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Simulation of Electric Fields in Small Size Divertor Tokamak Plasma Edge

A. H. BEKHEIT
Plasma & Nuclear Fusion Department, Nuclear Research Centre, Atomic Energy Authority, Cairo, Egypt
Email: *amrbekheitga@yahoo.com*

Abstract: The fluid simulation of Small Size Divertor Tokamak (SSDT) plasma edge by the B2-SOLPS5.0 2D [1] transport code gives the following results: First, in the vicinity of separatrix the radial electric field result is not close to the neoclassical electric field. Second, the shear of radial electric field is independent on plasma parameters. Third, switching on poloidal drifts (E×B and diamagnetic drifts) leads to asymmetric parallel and poloidal fluxes from outer to inner plates and upper part of SOL for normal direction of toroidal magnetic field. Fourth, for the normal direction of toroidal magnetic, the radial electric field of SSDT is affected by the variation in temperature heating of plasma. Fifth, the parallel flux is directed from inner to outer plate in case of discharge without neutral beam injection (NBI).

Keywords: electric field, transport codes, divertor tokamak

1. Introduction

A regime of improved confinement is extremely important for the operation of a thermonuclear reactor. A transition from the low confinement (L-mode) to high confinement regime (H-mode) was discovered [2], and since then it has been observed on many tokamaks and stellarators. The L-H transition may be caused by a strong radial electric field at the edge plasma and suppression of the fluctuation level by strong poloidal rotation in the E×B fields [3,4]. As a result, the transport coefficients are strongly reduced in the H-mode and transport barriers with steep density and temperature gradients were formed near the separatrix or close flux surface. The key element in the transition physics is the origin of the strong radial electric field in the edge plasma. If the radial electric field is sufficiently strong, the poloidal $E\times B$ flow acquires a large shear, which is considered to be necessary for suppression of edge turbulence. The radial electric field in the separatrix vicinity is simulated by using the B2-SOLPS5.0 two dimensional fluid code [1], in which most complete system of transport equations is solved including all the important perpendicular current and E×B drifts for SSDT. This code differs from the similar fluid codes (e.g. codes [5,6]), since it included detail account of parallel viscosity and perpendicular current. The equation system provides a transition to the neoclassical equation when the anomalous transport coefficients are replaced by classical value. The simulation is performed for SSDT, where the plasma parameters in the separatrix vicinity and the Scrap Off Layer (SOL) correspond to Pfirch-Schlueter regime [7], thus justifying the applicability of the fluid equations. On the basis of simulation for different power of additional heating, plasma densities, toroidal rotation velocities and magnetic field directions, it is demonstrated that the radial electric field in the separatrix vicinity is not of the order of the neoclassical field. In this paper the shear of the poloidal E×B drifts is calculated. It is shown that the shear of the poloidal rotation is not function of plasma parameters.

2. Simultion Results

The computation region for simulation is based on Single Null (SN) magnetic divertor and covers the SOL, core and private regions as shown in Figure 1. In computation region the coordinate which vary in the direction along flux surfaces (x-coordinate or poloidal coordinate) and the coordinate which vary in the direction across flux surfaces (y-coordinate or radial coordinate). The computation mesh is divided into 24×96 units (where $-1\leq x \leq 96$, $-1 \leq y\leq 24$) and the separatrix was at y=12. The simulations were performed for L-regimes of SSDT (minor radius a=0.1m, major radius R=0.3 m, I=50kA, B_T=1.7 T, electron density at equatorial midplane $n_e = n_i = n = 2 \times 10^{19}\ m^{-3}$, ion temperature T_i=31-93 eV).

