

# Sensitivity analysis of upstream plasma condition for SST-1 X-Divertor configuration with SOLPS

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**Abstract:** Extensive power exhausts and target heat loads are anticipated in reactor grade fusion devices. Prototyping of an X-Divertor based power exhaust scheme is being attempted by means of simulations of Scrape-off Layer plasma transport in the diverted plasma equilibria of SST-1 tokamak using SOLPS5.1. Evaluation of the relative advantages of an X-Divertor configuration involves simulating the SST-1 standard divertor scheme plasma transport for the reference and then achieving equivalent upstream plasma conditions in the X-divertor equilibrium to ensure equivalent core plasma in both the cases. The first optimization is to be achieved by simulating effects of an external gas puff in the SOL region for controlling separatrix density in the X-divertor configuration with visible modifications in the downstream plasma conditions. The present work analyzes sensitivity of the upstream SOL plasma conditions to the gas puff intensity and its effect on the plasma neutral transport in the divertor region

## 1. Introduction

In order to handle the huge amount of heat loads in fusion grade reactors with Standard divertor (SD) configuration that are employed in the current machines (ITER) might be problematic. The X-divertor (XD) [1] was proposed for reactors to improve power exhaust by increasing flux expansion and line length. The magnetic geometry of the X-divertor is based on creating an extra X-point near the divertor plate to increase the flaring of field lines in the divertor region and hence plasma-wetted area and it considerably reduces heat flux on the divertor plates. The XD configuration is expected to reduce the heat load at strike point by efficiently depositing heat on the downstream. The neutral front is expected to move downstream in XD as compared to SD and will reduce the energy loss in the plasma. Before going to experimental XD configuration in SST-1 tokamak it is essential to quantify these advantages by modeling the plasma transport in this magnetic geometry.

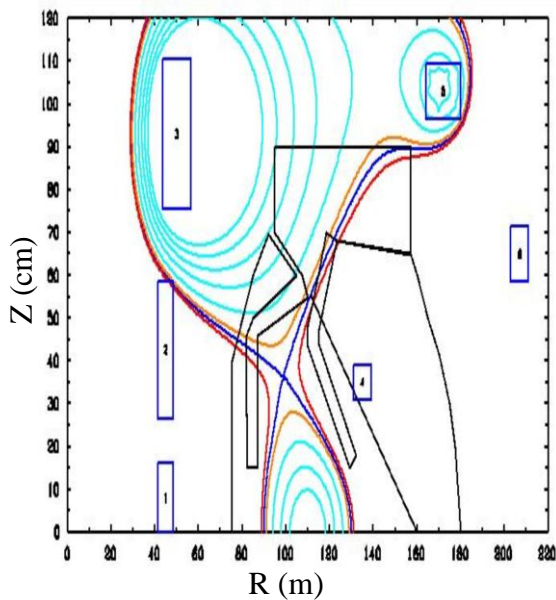
The free boundary magneto hydrodynamic (MHD) equilibrium code CORSICA [2] is used for SD and XD configurations. The quantitative measure of convergence of flux surfaces relative to the Standard Divertor (SD) is given by the SOL Divertor Index (DI). For SST-1, DI = 6.82 for XD means the flux surfaces are more flared than DI = 2.69 of SD. On these SD and XD configurations we performed transport simulations using SOLPS5.1 in order to see the qualitative performance of XD over SD. The SOLPS5.1 [3] couples the 2-D multi-fluid plasma code B2.5, handling the transport of electrons and multiple ionized states of ions, with neutral Monte-Carlo code EIRENE [4]. The computational mesh, produced by using CAREE [5] code available with the SOLPS5.1, is based on 2D magnetic field equilibrium and the real geometry of divertor and other boundaries in the device. Simulating



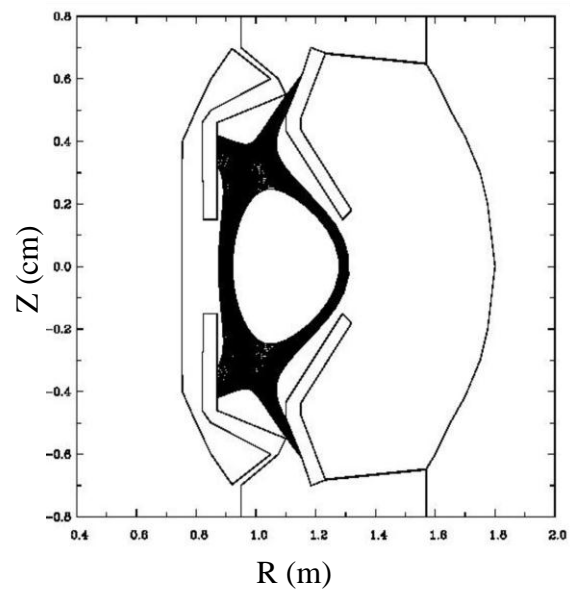
the effects of gas-puff in the SOL to ensure the core equivalence of both geometries and their effect at the divertor.

