Assessment of particle pinch velocity on pedestal stiffness in high opacity Alcator C-Mod discharges

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In ITER [1] and future fusion reactors the plasma's density in the pedestal will be so high it will limit the possibility to control the plasma core density with only gas injection and recycling at the plasma edge. Most of the neutrals will be ionized outside the separatrix and it will be necessary to use pellet injection for fuelling. The presence of an inward particle pinch velocity V_{pinch} in the pedestal region can ease fuelling requirements but it's not yet clear how to isolate its contribution experimentally. To this aim the edge code SOLEDGE2D-EIRENE [2], characterized by the extension of the plasma fluid mesh up to the first wall, has been used to assess the importance of V_{pinch} studying experimental electron density profiles n_e of high plasma opacity Alcator C-Mod pulses. An opacity parameter [3,4] could be defined as $\kappa = a \cdot < n_e > = a \cdot \frac{(n_{e,sep}+n_{e,ped})}{2}$ where a is the minor plasma radius, $n_{e,sep}$ and $n_{e,ped}$ are the electron plasma density at separatrix and pedestal. C-Mod [5] is an optimal device to study plasma opacity: it can achieve a value of κ around $7e^{19}m^{-2}$ that are nearly half of the ITER predicted value 1.2 $e^{20}m^{-2}$.

Table 1: main parameters

#Pulses	Bt (T)	Ip (MA)	Opaqueness [m^{-2}]	Pinput (MW)	Total gas injected (TorrL)
1160718012 [3,4]	5.4	1.3	5.4	3.2	8.25
1160729008	7.8	1.42	4.6	3.6	---

To perform this study, we have considered two H-mode pulses whose main parameters are listed in table 1. Key characterizing differences include a different plasma opacity, as well as the absence of gas puffing/pumping in discharge #1160729008 in the time window of experimental data chosen. The upstream OMP profiles are constructed from Thomson Scattering TS data which are measured along a vertical chord at R=0.69 m, then mapped onto the normalized poloidal flux coordinate ψ_{norm} with EFIT. SOLEDGE2D does not simulate plasma turbulence, and the anomalous radial transport coefficient profiles are prescribed for cross-field particle and energy transport to match experimental data at OMP and targets. The cross-field ion velocity in the continuity, momentum and energy equations is defined [2] as $\vec{v}_i = \vec{V}_{pinch,i} + D_i \cdot \frac{\vec{\nabla}_\perp(n_i)}{n_i}$ the sum of the $\vec{V}_{pinch,i}$ and the diffusive cross-field transport, controlled by the coefficient D. First the TS n_e profiles are reproduced varying V_{pinch} and D. The result is compared with a simulation where D ~ 0 and $V_{pinch} = 0$ inside the core.

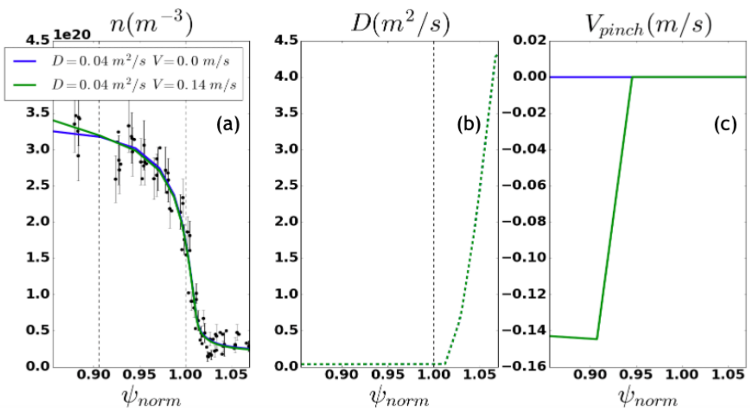

Figure 1: The #1160718012 TS n_e measurements (black) are compared in (a) with SOLEDGE2D simulation results. The blue and green lines represent the cases without pinch and with $V_{pinch}(\psi_{norm} < 0.9) = -0.14$ m/s respectively. Plots (b) and (c) show the D and V_{pinch} radial profile versus ψ_{norm}.