The anomalous values of diffusion and heat conductivity coefficients were chosen: D=0.5 m^2s^{-1}, $\chi_{e,i}$ = 0.7 m^2s^{-1}. The perpendicular viscosity was taken in the form $\eta = nm_iD$. The inner boundary flux surface, was located in the core few cm from the separetrix, the boundary conditions for the density of plasma, the average toroidal momentum flux, the electron and ion

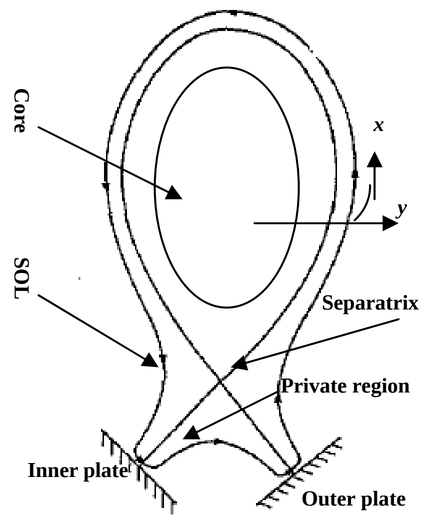

Figure 1. Coordinate system and simulation mesh

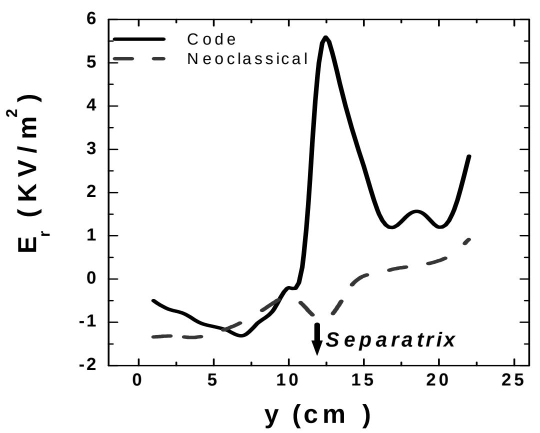

Figure 2. Radial electric field at edge of SSDT for discharge without neutral beam injection (NBI) at T_i = 31 e v, n_i = $4\times10^{19}m^{-3}$

heat fluxes were specified [8]. The first result of simulations for the radial electric field E_r was compared with the neoclassical electric field $E^{(NEO)}$ which is given by [7]:

$$E^{(NEO)} = \frac{T_i}{e}\left(\frac{1}{h_y}\frac{d\ln n}{dy} + k_T\frac{1}{h_y}\frac{d\ln T_i}{dy}\right) - b_x\frac{\oint\sqrt{g}V_{\|}B\,dx}{\oint\sqrt{g}\,dx} \tag{1}$$

where $b_x = B_x/B$ (B_x is poloidal magnetic field and $B=\sqrt{B_x^2+B_z^2}$ where B_z is toroidal magnetic fields), $\sqrt{g}=h_x h_y h_z$ is the metric coefficients, ($hx = 1/|\nabla x|$, $h_y = 1/|\nabla y|$, $h_z = 1/|\nabla z|$) $V_{\|}$ is the parallel (toroidal) velocity (the coefficient k_T = 2.7 corresponds to the Pfirsch-Schlueter regime).Typical radial electric field is shown in Figure 2. The comparison is showed that in the vicinity of separatrix the radial electric field is not order of the neoclassical electric field for both discharges without neutral beam injection (NBI). This fact means that, the radial transport of toroidal (parallel) momentum is larger than parallel viscosity in parallel momentum balance equation [8]. It is worth to mention that the averaged parallel velocity in Equation (1) is determined by the radial transport of parallel (toroidal) momentum i.e. by anomalous values of the diffusion and perpen-dicular viscosity coefficients. The radial profiles of parallel velocity for different values of average velocity at the inner boundary are shown in Figure 3. Even in the Ohmic case the contribution from the last term in Equation (1) is not negligible and should take into account. The second result, the radial electric field calculate by the code is negative in core, vicinity of separatrix and is positive in SOL, Figures 2. For normal direction of toroidal magnetic field in SOL one can see that the $E_r \times B_T$ drifts are directed from outer plate to inner plate in SOL, and from inner plate to outer plate in the private region as shown

