Kinetic Simulations of ITER Scrape-Off Layer

I. Vasileska[1], L. Kos[1]

[1] *Faculty of Mechanical Engineering, University of Ljubljana, 1000 Ljubljana, Slovenia*

Introduction

Particle-in-Cell (PIC) simulation represents a powerful tool for plasma studies having a number of advantages, like the fully kinetic description of high-dimensional plasma and the ability to incorporate complicated atomic and plasma-surface interactions. The PIC codes simulating the plasma edge usually include Monte Carlo routines simulating particle collision and plasma surface interactions. Therefore it is appropriate to call them PIC/MC code [1]. The PIC codes are usually associated with solving the equation of motion of particles and Maxwell's equations.

Electromagnetic PIC codes solves a whole set of Maxwell's equations and electrostatic if the code solves just Poisson equation. The electrostatic PIC/MC codes are ideal for the description of the plasma edge where particle distributions are usually far from equilibrium [1]. This kind of code allows a full diagnostic of the plasma.

In our work we use the electrostatic part of parallel PIC/MC code, BIT1 with 1D3V dimensionality. We are presenting the profiles of ITER SOL and prove some rules of the PIC modelling [2].

PIC/MC code

The scheme of the PIC simulation is presented on the Fig. 1. PIC simulation starts with an initialization and ends with the output of results. This part is similar to the input/output routines of any other numerical tool. Then it continues with solution of equation of motion (particle mover), calculating the force acting on the particles and then solve the Maxwell's equations. After that using the particle collisions from the Monte Carlo code and the characteristics of the plasma source and boundary effects, the plasma parameters are calculated (like density, potential, and so on). More explanation of the PIC modelling parts might be found [1, 2]

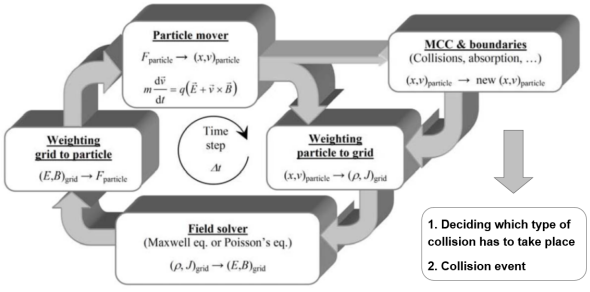

Figure 1: Particle-In-Cell (PIC)/ Monte Carlo (MC) code scheme

BIT1 simulation geometry

BIT1 (Fig. 2) is an electrostatic massively parallel Particle in Cell (PIC) code for simulation of plasma edge. It incorporates e, H, H_2, He, C, O_2, W, their isotopes and few hundreds of corresponding atomic, molecular and plasma surface interaction processes (AMS) processes. The number of implemented particle types is limited by available AMS data: searching for and validating of the corresponding differential cross-sections and of the plasma-surface interaction (PSI) data is one of the most time consuming part in development of realistic plasma edge models [2]. The collision operators simulate atomic and molecular processes, conserving energy and momentum. The PSI represents a linear model with prescribed (energy and angular dependent) particle release coefficients and prescribed velocity distributions of particles released from the wall.

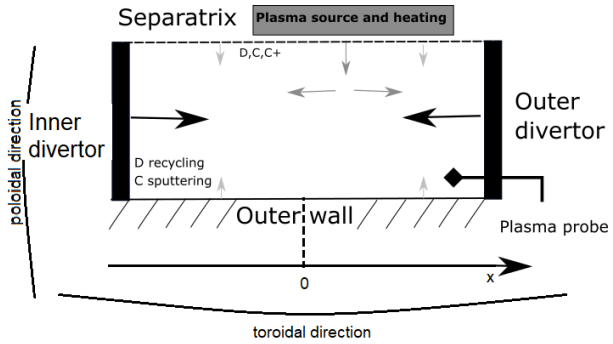

Figure 2: BIT1 simulation geometry

BIT1 simulations results

In order to demonstrate BIT1 code and the validity of PIC modelling, we performed a set of test runs. The BIT1 simulations were performed for burning plasma conditions corresponding to ITER's, for which the poloidal length of the 1D SOL is ~ 20 m from inner to outer target. Inclined magnetic fields at the targets ($\sim 5^{\circ}$) are included, as are particle collisions, with a total of $3.4 \cdot 10^5$ poloidal grid cells with the shortening factor set to 20. For this simulations the secondary electron emission at the tungsten targets is neglected and also the neutrals and impurities are not included. A fully independent run was done, which means that we started with empty system and reached the stationary state. A standard BIT1 simulation runs for about 60 days in a parallel computing mode on 1152-2304 computer cores.

The results, electron and ion densities, electron and ion temperatures, plasma potential and electron and ion parallel velocity in stationary state depending of the poloidal length, obtained from the BIT1 code simulations are shown in Fig 3.

The peaking values of the electron, 195 eV, and ion temperature, 245 eV, as well as the plasma density, $5.5 \cdot 10^{19}\ m^{-3}$, are obtained at the outer mid-plane (OMP), close to 12 m on poloidal direction from the inner divertor. The plasma is quazineutral in all the SOL except the narrow Debye sheath in front of the divertor plates. Also the plasma potential is peaking at the OMP reaching 700 V there.

Kinetic factors

The BIT1 simulations can alse be used for obtaining the kinetic factors by experimental way. There are two types of kinetic factors that specifies parallel transport of stationary SOL: (i) boundary conditions (BCs) in front of the divertor targets, and (ii) particle heat flux and ion viscosity [3].