The #1160718012 measured TS n_e data at OMP is compared with the SOLEDGE2D result in figure 1(a). The experimental data are represented by black dots with own error bars. The SOLEDGE2D results without any V_{pinch} and the case with $V_{pinch}(\psi_{norm} < 0.9) = -0.14$ m/s (figure 1(c)) are respectively the blue and the green line. In both cases with and without a pinch velocity, $D = 0.04\ m^2/s$ is set inside the core (figure 1(b)). Around the separatrix, a convective velocity is not required to reproduce the experimental data and D alone can, provide a good agreement between SOLEDGE2D and TS. The V_{pinch} effect can be observed around $\psi_{norm} = 0.9$ as can be seen in figure 2(a). The green profile (with V_{pinch}) continues to increase into the core region with the TS data, whereas the instead the blue profile (without V_{pinch}) trends to a plateau. An alternative way to increase n_e is the reduction of D (the orange profile in figure 2(b) and 2(c)) in the same position of V_{pinch} drop. This is coherent with the D calculates in [6] from force balance equation solved for special pulses of DIII-D, where the neutral flux effect is negligible and V_{pinch} is dominant. The figure 3(a) illustrates the comparison between #1160729008 TS n_e at OMP with SOLEDGE2D results, where the experimental data and the simulation ones are respectively the black dots and the continuous lines. The blue case is purely diffusive (D = 0.01 m^2/s), whereas the green case includes also a negative $V_{pinch} = -0.13\ m/s$ for $\psi_{norm} = 0.9$.

Around the separatrix, the D coefficient alone can reproduce the experimental data as in the previous case.

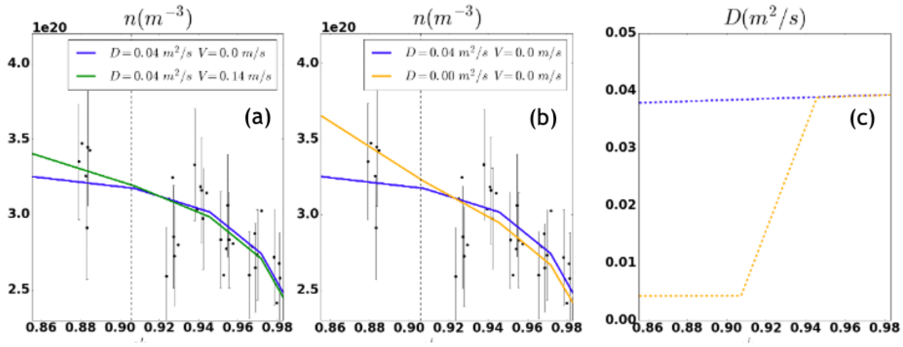

Figure 2: Zoom of fig. 1 around the pedestal, where the orange profile is the case with D~0 at ψ_{norm} = 0.9.

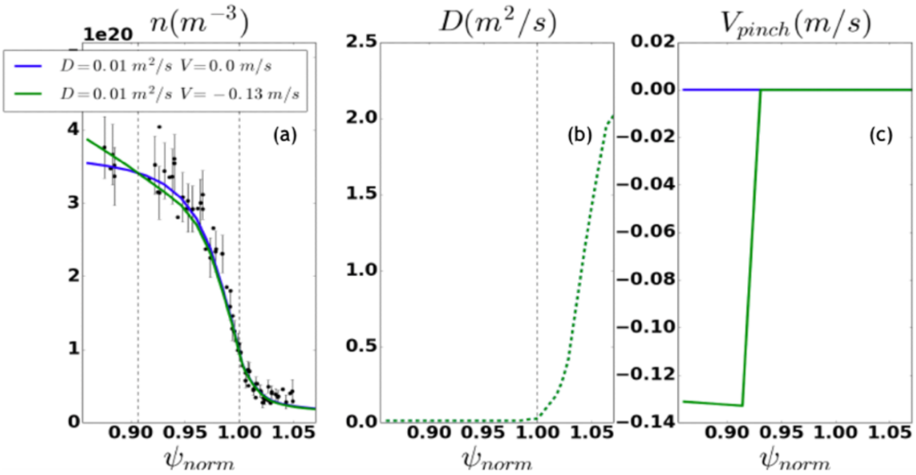

Figure 3: The #1160729008 TS n_e data (black) are compared in (a) with SOLEDGE2D results. The blue and green lines represent the cases without pinch and with V_{pinch} (ψ_{norm} < 0.9) = −0.13 m/s respectively. Plots (b) and (c) show the D and V_{pinch} radial profile versus ψ_{norm}.