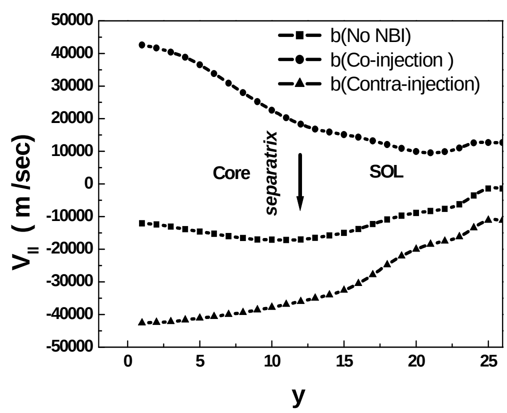

Figure 3. Parallel velocity for discharges with co and contra-injection neutral beam (NBI), for parameter of SSDT

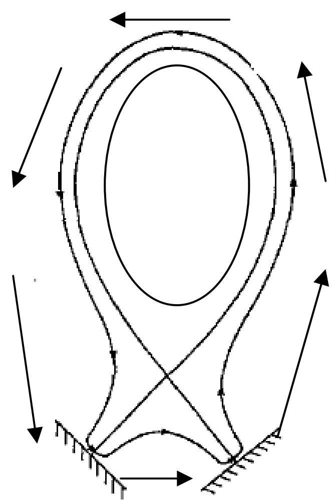

Figure 4. The arrows shows the direction of *E* × *B* drifts in the edge plasma of small size divertor tokamak

in Figure 4. Plasma rotates in the core in the direction opposite to that in the SOL, thus creating a shear near separatrix. The third result it has been found that radial electric field is affected by the variation in temperature of plasma heating (temperature heating of plasma given by $T_{heating} = 2 \times A_p \times \alpha$, where A_p surface plasma area = 1.53 for SSDT and α is constant given by code. For example, for $\alpha = 98.125$, $T_{heating} = 2 \times 1.53 \times 98.125 = 300.27$ eV) for SSDT as shown in Figure 5.Therefore, the increasing of the temperature heating of plasma causes a change in the structure of the edge radial electric field of SSDT (the electric field is more negative in the core). The fourth result is in the simulations, the parametric independence of radial electric field and its shear ω_s [9] defined by Equation, $\omega_s = \left| d V_{E\times B} / dy \right| = (RB_x / B) \left| d (E_y / RB_x) / h_y dy \right|$, on plasma parameters has been studied. The independence of shear of the electric field on plasma parameters was obtained, Figures (6–8).

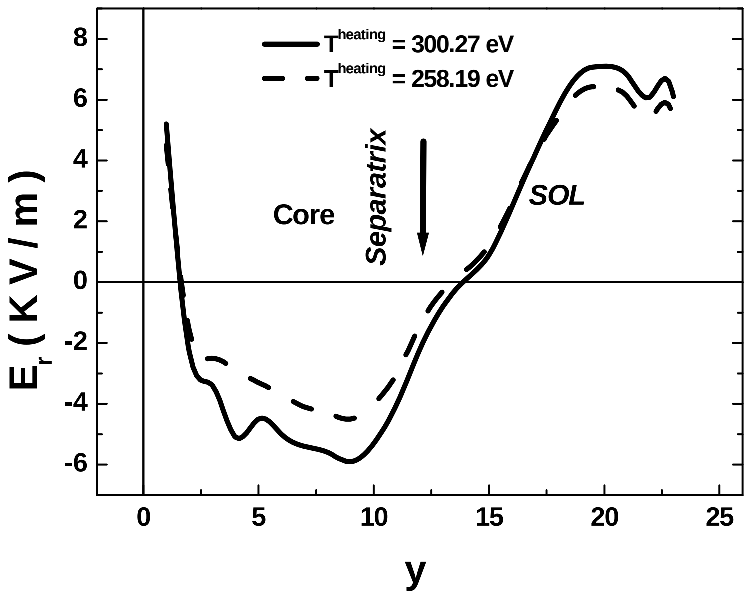

Figure 5. The radial electric field at different temperatures heating of plasma for SSDT

