_i$ ($\sim 1$)is the polytrophic constant. $q_{SH} = -\chi_{\parallel}\partial_s T$ and $q_{FS} = \Gamma T$ are the Spitzer-Harm and the free-streaming heat fluxes, and $\pi_{\parallel}^{Br} = -\frac{4}{3}\eta_{\parallel}\partial_s V_{\parallel}$ is the Braginskii ion parallel viscosity term. The KF represent the Mach number M , the sheath heat transmission coefficients $\gamma$, the normalized potential drop $\varphi$ and the heat and viscosity limiters, $\alpha$ and $b$.

The paper consists of two parts corresponding to the stationary (ELM-free) and Type-I ELMy SOLs with post-ELM.

**Time dependent kinetic factors**

The kinetic simulations, from which were obtained the KF corresponding to ITER SOL, are performed via 1D3V electrostatic Particle-in-Cell (PIC) code BIT1. To determine the boundary conditions (BCs) and limiting factors at the plasma sheath, the point at plasma sheath is fixed. These calculations are explained in our studies [6, 7, 8, 9]. The BIT1 code also can be used for obtaining time depending profiles during fixed point. We fixed the plasma sheath point and run the BIT1 simulation during 200$\mu s$ at ELM-free and 400$\mu s$ at Type I ELM. In previous works [7, 6] were presented the results during ELM-free.

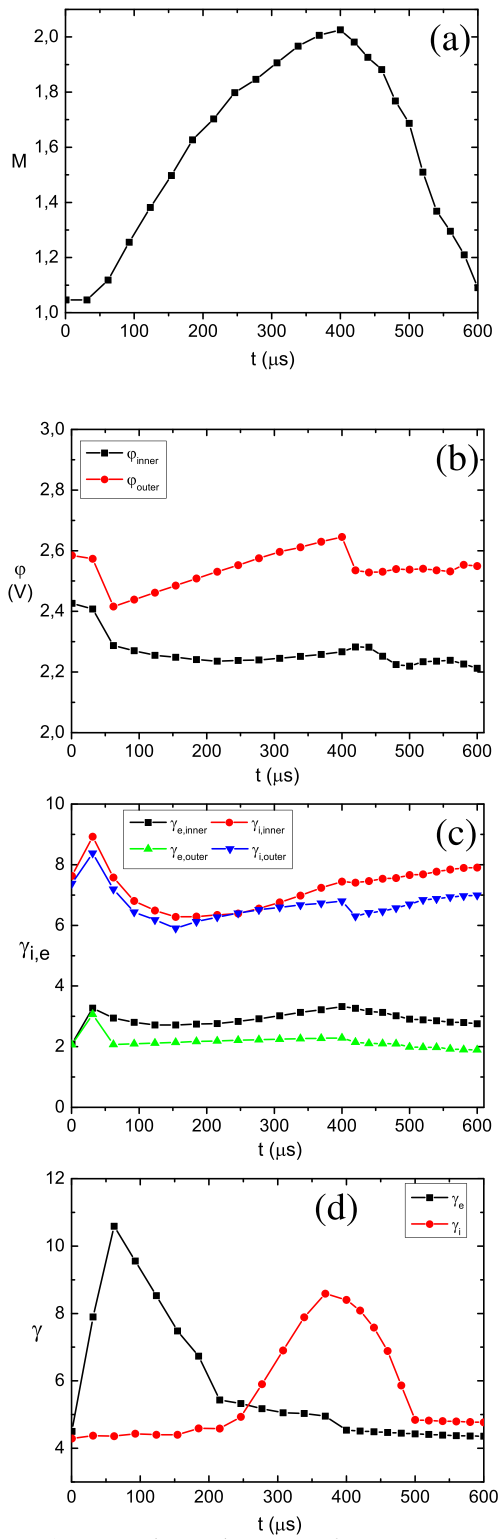


*Figure 1: Time dependent BCs for Type I ELM (a)- Mach number, (b)-normalized potential drop for inner and outer divertor, (c) - Sheath transmission coefficients for electron and ion on the wall at inner and outer divertor, (d)- Transmission coefficients at sheath*

The BCs, are normalised on the ELM-free values. The Fig. 1, shows that during Type-I ELM the BCs increase until 400 $\mu s$. The maximum value of the Mach number is 2 (Fig. 1 (a)), the normalised potential drop for the inner and outer divertor decreases and then slightly increases till 2.3 and 2. 7 V respectively, see (Fig. 1 (b)). The sheath transmission coefficients for the electrons and ions on the inner divertor rapidly increase and reach the peak values, for electron 3, for ion 9, at 50$\mu s$ then slightly decrease and vary during that time Fig. 1 (c). The sheath transmission coefficients at the outer divertor have the same dependencies as at inner. The transmission coefficients at the sheath are opposite to the transmission coefficients on the targets, because as was said before, the plasma sheath acts as a energy filter. For the electrons the maximum value is $\sim 11$ at 75 $\mu s$ and for ion 8 at 350 $\mu s$ (see Fig. 1 (d)). After 400$\mu s$, the simulations are switched to post-ELM. The values for the Mach number decrease during 200$\mu s$ to the theoretical value (1). The normalised potential drops for the inner and the outer divertor decrease slightly to their theoretical values as well. The sheath transmission coefficients for electrons and ions at the inner and outer divertor, slightly decrease to their theoretical values (2 for electron and 7 for ion). The same dependence during post-ELM are observed for the transmission coefficients at the plasma sheath.

