Effect of SOL Temperature on Filament Dynamics in MAST

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1. Introduction

In ITER, a large fraction of ELM heat loads is expected on the divertor targets, the remaining arriving on the first wall. In view of lifetime issues for PFCs on ITER, it is important to determine what fraction of these ELM losses would be deposited on the first wall by filaments (compared to those on the divertor). Simulations with JOREK predict filaments will not reach the wall in ITER [1], but in MAST filaments travel at constant radial speeds between the pedestal and the first wall (about 40cm). In JET, which has a relatively short SOL width in comparison, IR diagnostics clearly show filaments arriving at the wall with non-negligible energy [2,3]. Although this certifies that the filaments do reach the wall in JET, it does not give any information about the radial speed of those filaments, on which heat-fluxes depend. For example, if it were the case that those filaments are strongly deccelerating outside the separatrix, then having a slightly larger SOL would strongly benefit the first wall in terms of ELM errosion. This paper addresses the issue of filament dynamics in MAST, and explores the different SOL parameters that may affect the radial speed of ELM filaments. In particular, since resistivity and viscosity both have a dependence on electron temperature, the following study will describe how SOL temperature levels affect filaments outside the separatrix.

2. Simulations of ELMs in MAST with the JOREK Code

The simulations were run using the 3D nonlinear MHD code JOREK, with the reduced MHD model described in [4]. The same MAST discharge #24763 is used here; it is a 0.85MA DND pulse for a 0.425T field. This pulse has pedestal electron density and temperature $n_{ped} = 4\times10^{19}$ m^{-3} and T_{ped} = 220 eV. Previous sudies of ELMs in MAST have demonstrated that simulations with the toroidal mode n=20 result in filaments of poloidal/radial cross-section comparable to experiments [4], hence simulations here were also done for a single toroidal mode number n=20. A poloidal resolution about twice higher is used here than in the previous study in [4], with an average poloidal element width of 2.3cm along the separatrix; the radial element width is 0.2cm in the pedestal.

It was also found in previous work [4] that filament dynamics was closest to experiments for resistive ballooning modes, with $\eta = 6\times10^{-6}$ Ω.m (200 times the Spitzer value at 1keV), and the same regime was used for the present paper. The perpendicular diffusivity is $D_\perp$ = 2.4 m^2.s^{-1} in the core and drops one order of magnitude at normalised ψ_n = 0.85. Likewise the perpendicular conductivity drops from $\kappa_\perp = 6\times10^{-7}$ kg.m^{-1}.s^{-1} in the core to 6×10^{-8} kg.m^{-1}.s^{-1} in the pedestal and SOL, for both T_i and T_e. The parallel conductivity is set to the exact Braginskii values $\kappa_{e,//} = 10^3$ kg.m^{-1}.s^{-1} for T_e and $\kappa_{i,//} = 0.25\times10^2$ kg.m^{-1}.s^{-1} for T_i on the axis, with the temperature dependence $T_j^{2.5}$. The parallel viscosity is set to $\mu_{//} = 1.6\times10^{-6}$ kg.m^{-1}.s^{-1} and the perpendicular viscosity to $\mu_\perp = 10^{-7}$ kg.m^{-1}.s^{-1}.

The set of simulations presented here were obtained by varying the SOL temperature level between the values T_{SOL} = [6.10 ; 12.20 ; 18.30 ; 24.4] eV. This T_{SOL} is defined as the temperature outside the separatrix, after the exponential decay of the profile. Note that the values for η and $\mu_\perp$ are set at the axis, so that with the temperature dependence of resistivity and viscosity, the corresponding values in the SOL have to be multiplied by the quantity $[T_{SOL} / T_{AXIS}]^{-1.5}$. Note that in JOREK $\mu_\perp \sim T_e^{-1.5}$, in order to keep the Prandl number constant. Hence, with T_{AXIS}=1.1 keV, the SOL values for resistivity and viscosity can be calculated to be:

	AXIS	SOL			
T_e [eV]	1.1×10^3	6.10	12.20	18.30	24.4
η [Ω.m]	6×10^{-6}	1.5×10^{-2}	5.1×10^{-3}	2.8×10^{-3}	1.8×10^{-3}
$\mu_\perp$ [kg.m^{-1}.s^{-1}]	10^{-7}	2.4×10^{-4}	8.6×10^{-5}	4.7×10^{-5}	3.0×10^{-5}

Thus, resistivity and viscosity change by almost one order of magnitude between the lowest and the highest SOL temperature cases.