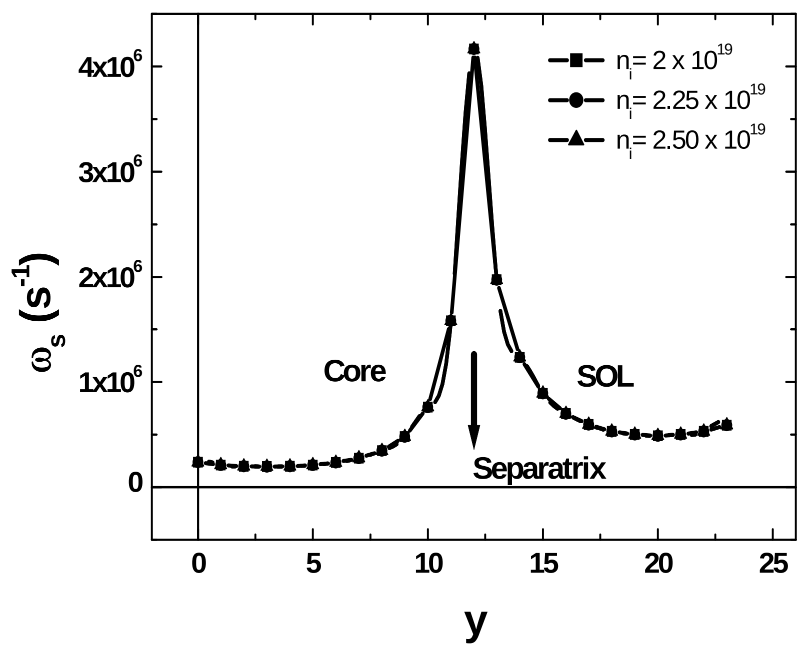

Figure 6. *E* × *B* shear at different plasma density

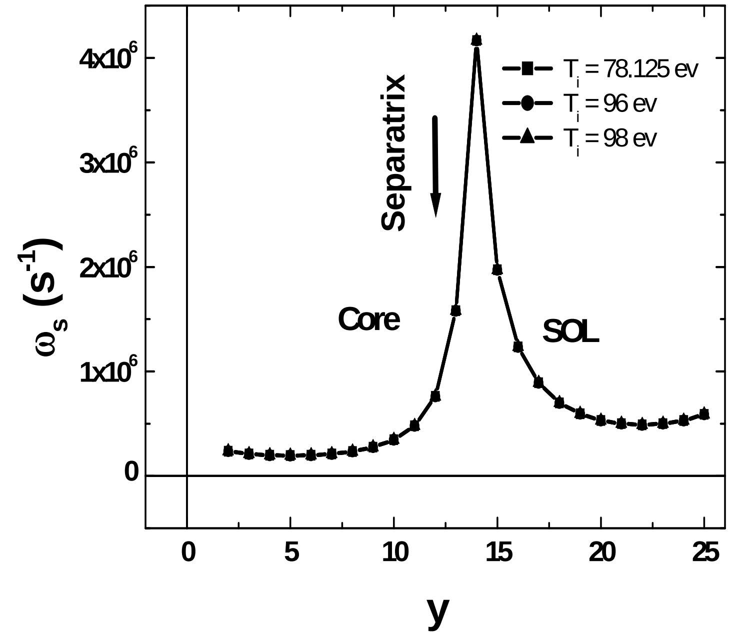

Figure 7. ***E*** **×** ***B*** **shear at different ion temperature**

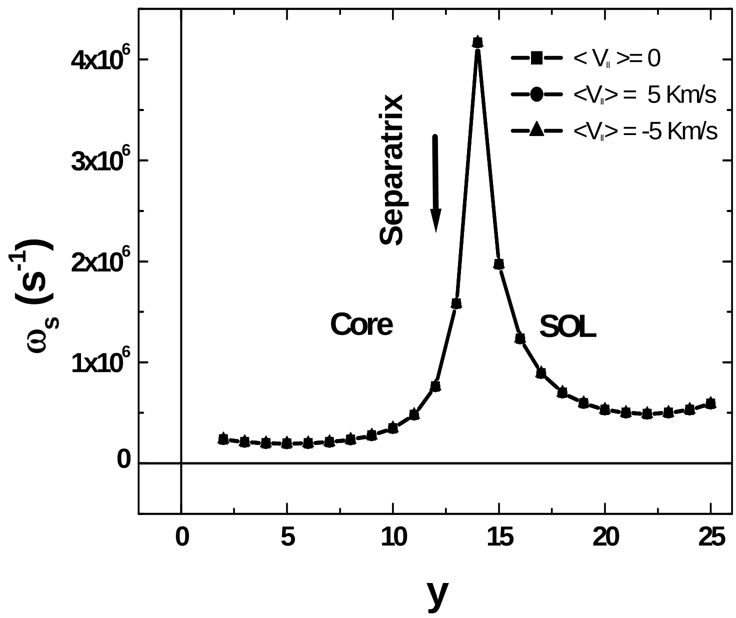

Figure 8. ***E*** **×** ***B*** **shear at different average parallel velocity**

To obtain a scaling for the L-H transition threshold it is necessary to specify the critical shear when the transition starts. For the critical shear we chose the value of ω_s independently of the regime due to limited knowledge of the turbulent processes. This value must be gives best fitting to the experiment. To reach the chosen critical shear it is necessary to increase the heating power proportionally to the local density and the toroidal magnetic field. This result is explained by the neoclassical nature of the simulated radial electric field. Indeed, the linear dependence of the threshold heating power on the local density corresponds to the constant critical value of the ion temperature, which determines the critical shear. In the vicinity of separatrix the radial electric field of SSDT, is not of order of neoclassical field. Therefore, for SSDT it's can't reach to critical shear to start L-H transition. The deviation of the electric field from the neoclassical value is relatively pronounced near the separatrix in the outer midplane, as shown in Figure 2. The reason for this difference is connected with the contribution of anomalous radial transport of the toroidal (parallel) momentum to the parallel momentum balance equation [8]. As result, for normal direction of toroidal magnetic field, the parallel fluxes inside and outside the separatrix are coupled Figure (9). The fifth result of simulation is studding the influence of drifts ($E \times B$ and diamagnetic drifts) on the fluxes in SOL. This could be understood from the analysis of parallel and poloidal fluxes in SOL. The structure of the parallel fluxes in the SOL is governed by the combination of three factors. The first is the Pfirch – Schlueter (PS) parallel fluxes close the vertical ion ∇ B drift, and their direction depends on the toroidal magnetic field. The second is the contribution from the radial electric field to the PS fluxes has the same sign as the contribution from ∇ B drift in the SOL since the radial electric

