Modeling of edge plasma of MAST-Upgrade with Super-X divertor

V. Rozhansky[1], P. Molchanov[1], I. Veselova[1], S. Voskoboynikov[1], A. Kirk[2], G. Fishpool[2], P. Boerner[3], D. Reiter[3] and D. Coster[4]

[1]Plasma physics chair, St.Petersburg State Polytechnical University, Polytechnicheskaya 29, 195251 St.Petersburg, Russia
[2] EURATOM/CCFE Fusion Association, Culham Science Centre, Abingdon, Oxon, OX14 3DB, UK
[3]Forschungszentrum Jülich GmbHInstitute of Energy and Climate Research - Plasma Physics 52425 Jülich
[4]Max-Planck Institut für Plasmaphysik, EURATOM Association, D-85748 Garching, Germany

E-Mail: rozhansky@mail.ru

Abstract

The Super-X divertor (SXD) edge plasma of the future MAST Upgrade tokamak [1-3] was simulated with the B2SOLPS5.2 transport code including for the first time the effects of drifts due to electric field and magnetic field gradient. The expected reduction of the temperatures and heat flux densities at the low field side divertors was obtained in the simulations. Account of $\vec{E}\times\vec{B}$ drifts and parallel currents leads to up-down asymmetry of the power to the plates in the connected double null (CDN) configuration.

PACS: 52.25.Fi, 52.55.Fa, 52.65.Kj

1. Introduction

The concept of the Super-X divertor (SXD) is aimed at reducing heat flux density at the divertor plates in future tokamak reactors [4]. One advantage of such a divertor configuration with a low poloidal field region on the divertor leg is that the wetted area can be increased through it increasing in proportion to the major radius of the plates with respect to the conventional divertor configuration of similar flux expansion at the target. The connection length also becomes larger, which should increase the scrape-off layer (SOL) width and also should increase volumetric radiation losses. Simulations with the SOLPS code [1], [5] supported this concept and demonstrated the reduction of the temperatures and the heat flux densities at the low field side (LFS) divertor target plates with respect to conventional tokamak divertors.

Two important issues were not considered in the initial simulations. The first issue is that these simulations were made with constant transport coefficients while in the H-mode the transport coefficients, in particular the diffusion coefficients, are reduced in the edge barrier region. Account of the reduced diffusion in the edge transport barrier (ETB) leads to the reduction of the separatrix density since increase in the density gradient causes the larger difference between the pedestal and the separatrix density. As a result the SOL becomes narrower and divertor parameters differ from the case without the barrier. The second issue is that no account was made for the symmetry breaking effects of drifts and currents. As was demonstrated previously, in [6] and references therein, in the connected double null (CDN) configuration more power goes to the lower plates (for the normal direction of the magnetic field with ion ∇B drift directed towards the X-point) due to the convective heat flux caused by parallel currents.

In this paper we present results of new simulations with the B2SOLPS5.2 transport code made for the MAST Upgrade geometry with transport coefficients that represent those deduced from experiment, and taking into account the effects of drifts and parallel currents. The main runs were obtained with a fluid description of neutral particles, while EIRENE runs were made for the cases with drifts switched off and were used to verify the fluid runs. It was demonstrated that, for the MAST Upgrade geometry and representative parameters, the temperatures at the LFS plates indeed should be relatively low, of the order of the few *eV*. The heat flux densities at the plates are also rather low in accordance with the SXD concept. The power going to the lower plates is almost twice that going to the upper plates due to the convective heat flux associated with the parallel current similar to the conventional cases [6], however the effect for the SXD case is stronger. In general the simulation results support the SXD concept.

2. Modeling

The following MAST Upgrade parameters were chosen for simulation. Plasma current I=1.0MA, vacuum toroidal magnetic field at R=0.8m is $B_T = 0.8T$, power going to the SOL $P_{SOL} = 4.6MW$. A shot without additional gas puffing has been simulated. The choice of transport coefficients was based on the results of the previous modeling performed earlier for MAST [7]. The chosen transport coefficients are shown in Fig. 1. The simulation mesh is presented in Fig.2. The calculated density and electron temperature radial profiles at the outer mid-plane are shown in Fig.3 a,b. The radial electric field profile is shown in Fig. 4.