## 2. SOLPS5.1 Modeling

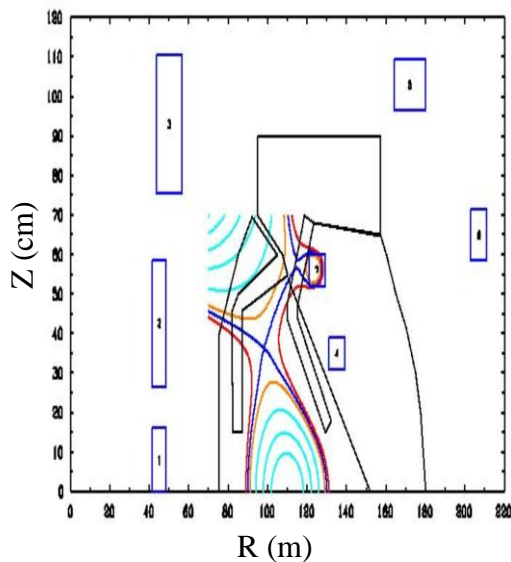
MHD equilibrium of SD and XD divertor geometry shown in figure 1(a) & 2(a) are predicted by using CORSICA with operational parameters of plasma current  $I_p = 220$  kA and toroidal field  $B_0 = 3$  T. The computational meshes used for the modeling of SD and XD are produced by using Carre in the SOLPS5.1 code package are shown in figure 1(b) & 2(b) which has a resolution of  $98 \times 36$ . The computational modeling region is based on Double Null (DN) and covers the outer SOL, the divertor targets below the mid-plane plus a small segment of the region of closed flux surfaces and of the private flux region. The two coordinates in 2D modeling are one along the magnetic flux surface (poloidal or x-coordinate) and other across the flux surface (radial or y-coordinate).