Can be assumed that the energy received from the Type-I ELM phase, increases the ion fluid velocity. At 400 $\mu s$, the ion fluid velocity is 2 times greater than the ion-sound velocity. In post-ELM, the received energy is consumed. For that reason, the ion fluid velocity is decreasing till becomes equal to ion-sound velocity. The potential drop is directly related to the particle temperatures. Hence, the potential drop value during Type-I ELM is increasing due to the electron cooling rate and small ion acceleration. The plasma sheath acts as an energy filter. The lost energy from the electron is gained by the ion, and for that reason the electron sheath transmission coefficient on the sheath is higher than on the targets. Therefore, the sheath has cooling effects on the electrons. The reason of extremely high pre-ELM divertor temperatures is the absence of plasma recycling and cooling impurity interaction.

In the set of the kinetic factors (KFs), beside the boundary conditions (BCs) also are the kinetic flux limiters and ion viscosity. Using Eq. 2 the kinetic flux limiters for electrons and ions ($\alpha_e$ and $\alpha_i$) and ion viscosity limiter ($b$) are calculated and presented at. Fig. 2.

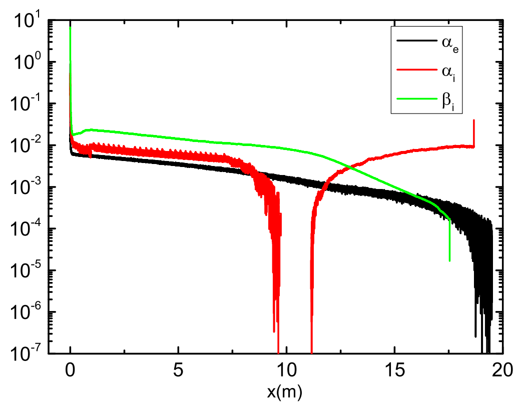


*Figure 2: ITER poloidal profiles of the $\alpha_e$, $\alpha_i$ and $b$*

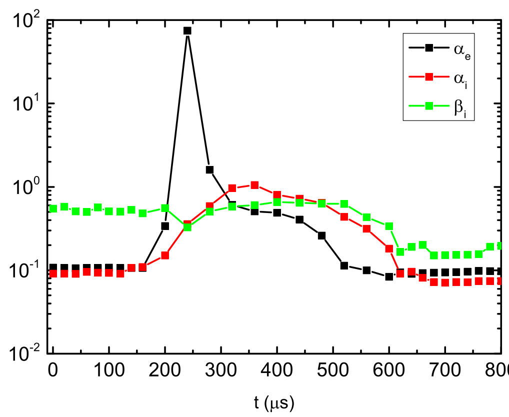


*Figure 3: ITER $\alpha_e$, $\alpha_i$ and $b$ during ELMs at plasma sheath*

The heat flux limiting factors are used to precisely model the heat flux in the collisionless plasma. From the poloidal profile the electron and ion flux limiters are nonuniform. From the behaviour of the electron and ion heat flux limiters can assume that the electron heat flux do not depend from the local temperature i.e SOL, but ion heat flux more depend from the source temperature (outer midplane point) i.e core. The viscosity does not change during the SOL, which means that the ion-ion or electron-electron collisionality do not rise during all poloidal length.

Using the values of the plasma parameters during ELMs the kinetic flux limiters are calculated (see Fig. 3). During ELM-free (200 $\mu s$) the limiters are constant and are equal to 0.1 and $b \sim 0.5$ (theoretical values). At Type-I ELM $\alpha_e$ is reaching the maximum value when ELM starts and is equal to 70, $\alpha_i$ is increasing at 150 $\mu s$ after ELM starts and is equal to 10. $b$ is not changing during ELM and is equal to 0.6. The same decreasing continue at the next 200 $\mu s$, when post-ELM phase starts. The electron heat flux reaches the peak at the same moment when the electron sheath heat flux limiter increases (Fig. 1 (d)), due to the electron energy flux at that moment. The ion heat flux does not peak drastically due to the small ion acceleration. The viscosity does not change so much during ELMs cycle, which means that ion-ion collisions do not rise during time. The behaviour of KFs indicate a strong variation during ELM due to the mixture of thermal and ELMy plasma that exists.

## Conclusion

This work present fully description of the KFs during ELMs phases. At ELM-free the values for the boundary conditions, kinetic flux limiters and viscosity are constant and equal to the classical one, which means that the calculation method is correct. Switching to Type I ELM the values increases at different time. The sheath transmission coefficients reach the maximum values at 50 $\mu s$, the Much number, normalized potential drops and viscosity at 400 $\mu s$ and the flux limiters at 150 $\mu s$. Switching back to post-ELM the values decreased to the classical one. Because this is a plasma without neutrals (non real ITER plasma) for a future wok first in the simulations will be added the neutrals and than using the same method will be calculated the KFs and then they will be used in the fluid code SOLPS-ITER.

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