The set of electron density and temperature profiles at the outer divertor plates are shown in Fig. 5 a,b,c,d. At the low field side (LFS) the lower divertor is significantly hotter than the upper one. The electron densities are of the same order but the density peak at the upper divertor is shifted outward, consistent with both the direction of the radial $\vec{E} \times \vec{B}$ drift, and also with the partial detachment of the divertor leg close to the separatrix. The neutral density is larger at the upper divertor.

The power distribution at the outer plates is shown in Fig. 6 a,b. The heat flux density at the LFS plates is rather low, as was expected according to the SXD concept. The up-down asymmetry is caused by the electron heat flux, which is proportional to the parallel current (though obviously in the opposite direction). The current at the LFS is flowing from bottom to top, and hence the electron flow is from the upper, cooler plate to the lower, hotter plate. To verify that the fluid description of neutral particles is sufficient in these simulation, further runs were conducted with a version of the code in which the drifts were switched off (for computational efficiency), and the neutral particle effects were simulated through coupling with the EIRENE code. For an albedo of 0.95 at the pump entrance the results were similar to the results of the fluid runs without drifts.

3. Discussion

The temperatures and heat flux density at the LFS divertor plate are rather low, which demonstrates the strong effect of the SXD configuration. Simulations were also carried out with a plasma having a conventional divertor configuration, with similar assumptions about the core and upstream plasma parameters. The temperatures and heat flux densities at the LFS in the SXD case were indeed significantly smaller than for the conventional case as in the previous simulations [1-5], the reduction of the heat flux density was up to the order of magnitude.

The role of the drifts is similar to that in conventional tokamaks [6]. At the LFS the plasma density at the upper plate becomes larger than the density at the lower plate, but only further away from the separatrix. In contrast at the HFS plates the situation is reversed - the plasma density at the upper plate is smaller than the density at the lower plate. The up-down asymmetry of the peak temperatures is opposite to the density asymmetry - the denser divertor corresponding to the lower temperature and vice versa. However the locations of the peak densities and peak temperatures are different, as expected when there is a horizontal target geometry and neutrals are directed out into the further SOL. The ion saturation current to the plate is larger for the plate with higher density.

Since the plasma potential in the SOL decreases from the separatrix in the radial direction, the poloidal $\vec{E} \times \vec{B}$ drift at the LFS is directed away from the plate at the upper plate and towards the plate at the lower plate. This is then consistent with the greater heat flux at the lower target. Looking at the detailed shape of the density profile, the density close to the peak temperature (and to the separatrix) is highest in the lower divertor i.e. the plate to which the poloidal $\vec{E} \times \vec{B}$ drift is directed. Further out in the profile at the upper plate there is increased density, and this is consistent with the neutrals from the "horizontal" type target interaction, with the main part of the strike zone starting to detach.

At the hotter target plate the floating potential drop is larger than at the colder one and thermal current arises flowing from the hotter to the colder divertor (with electrons flowing the opposite way). Hence, the convective electron heat flux caused by the parallel current at the LFS flows from the upper plate to the lower plate. The convective flux is added to the conductive one. This is an additional factor self-enhancing, as it were, the electron power at the lower LFS plate. This effect was observed on MAST [8-9] and is clearly seen in the simulation results, Fig.6.

The HFS situation in the absence of gas puffing is not typical for the experiment since the heat flux is not conductive but free streaming. It should change with additional gas puff, and will be studied in more detail in future work.

4. Conclusions

The Super-X divertor (SXD) edge plasma of MAST Upgrade tokamak was simulated using the B2SOLPS5.2 transport code with all drifts switched on. Reduction of the temperatures and heat flux densities at the low field side divertors was obtained in the simulations. Account of $\vec{E} \times \vec{B}$ drifts and parallel currents leads to the up-down asymmetry of heat flux densities at the plates in the connected double null (CDN) configuration, consistent with the results seen in experiments with more conventional divertor geometries.

