Simulation of Neoclassical Effects with B2SOLPS5.0 for MAST

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Motivation

- In the real experiments neoclassical effects on the closed flux surfaces exist in combination with strong anomalous transport in the presence of sources and sinks, and therefore it was unclear which of neoclassical results are valid in the separatrix vicinity.

- Neoclassical effects should be more pronounced in MAST than in the standard tokamaks due to its tight aspect ratio.

- Code B2SOLPS5.0 is able to reproduce all neoclassical effects since the equations solved are reduced to neoclassical equations, when the anomalous transport coefficients are replaced by their classical values.
Modeling parameters

Two L-mode Disconnected Double Null MAST discharges №6467 and №6468 with active lower divertor were modeled. Anomalous transport coefficients:

\[ D = 1.5 \, m^2 / s, \]
\[ \frac{\kappa_e}{n_e} = 2.5 \, m^2 / s, \quad \frac{\kappa_i}{n_e} = 3.75 \, m^2 / s \]

At the inner boundary (6 cm inside the separatrix at the outer midplane):

\[ n_e \big|_{\text{core}} = 1.75 \cdot 10^{19} \, m^{-3}, \]
\[ T_e \big|_{\text{core}} = 120 \, eV, \quad T_i \big|_{\text{core}} = 120 \, eV \]

Gas puff \( \Gamma = 6.3 \cdot 10^{21} \, s^{-1} \)

was imposed at the outer midplane for shot 6467 and at the inner midplane for shot 6468.
Predictions of neoclassical theory

- Pfirsch-Schlueter ion heat fluxes cause an up-down ion temperature asymmetry.
- Corresponding electron density and electrostatic potential perturbations arise.
- Integral radial fluxes of particles associated with $E \times B$ and $\nabla B$ drifts almost compensate each other.
- The same for electron heat flux.
- Due to the ion temperature perturbation additional convective $\nabla B$ drift ion heat flux arise, which is not compensated by $E \times B$ drift flux.
The parallel ion heat flux calculated in the code is close to neoclassical Pfirsch-Schlueter heat flux.

Neoclassical parallel ion heat flux, which closes the vertical heat flux caused by ion \( \nabla B \) drift, is directed from the lower to the upper part of the torus (\( \nabla B \) drift of ions is directed towards lower X-point):

\[
q_{||}^{P.S.} = \frac{5}{2} \frac{n_e T_i}{e} \frac{\partial T_i}{\partial y} B_z \left( B_y \frac{B^2}{B^2} \right)
\]

Here \( x \) and \( y \) are poloidal (directed from the inner to the outer plate) and radial coordinates accordingly, \( h_x, h_y \) are metric coefficients.
Closed flux surface 15 mm inside the separatrix (distance at the outer midplane), shot № 6467.

Ion temperature perturbation, corresponding to neoclassical heat flux, is of the order of 20%. In the estimate of the perturbation it should be taken into account that plasma in MAST inside the separatrix is in the plateau regime.

Density perturbation may be calculated from the condition:

\[ p = n_e (T_e + T_i) = \text{const} \]

The perturbation of electrostatic potential corresponds to the Boltzmann distribution for electrons:

\[ \delta \phi = (T_e / e) \ln n_e + \text{const} \]
Neoclassical contributions to radial fluxes

Components of integral particle flux through the flux surface for shot №6467.

In agreement with the prediction of the neoclassical theory fluxes corresponding to $ExB$ drift and $grad B$ drift almost completely compensate each other after integration over the flux surface.
Components of integral electron heat flux through the flux surface for shot №6467.  
1- heat flux connected with anomalous diffusion;  
2- anomalous heat conduction contribution;  
3- neoclassical heat flux.  
**In agreement with the the neoclassical theory integral electron heat fluxes corresponding to $ExB$ drift and $grad B$ drift compensate each other. The main contributions to heat flux are anomalous.**
Components of integral ion heat flux through the flux surface for shot № 6467.
1- heat flux caused by anomalous diffusion and convective flux of neutrals;
2- contribution of ion anomalous heat conduction and neutral heat conduction;
3- neoclassical heat flux.

The neoclassical ion heat conductivity is larger than the neoclassical electron heat conductivity,

\[ \frac{k_{i}^{\text{NEO}}}{k_{e}^{\text{NEO}}} = \left( \frac{m_{i}}{m_{e}} \right)^{1/2} \]

The neoclassical ion heat flux in MAST is significant.
Poloidal perturbations of plasma parameters are shifted poloidally towards the high field side due to the heat sink associated with neutrals.

Drift (neoclassical) contribution to radial heat fluxes do not change considerably.

Components of integral ion heat flux through the flux surface for the case of inboard puffing, shot №6468.
1- heat flux caused by anomalous diffusion and convective flux of neutrals;
2-contribution of ion anomalous heat conduction and neutral heat conduction;
3-neoclassical heat flux.
Radial electric field in the core is close to the neoclassical electric field, both for outboard gas puffing and inboard gas puffing. This electric field is similar to that simulated for standard tokamaks.
Conclusions

- In the spherical tokamak MAST the neoclassical effects exist in spite of the presence of strong anomalous fluxes.
- The neoclassical ion heat flux is comparable with the anomalous radial ion heat flux in the L-regime while neoclassical contributions to the particle and electron heat fluxes are negligible.
- The poloidal perturbations of plasma parameters are close to that predicted by neoclassical theory for outboard gas puffing and differ significantly for inboard gas puffing.
- The radial electric field in the vicinity of a separatrix is close to the neoclassical value.
Profiles at the inner and outer midplane for shot №6467(LDND)

Electron density

Electron temperature
Electron temperature near the plates for shot №6467 (LDND)

- Inner upper divertor
- Outer upper divertor
- Inner lower divertor
- Outer lower divertor
Saturation current to the plates for shot №6467 (LDND)

[Graphs showing saturation current in different divertor sections with SOL marked on each graph.]