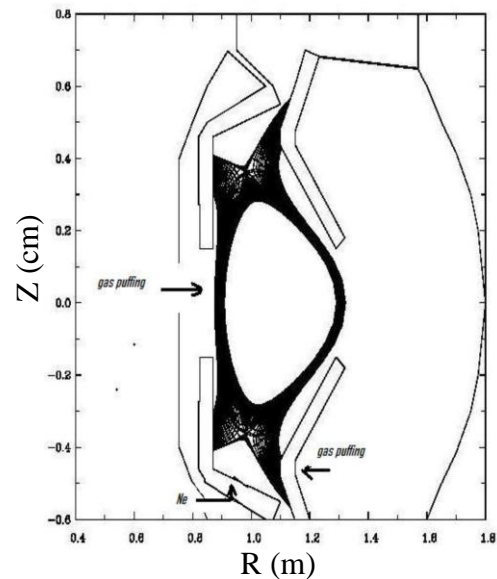
**Figure 1(a).** SD Plasma equilibrium



**Figure 1(b).** SOLPS computational grid  $98 \times 36$



**Figure 2(a).** XD Plasma equilibrium

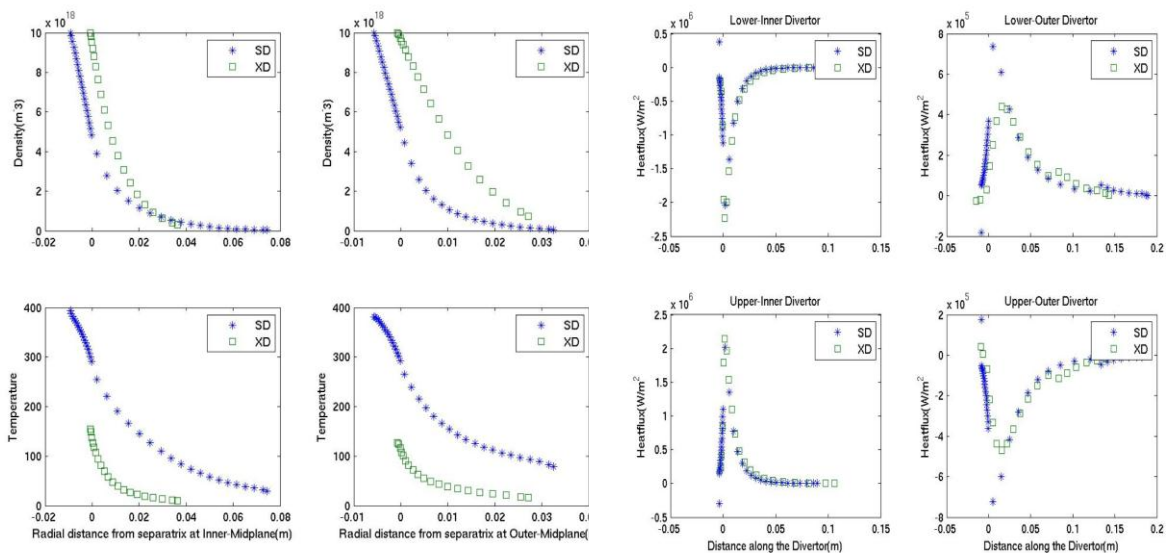


**Figure 2(b).** SOLPS computation grid  $98 \times 36$

The boundary conditions used in the SOLPS5.1 are at the core-edge interface(which is the inner most closed flux surface) is either plasma density  $n_e$  or fixed particle flux  $\Gamma_e$ , allowing one of them to be determined by the computations. The input power at the core-edge interface shared between the electron and ion equally and was taken as 1MW. The recycling coefficient at the walls and target surfaces are taken as unity. The out flow of all charged particles is at sound velocity. In the present modeling, the plasma species includes the neutral deuterium atom  $D^0$ , deuterium ion  $D^+$ , and electron. The parallel heat and momentum transport are classical but flux limited. Perpendicular transport which is anomalous and their coefficients are kept as  $D_{\perp} = 0.4 \text{ m}^2/\text{s}$  and  $\chi_{\perp} = 0.6 \text{ m}^2/\text{s}$ . In this study we try to check the advantages of XD over SD configuration through achieving the same upstream conditions to ensure the core equivalence of two configurations and see the effect of divertor geometry on the power deposition.

### 3. Optimized Modeling results of SD & XD

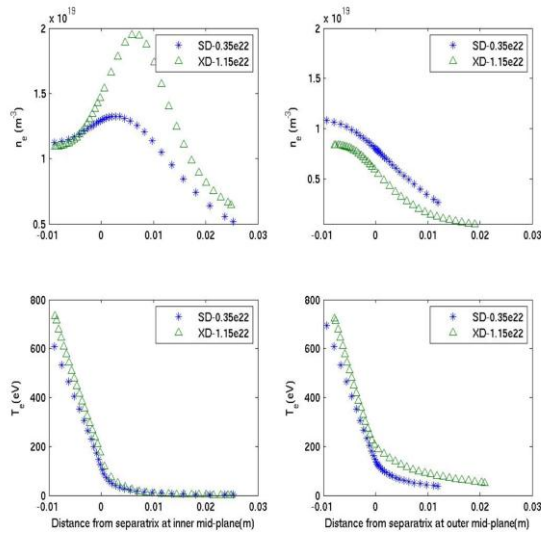
The equilibrium plasma configuration in SOL of SD and XD are determined by using input power  $P = 1 \text{ MW}$  and fixed core-SOL interface density  $n_e = 1 \times 10^{19} \text{ m}^{-3}$ . The radial distribution of plasma density and temperature at the inner and outer mid-planes of SD and XD are plotted in figure 3(a). The distribution of heat flux on divertors at the outboard side of XD is showing 25 % reduction as compared to SD is presented in figure 3(b). Since figure 3(a) is not showing same core conditions as expected it is difficult to say, XD geometry whose field lines are diverged as compared to SD has reduced the power deposition on the targets until unless we have the same upstream conditions.



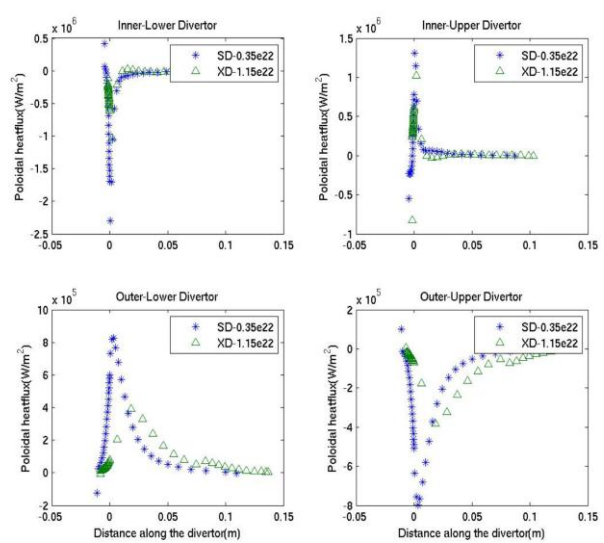
**Figure 3(a).** Plasma density  $n_e$  and temperature  $T_e$  at the inner and outer midplane for the input Power  $P = 1 \text{ MW}$  and  $n_e = 1 \times 10^{19} \text{ m}^{-3}$