Acknowledgements

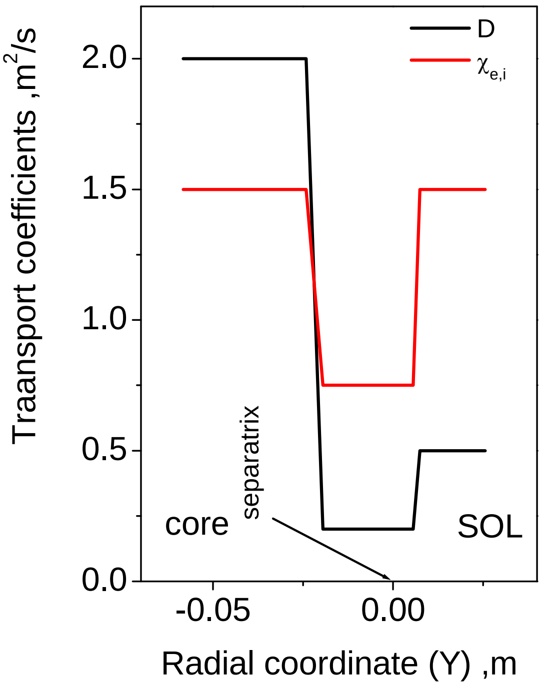
This work was part-funded by the RCUK Energy Programme under grant EP/I501045 and the European Communities under the contract of Association between EURATOM and CCFE. The views and opinions expressed herein do not necessarily reflect those of the European Commission. This work was also supported by Russian Government Grant according to Ordinance No. 220 under Agreement No. 11.G34.31.0041 with Ministry of Education and Science of Russia and by RFBR Grant 10-02-00158-a.

References

[1] S. Lisgo et al. 2009 *36th EPS Plasma Physics Conference* O4-046 http://epsppd.epfl.ch/Sofia/pdf/O4_046.pdf
[2] I. Katramados et al. 2011 *Fusion Engineering and Design* **86** 1595
[3] A W Morris 2012 *IEEE Transactions on Plasma Science* **40** 682
[4] P.M. Valanju et al 2009 *Phys. Plasmas* **16** 056110
[5] M. Kotschenreuither et al 2010 *Nuclear Fusion* **50** 035003
[6] V. Rozhansky et al 2012 (accepted) *Nuclear Fusion* **52**
[7] V. Rozhansky et al 2009 *Nuclear Fusion* **49** 025007
[8] J-W Ahn et al 2002 *29th Conf. on Plasma Phys. Contr. Fusion Montreaux ECA* **26B** P1-055 http://epsppd.epfl.ch/Montreux/pdf/P1_055.pdf
[9] G De Temmerman 2010 *Plasma Phys. Contr. Fus.* **52** 095005