3. Effect of Resistivity and Viscosity on Filament Dynamics

Varying the SOL temperature level in simulations has several different effects on the filaments dynamics, but these can be separated into two groups: those caused by the change in resistivity, and those caused by the change in viscosity. Hence, before addressing the effects of T_{SOL} variations, it is necessary to understand the effects of resistivity and viscosity variations separately.

A detailed scan in resistivity has already been produced in [4], showing that in a resistive ballooning regime, the direct influence of resistivity on the ballooning growth rate has a clear effect on the filament radial speed. In other words, filament speed increases with resistivity. For all resistivity cases, filaments travel at constant speed between the separatrix and the first-wall. For the lowest resistivity, the filament speed is so low that the filaments desintegrate long before reaching the wall, but their radial speed is constant nonetheless. Hence resistivity only affects the ballooning growth rates (and indirectly filament speed), but it does not affect filament dynamics otherwise. This resistivity scan was produced at a relatively high viscosity $\mu_\perp = 3.3\times10^{-6}$ kg.m^{-1}.s^{-1}.

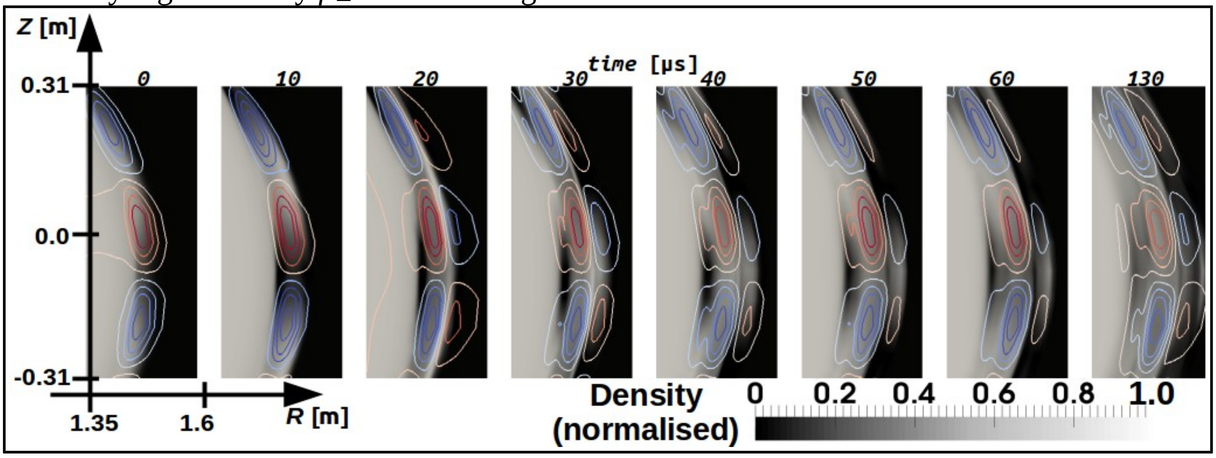

Figure 1:
Poloidal snapshots of midplane region on HFS, showing density filaments travelling in the SOL, for a low viscosity $\mu_\perp = 10^{-7}$ kg.m^{-1}.s^{-1}. Electric Potential contours are also pictured. The filaments travel a few cm across the separatrix, stop, and then combine poloidally to form a new density front, from which a new set of filaments emerges, at a different poloidal location, and picks up speed again.

Changing viscosity, however, influences filament dynamics directly. Like resistivity, viscosity affects ballooning growth rates: at lower viscosity, higher growth rates result in higher initial filament speed. But outside the separatrix, filament dynamics differs. For high viscosity $\mu_\perp = 3.3\times10^{-6}$ kg.m^{-1}.s^{-1}, filaments have a lower initial speed, but they travel at constant speed after crossing the separatrix. At low viscosity $\mu_\perp = 10^{-7}$ kg.m^{-1}.s^{-1}, filaments have a larger initial speed, but they significantly decelerate after crossing the separatrix.

In fact, a distinctive filament dynamics is observed at low viscosity: deccelerating to full stop at about 3.5cm outside the separatrix, the filaments are then sheared poloidally and rapidly combine to form a new density front, from which a new set of filaments is born. The time it takes for those filaments to combine poloidally is about 12µs, shorter than the time it took those initial filaments to travel these 3.5cm, hence this poloidal shearing does not result from a diffusion process, but from convection cells. Another aspect of this dynamics is that the new filaments that emerge from this new density front are located at a different poloidal location than the initial filaments (inbetween). This behaviour is represented in Figure-1.