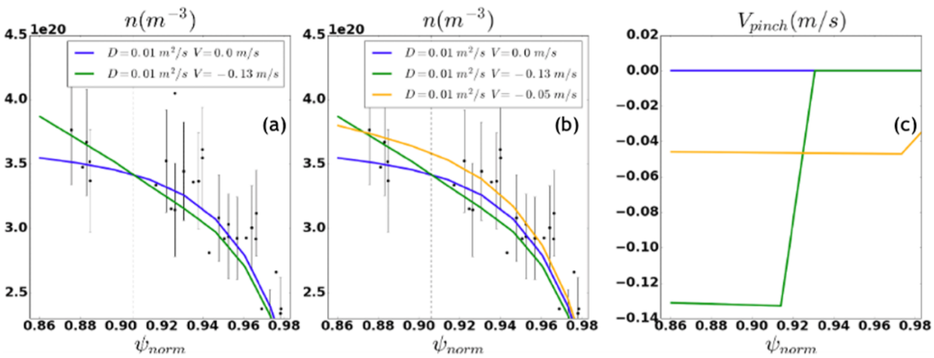

Figure 4: Zoom of fig. 3 around the pedestal, where the orange profile is the case with V_{pinch} = −0.05 m/s

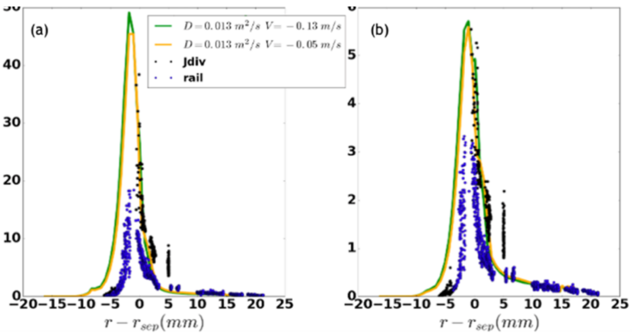

Figure 5: Plots of (a) n_e and (b) J_{sat} at the outer divertor target, where the blue and the black dots are the Rail Langmuir probe and the Mirror Langmuir probe arrays respectively. The green and orange line show the SOLEDGE2D simulation results with V_{pinch} = −0.14 m/s and V_{pinch} = −0.05 m/s

The V_{pinch} affects mainly the profile around ψ_{norm} = 0.90 (figure 4(a)). The green curve increases as does TS density measurement, diverging with the blue (zeropinch) line. The figure 4(c) shows a comparison of two different V_{pinch} drop positions, respectively at ψ_{norm} = 0.90 and ψ_{norm} = 0.96. The orange profile in figure 4(b) can better reproduce the TS data between 0.98 and 0.92, but it shows a similar plateau shape to the blue profile around ψ_{norm} = 0.98. The #1160729008 V_{pinch} could have a more complex shape than the first pulse. The two shots have similar pedestals but different separatrix densities, likely caused by the presence of puffing in #1160718012. This difference can be important since it seems to reduce the effect of pinch drop near the separatrix, and it will be investigated in the future work. In the #1160729008 discharge, it's possible to compare the Langmuir probe measurement at the outer target OT with the same quantities simulated in SOLEDGE2D. In the #1160729008 discharge, it's possible to compare the Langmuir probe measurement at the outer target OT with the same quantities simulated in SOLEDGE2D. Figures 5(a) and 5(b) are respectively the n_e and the J_{sat} from the Rail Langmuir probe (blue dots) and the Mirror Langmuir probe (black dots). All quantities are mapped to the OMP and n function of distance from the separatrix ($r-r_{sep}$). There is a good agreement between the experimental data and the simulation in both quantities with the V_{pinch} model. Results of this work indicate it's possible to reproduce the high opacity C-Mod pulses OMP density profiles with SOL simulation only by using an important reduction of the diffusion coefficient D at the pedestal in a diffusive-only transport model. The preliminary analysis suggests that the pinch velocity model improves experimental data modelling, indicating that this phenomenon can play an important role in edge transport. It has potential to have a significant contribution in ITER future operation, where the opacity value exceeds the C-Mod condition, but there is an important link between puffing and the V_{pinch} to be investigated. The future work will be dedicated to the analysis of the specific set of shots with similar parameters but different opacity to understand the evolution of the V_{pinch} value and profile.

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