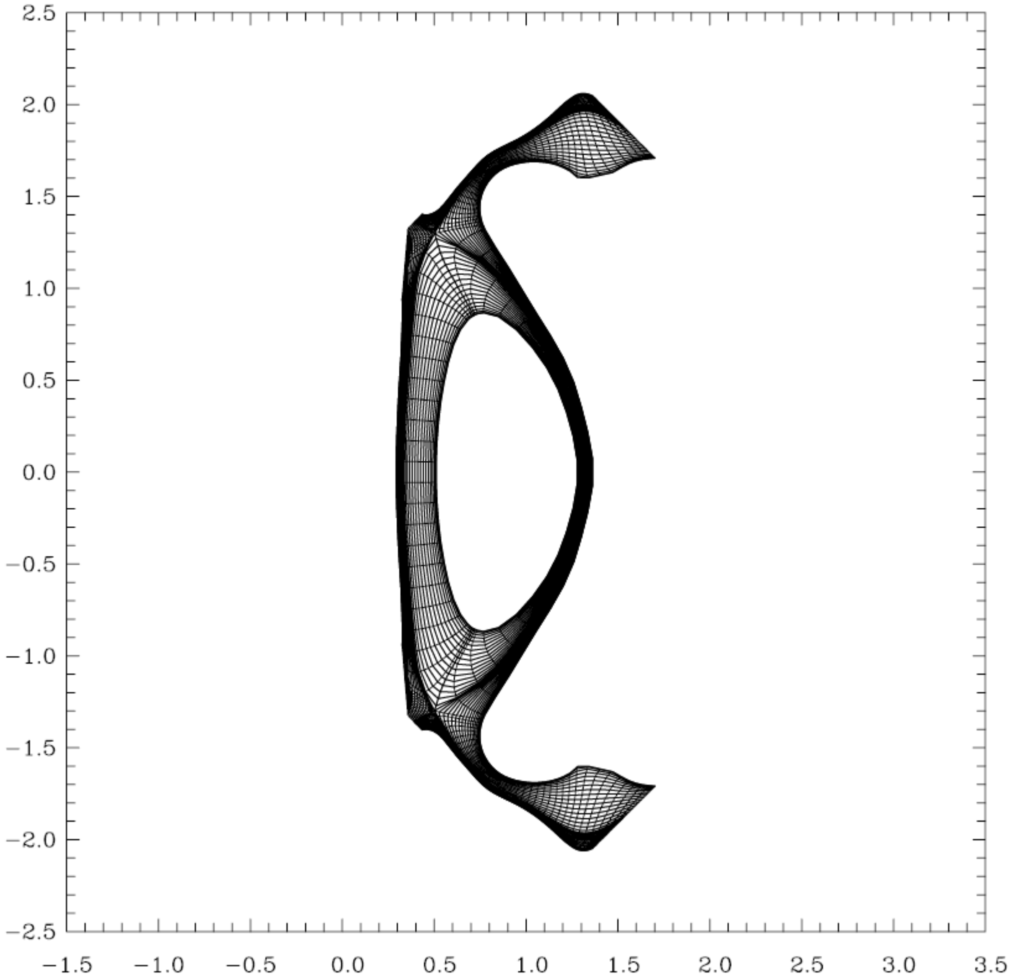
Figure captions

Figure 1. Transport coefficients at the outer mid-plane.
Figure 2. Simulation mesh (*a*), simulation mesh above the upper *X*-point (*b*)
Figure 3. Electron density (*a*) and electron temperature (*b*) profiles at the outer mid-plane.
Figure 4. Radial electric field at the equatorial mid-plane.
Figure 5. The electron density: (*a*) at the outer upper divertor plate, (*b)* at the outer lower divertor plate; the electron temperature: (*c*) at the outer upper divertor plate (*d*) at the outer lower divertor plate.
Figure 6. The heat flux density at the divertor plates: (*a*) outer upper divertor, (*b*) outer lower divertor.

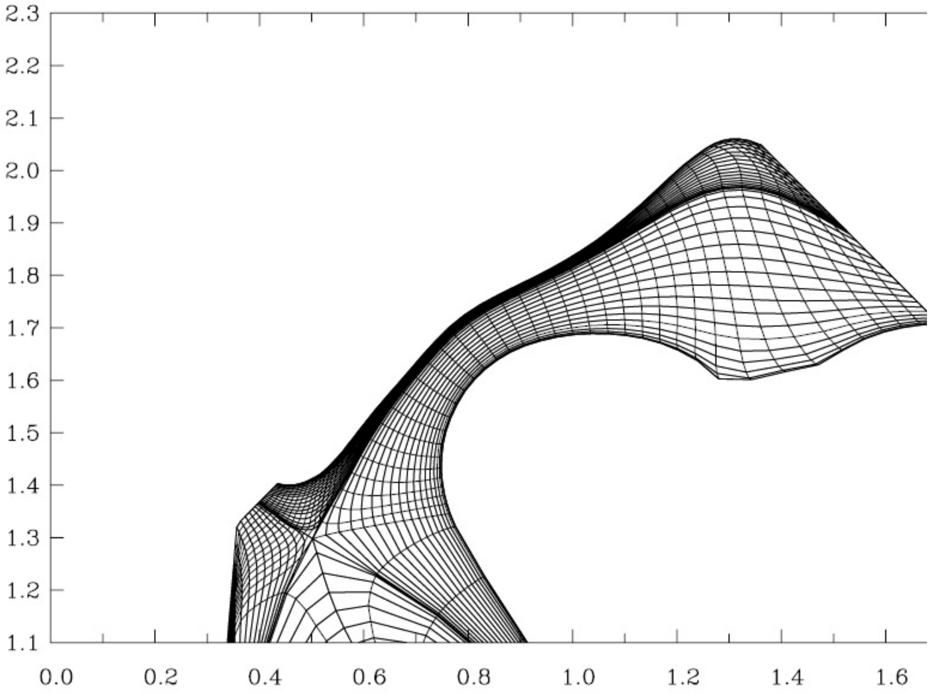


D
$\chi_{e,i}$
2.0
1.5
1.0
0.5
0.0
Traansport coefficients ,m^2/s
separatrix
core
SOL
-0.05
0.00
Radial coordinate (Y) ,m

Figure 1.