The filament dynamics described above has clearly not been observed on MAST during type-I ELMs, but when considering an intermediate viscosity $\mu_\perp = 10^{-6}$ kg.m^{-1}.s^{-1}, something more realistic occurs: filaments slow down after crossing the separatrix, but they do not come to full stop, nor do they combine poloidally – they start accelerating again (see Figure-2). Filaments in MAST have been observed to accelerate in the SOL, after crossing the separatrix [5].

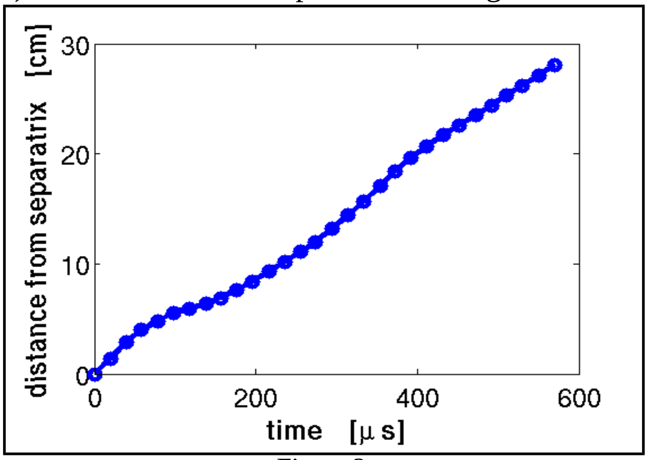

Figure 2:
Distance of filament from separatrix as a function of time. For an intermediate viscosity value $\mu_\perp = 10^{-6}$ kg.m^{-1}.s^{-1}, the filaments are observed to deccelerate radially after crossing the separatrix, before picking up speed again.

Note that this viscosity scan was done for a resistivity $\eta = 10^{-6}$ Ω.m, for which filaments travel slightly slower than in the MAST type-I ELMs discharges, at about 0.5 km/s. For the SOL temperature scan, the resistivity $\eta = 6\times10^{-6}$ Ω.m was used, which gives radial filament speeds closer to experiments, at about 3 km/s.

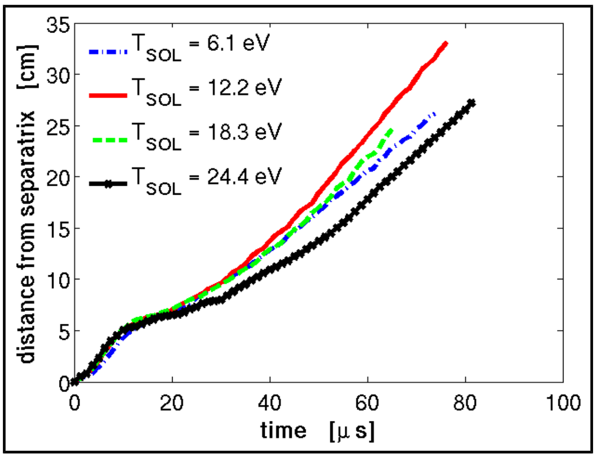

Figure 3:
Distance of filaments from separatrix as a function of time, for all T_{SOL} cases. Filaments deccelerate and accelerate in the SOL.

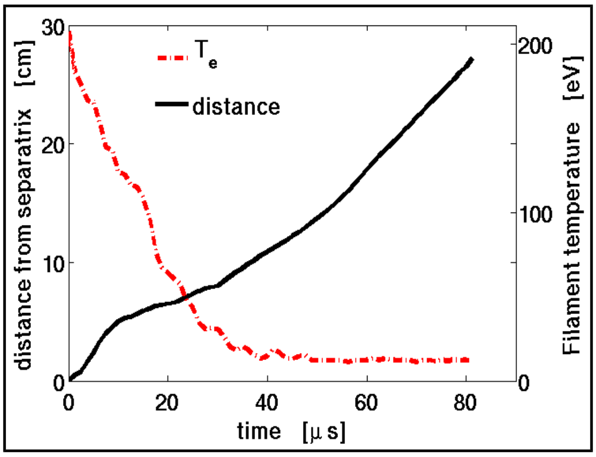

Figure 4:
The highest T_{SOL} case (24.4 eV). Filaments deccelerate until their temperature drops, at which point they start accelerating again.