The boundary conditions are formulated at the boundary between the magnetic and collisional presheaths, named sheath edge (SE) [4, 5]. The BCs represent the conditions for ion parallel speed ($V_{\|}^{i}$), energy fluxes at the sheath (Q_{sh}) and potential drop across the sheath ($\Delta\phi$). Those quantities are calculated from a set of equations (1) [5]:

$$M = \frac{V_{\|}^{i}}{C_s}; \quad \gamma = \frac{Q_{sh}}{\Gamma \cdot T_e}; \quad \varphi = \frac{e\Delta\phi}{T_e} \qquad (1)$$

where M, $C_s = \sqrt{\frac{Te+\delta_i T_i}{m_i}}$, γ, Γ and φ are the Mach number, is the ion-sound speed, the sheath heat transmission factor, the plasma flux to the divertor, and the normalized potential drop, re-

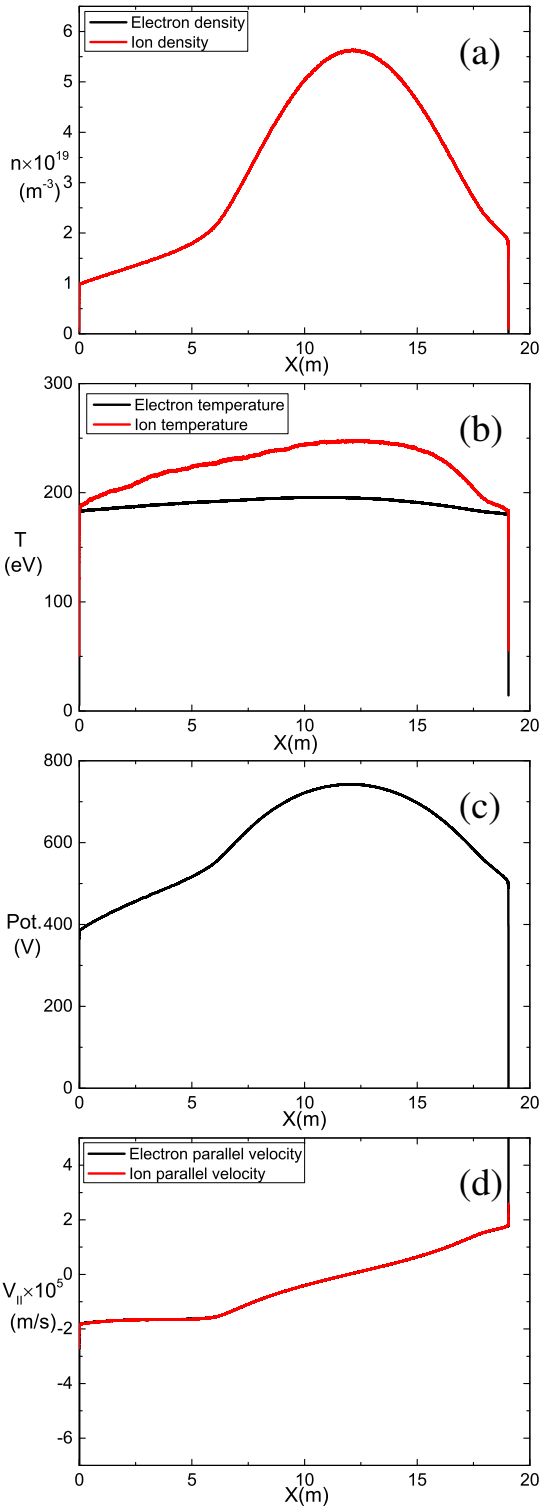

Figure 3: The BIT1 simulations were performed for burning plasma conditions corresponding to the ITER. The poloidal length of the 1D SOL from the inner to the outer divertor is 20 *m. (a)– Electron and ion densities, (b)–Electron and ion temperature, (c)– plasma potential and (d)– electron and ion parallel velocity.*

spectively. Here δ_i $(\sim 1)$is the polytrophic constant. This analytical investigation will be used in further work.

Conclusion

The importance of parallel kinetic modelling is to simulate huge number of particles for very short time. In this article were presented the characteristics of the parallel kinetic modelling code PIC/MC BIT1. As a test simulation of BIT1 the SOL of ITER tokamak plasma was simulated including electrons and ions. For further research, these results will help us to investigate and obtain the time dependencies of the boundary conditions that are to be used in the fluid codes for modelling ELM target heat loads.

Acknowledgement

The simulations were performed on the EUROfusion High Performance Computer (Marconi-Fusion) under SOLDyn grant. This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission. We are grateful to Richard A. Pitts and David Tskhakaya for many useful advises and guidance towards ITER scale ELM simulations.

References

[1] C. K. Birdsall and A. B. Langdon, *Plasma physics via computer simulation* (Taylor and Francis, New York, 2005).

[2] D. Tskhakaya, A. Soba, R. Schneider, M. Borchardt, E. Yurtesen, and J. Westerholm, 2010 18th Euromicro Conference on Parallel, Distributed and Network-based Processing , 476 (2010).

[3] D. Tskhakaya, S. Kuhn, Y. Tomita, K. Matyash, R. Schneider, and F. Taccogna, Contrib. Plasma Phys. **48**, 121 (2008).

[4] P. C. Stangeby, *The Plasma Boundary of Magnetic Fusion Devices* (Institute of Physics Publishing Ltd, Bristol, 2000).

[5] D. Tskhakaya, R. A. Pitts, W. Fundamenski, T. Eiche, S. Kuhn, and J. E. Contributors, Journal of Nuclear Materials **390-391**, 335 (2009).