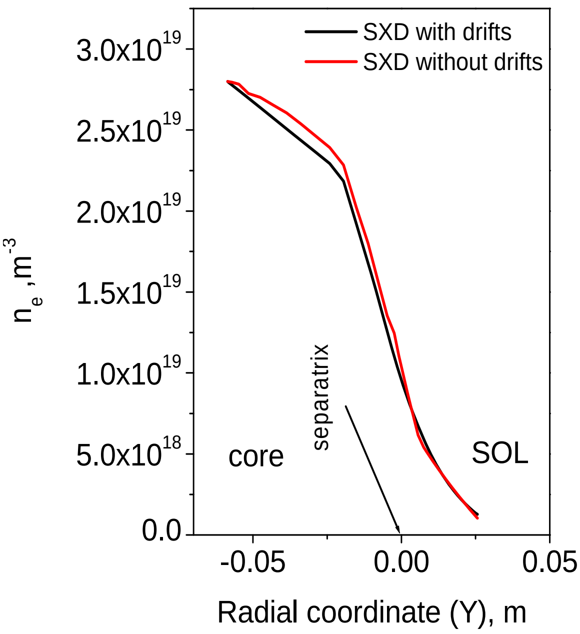

2.5
2.0
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2.5
−1.5
−1.0
−0.5
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5

(*a*)

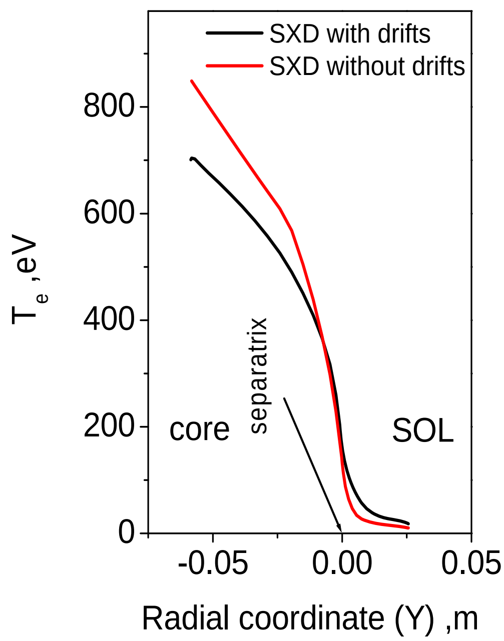

2.3
2.2
2.1
2.0
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6

(*b*)

Figure 2



(*a*)



(*b*)

Figure 3.