<u>4. Effect of SOL Temperature on Filament Dynamics</u>

Considering the above, since lowering T_{SOL} induces an increase in both SOL resistivity and viscosity, it should be expected that the radial speed of filaments is not considerably affected. Firstly because the resistivity and viscosity are only increased in the SOL, and possibly at the bottom of the pedestal, which is not where the ballooning modes are most unstable. But also because increasing viscosity and increasing resistivity have the opposite effect on the ballooning growth rates. In fact, the ballooning growth rates are not strongly affected by the T_{SOL} variation, with the lowest T_{SOL} case having a growth rate only 4.2% lower than the highest T_{SOL} case.

Given the similar ballooning growth rates, initial filament speed when crossing the separatrix is similar for all T_{SOL} cases. However, with respect to the viscosity scan, it was expected that the filament speed would be constant in the SOL at least for the lowest T_{SOL} = 6.10 eV. Instead, filaments are oserved to deccelerate and accelerate for all T_{SOL} cases, even though this is less pronounced for the lowest T_{SOL} case. Figure-3 illustrates the effect of T_{SOL} on filament speed.

This demonstrates that it is not only the temperature level in the SOL that determines the filaments dynamics, but also the temperature inside the filaments. When measuring temperature within the largest filament near the midplane, it appears that while the filament is hot, it deccelerates, until temperature drops close to T_{SOL}, at which point the filament accelerates again, as shown in Figure-4.

5. Conclusion

The level of temperature in the SOL for MHD simulations may affect filament dynamics. Simulated filaments deccelerate radially after crossing the separatrix, coming to full stop ins some cases, unless they have a large initial speed when crossing the separatrix, in which case they start picking up speed again after their decceleration. Although this re-acceleration was observed for all T_{SOL} values, it is less pronouced at lower T_{SOL}, where filament speed is almost constant. Filament speed in the SOL is directly related to the filament temperature, not just to T_{SOL}. In addition, poloidal shearing/combination of filaments was observed at low viscosity and low filament speed. Whether this is physically realistic is subject to discussion, as it has not been observed on MAST during type-I ELMs.

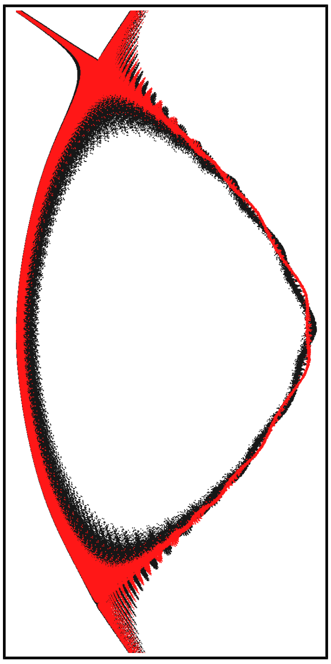

Figure 5: Target-connected field-lines. Larger field perturbation is observed for highest T_{SOL} case (black).

Finally, T_{SOL} also has another important effect: on ELM energy losses. It was found that the lowest T_{SOL} case has lower ballooning growth rates (4.2% lower), and so its energy losses are also smaller, 2.7% against 4.3% for the highest T_{SOL} case. In addition, balooning modes perturb the magnetic field much further inside the separatrix for the highest T_{SOL}: up to 14.5% of the minor radius, while only 7.1% of the minor radius is perturbed for the lowest T_{SOL} . Note that this increase in ELM energy loss is not only due to the 4.2% increase in balooning growth rates, but at higher T_{SOL}, the ELM is more active after the first set of filaments, ejecting 4 distinct sets of filaments one after the other, while the lower T_{SOL} case only evacuates 2 sets of filaments.

In future, it is planned to implement the Braginskii viscosity in JOREK, which has the dependence $\mu_\perp \sim T_i^{2.5}$, for which T_{SOL} could have an even larger effect on filament dynamics.

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[1]. *G.T.A. Huijsmans and A. Loarte*, ***Nucl. Fusion*** *53 (2013) 123023*
[2]. *W.Fundamenski* et al., ***Journal of Nuclear Materials*** *363–365 (2007) 319–324*
[3]. *R.Pitts* et al., ***Nucl. Fusion*** *47 (2007) 1437–1448*
[4]. *S.Pamela* et al., ***Plasma Phys. Control. Fusion 55*** *(2013) 095001*
[5]. *A.Kirk* et al., ***Plasma Phys. Control. Fusion*** *49 (2007) 1259–1275*