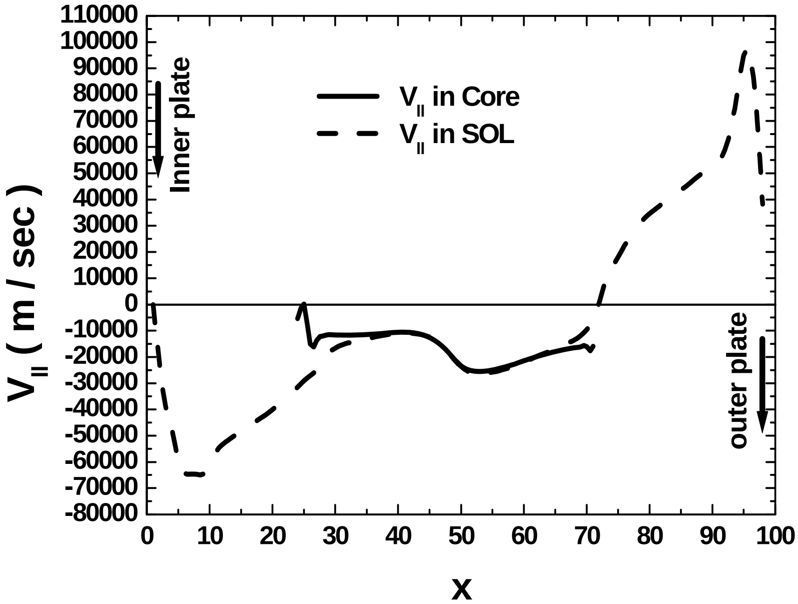

Figure 9. Parallel velocity inside and outside the separatrix

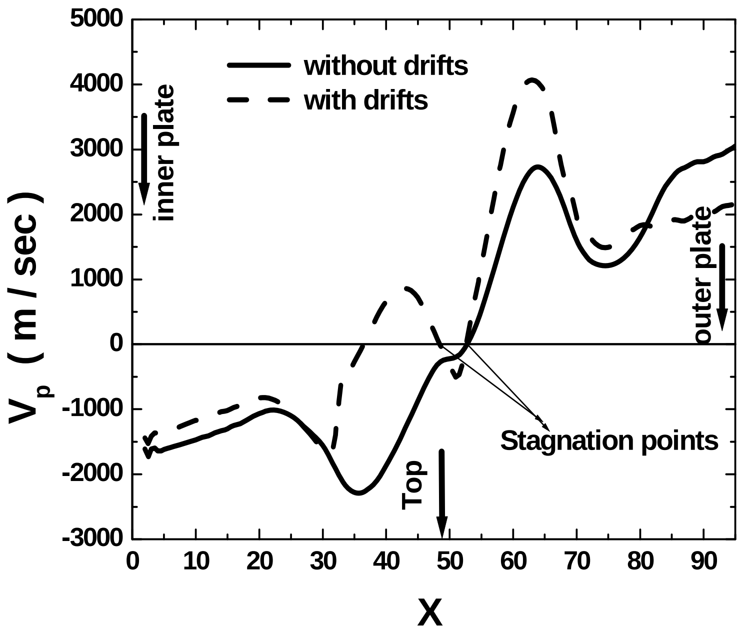

Figure 10. Poloidal velocity in SOL with and without drifts

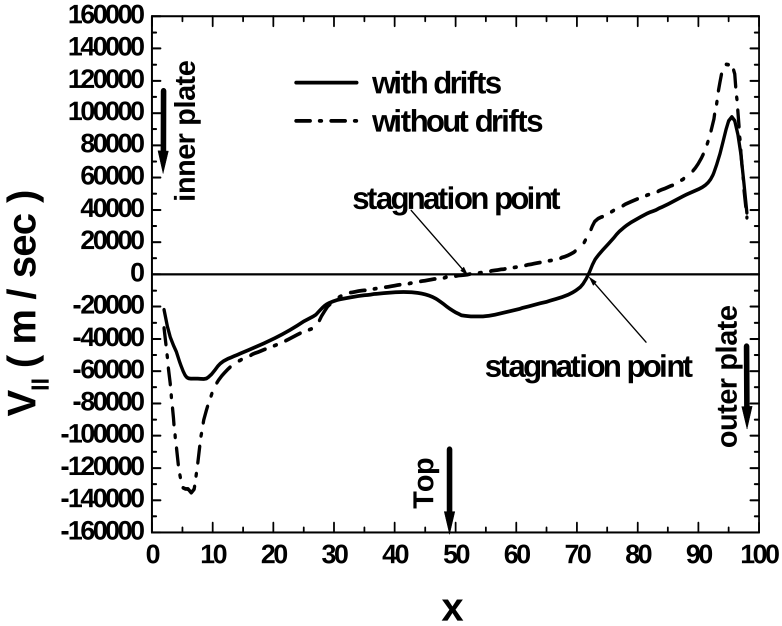

Figure 11. Parallel velocity with and without drifts

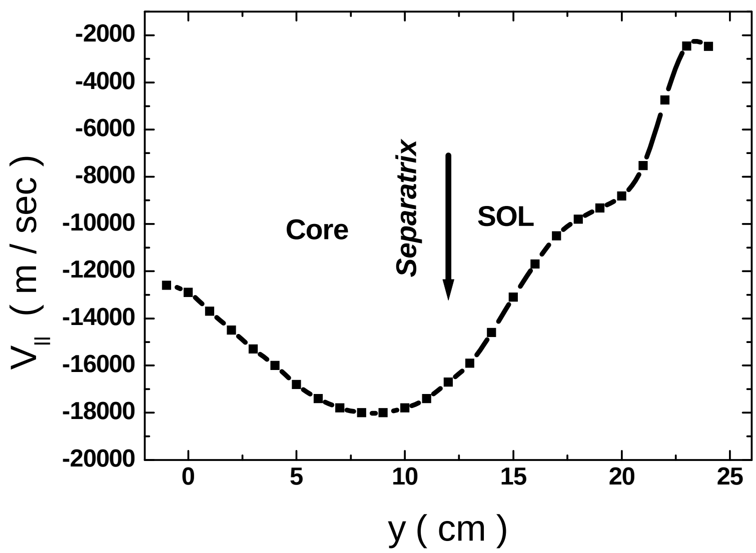

Figure 12. Parallel flux in the edge of SSDT

field is positive in the SOL as shown in Figure 2 (inside separatrix, where the radial electric field is negative, the contribution to PS fluxes ∇ B drifts and E×B drift compensate each other in accordance with neoclassical theory). The third contribution arises from the poloidal fluxes that are responsible for the particle transport to the plates. Those poloidal fluxes are closed the radial diffusive particle fluxes. In the absence of the poloidal E×B and ∇ B drifts these fluxes coincide with the projection of the parallel fluxes. On the one hand, the outer plate is larger than the inner plate and the integral poloidal flux to this plate should be larger. On the other hand, since the plasma in the vicinity of the inner plate is colder and denser, the particle flux per square meter to this plate that is proportional to n $(T/m_i)^{1/2}$ is larger than particle flux to outer plate (the pressure is almost the same at the plates).

Switching on E×*B* drift leads to asymmetric in parallel and poloidal fluxes from outer to inner plates and upper part of SOL as shown as in Figures (10,11). Also switching on the poloidal drifts leads to decrease of the parallel velocity, because the poloidal projection of the parallel velocity not compensates poloidal E×B drifts, so that the poloidal rotation changes. Moreover, the position