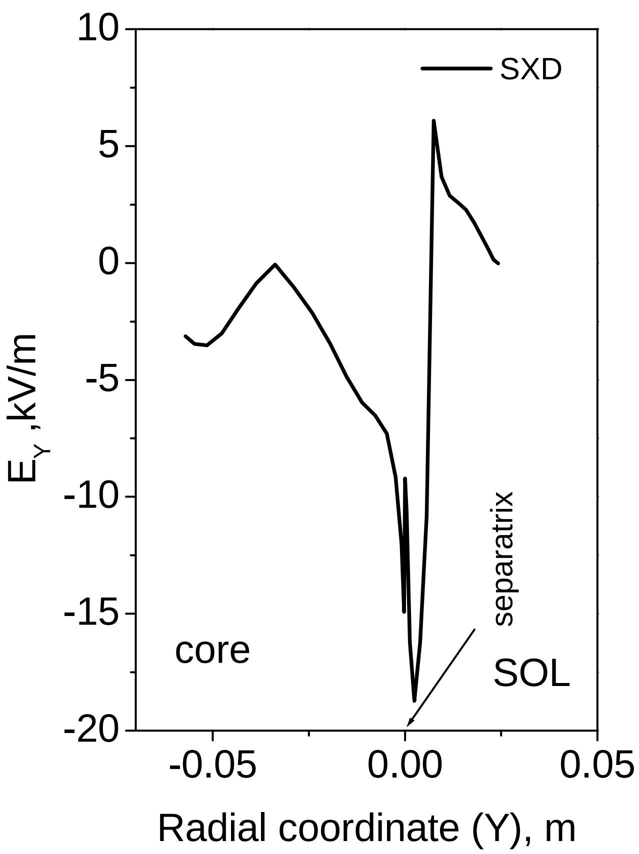
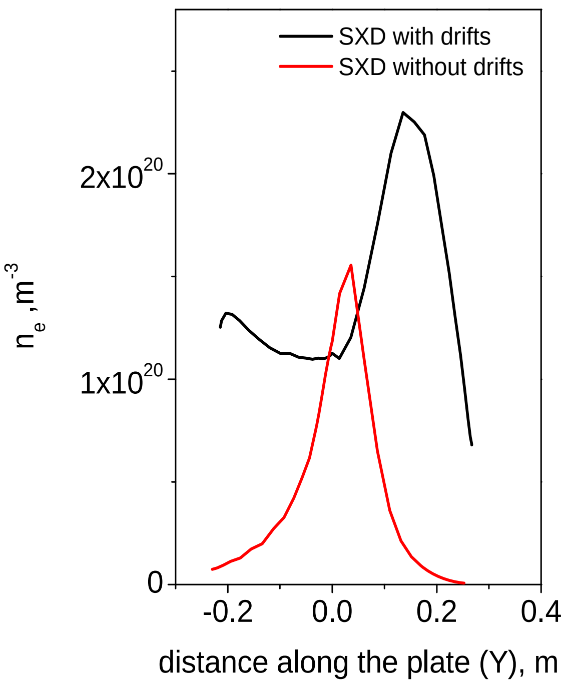
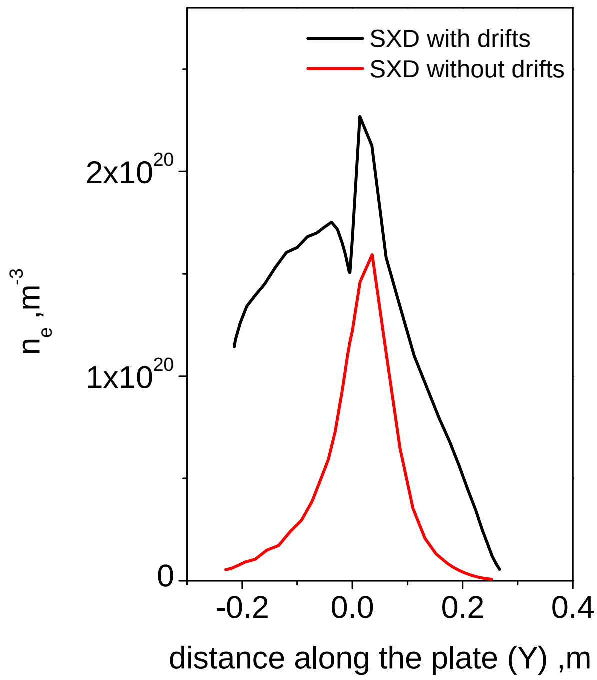