**Figure 3(b).** Distribution of Total heat flux as a function of distance from separatrix, at inner and outer divertors for input power  $P = 1 \text{ MW}$  and fixed core-sol interface density  $n_e = 1 \times 10^{19} \text{ m}^{-3}$

To match the upstream conditions of SD and XD configurations, opted another boundary condition zero net particle flux across the core-SOL interface with gas-puff at inboard mid-plane, density values at upstream of SD and XD has 40% difference. The difference has come down when we optimized the gas-puff can be seen in figure 4(a). Optimized gas-puff condition is showing two times reduction in power deposition and shift in the peak value of heat flux as compared to SD is shown in figure 4(b).

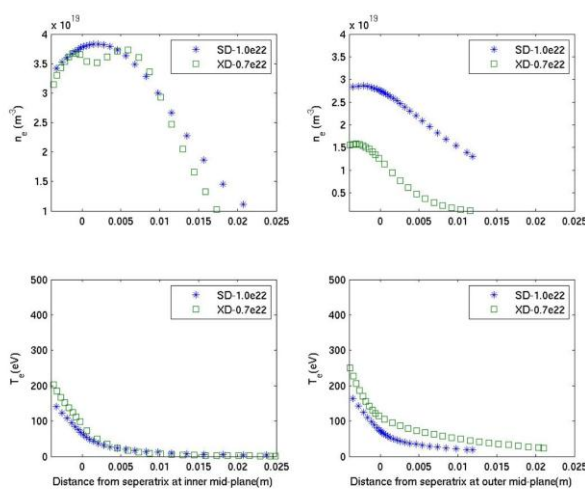


**Figure 4(a).** Radial distribution of Plasma density  $n_e$  and temperature  $T_e$  for input power  $P = 1$  MW with gas-puff intensities

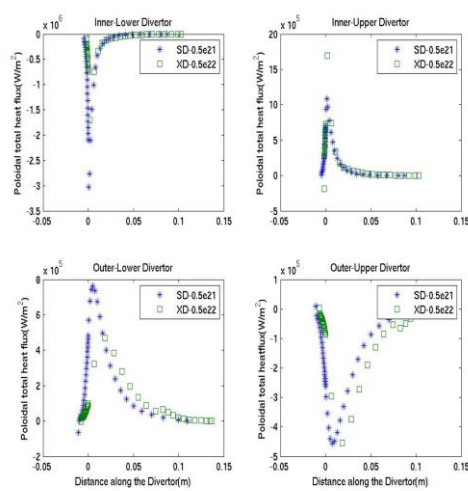


**Figure 4(b).** Distribution of Total heat flux on the inner and outer divertors for input power  $P = 1$  MW with gas-puff intensities

In order to control the separatrix density in the XD configuration used Ne impurities ( $1 \times 10^{20} \text{ s}^{-1}$ ) at Private Flux Region (PFR) shown in figure 2(b). When optimized the gas-puff at inner mid-plane, we are able to match the radial profiles of plasma density and temperature as shown in figure 5(a). Same kind of optimization done at the outboard side also to match the outboard midplane radial profiles of density and temperature. The density values at separatrix of SD and XD are matched but not the rest of SOL. Optimized gas-puff with impurities case is showing two times reduction in power deposition for XD as compared to SD is shown in figure 5(b).



**Figure 5 (a).** Radial distribution of Plasma density  $n_e$  and temperature  $T_e$  for input power  $P = 1$  MW with gas-puff intensities



**Figure 5(b).** Distribution of Total heat flux on inner and outer divertors for input power  $P = 1$  MW with gas-puff intensities

#### 4. Summary and Conclusions

X-Divertor configuration for SST-1 tokamak analyzed computationally with SOLPS5.1 transport code to explore the relative advantages in power deposition over SD of SST-1. Optimized gas-puff values showed similar upstream conditions to ensure the core equivalence for both geometries. X-divertor configuration is showing reduction in power deposition as compared to SD. In the preliminary study, XD geometry option for SST-1 is showing very little effect on power deposition on the targets. We need further study to equivalence the core conditions and see the advantages of XD in reduction of power deposition.

#### References

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