stagnation point for the poloidal did not change much which is located somewhere near the upper part of the SOL, as shown in Figure 11. In contrast, the position of the stagnation point for parallel flux may be significantly different Figure 11. For normal B the stagnation point is strongly shifted towards the outer plate. This fact is consistent with the observations with simulations [10]. Finally the parallel flow pattern is the result of all three factors. For normal B parallel flux in SOL is negative as shown in Figure 12. Therefore, for normal B parallel flux is directed from outer to inner plate.

3. Conclusions

In conclusion, the performed simulations for SSDT demonstrate the following results: (First) In the vicinity of separatrix the radial electric field was not close to the neoclassical electric field. (Second) the independence of the shear of radial electric field on plasma parameters. (Third) For normal direction of torodial magnetic field, the radial electric field of SSDT was affected by the variation in temperature heating of plasma. (Fourth) Switching on poloidal drifts leads to asymmetric parallel and poloidal fluxes from outer to inner plates and upper part of SOL for normal direction of toroidal magnetic field. Also switching on the poloidal drifts leads to decrease of the parallel velocity, because the poloidal projection of the parallel velocity not compensates poloidal E×B drifts, so that the poloidal rotation changes. (Fifth) The parallel flux is directed from outer to inner plate. (Sixth) The $E \times B$ drift are directed from outer plate to inner plate in SOL, and from inner plate to outer plate in the private region.

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