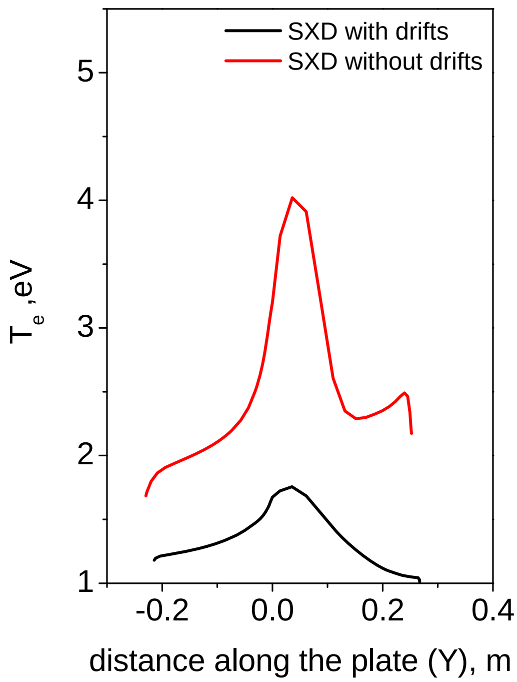
Figure 4



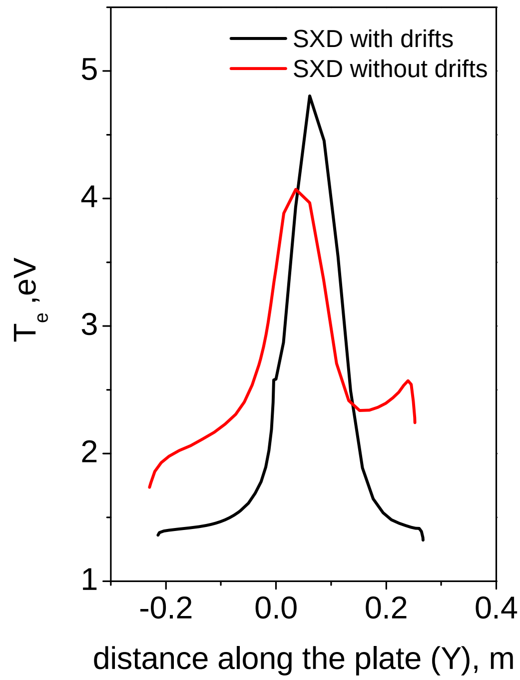
(a)



(*b*)

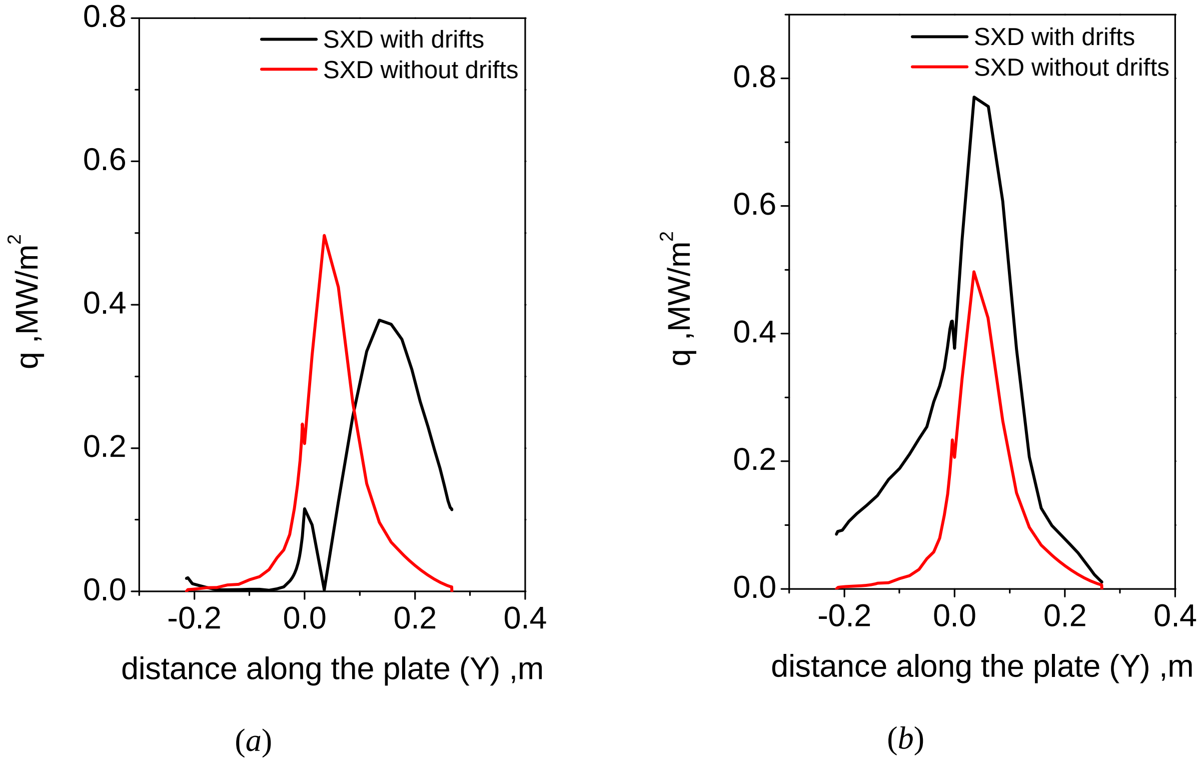


(*c*)



(*d*)

Figure 5.



0.8
0.6
0.4
0.2
0.0
q ,MW/m2
-0.2
0.0
0.2
0.4
distance along the plate (Y) ,m
SXD with drifts
SXD without drifts
(a)
0.8
0.6
0.4
0.2
0.0
q ,MW/m2
-0.2
0.0
0.2
0.4
distance along the plate (Y) ,m
SXD with drifts
SXD without drifts
(b)

Figure 6.