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# Introduction of kinetic effects to 1-D SOL/divertor plasma fluid simulation by collaborating a particle model


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## Background

- Importance of kinetic effects in the SOL/DIV plasma is recently re-focused. High energy tail particles remain collisionless, thus in the divetor region, plasma are non-Maxwellian.
- The fluid model cannot fully consider the kinetic effect, thus underestimates $T_e$, overestimates $n_e$ [1], and underestimates ion flow at the LFS [2].

➡ **It is necessary to introduce kinetic effects to fluid model.**

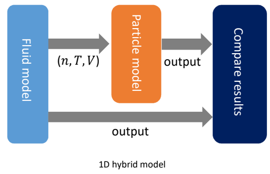
Kinetic effect・・・Microscopic phenomena (non-Maxwellian) appear as macroscopic effects

## Purpose

■Development of a hybrid code that introduces the kinetic particle calculation to the 1D fluid simulation.

■Introduction of kinetic effects in a cost-efficient way.

➢In future, kinetic corrections from particle model will be introduced into fluid model. In this study, We investigated the influence of kinetic effects by comparing results of the fluid model and the hybrid model.




## Conclusion

- We developed a 1-D fluid/particle hybrid code for further understandings of kinetic effects in the SOL/DIV plasma.
- As we artificially increases collisionality, lower electron heat conductivity appears and results between the fluid model and the (kinetic) hybrid model becomes closer.
- Further investigations (kinetic effects of ion, heat flux) will be taken in this 1-d simulation. Then the model will be applied for 2D codes such as SOLPS and/or SONIC.

## Fluid model

■Plasma transport calculation

- Continuity equation

$$\frac{\partial n_i}{\partial t}+\frac{\partial n_i V}{\partial x}=S$$

- Momentum equation

$$\frac{\partial m_i n_i V}{\partial t}+\frac{\partial}{\partial x}\{m_i n_i V^2+(n_i+n_e)T\}=M$$

- Energy equation

$$\frac{\partial}{\partial t}\left\{\frac{1}{2}m_i n_i V^2+\frac{3}{2}(n_i+n_e)T\right\}+\frac{\partial}{\partial x}\left\{\frac{1}{2}m_i n_i V^2+\frac{5}{2}(n_i+n_e)TV-\kappa_{e,\parallel}\frac{\partial T}{\partial x}\right\}=Q$$

$n_i, n_e$: ion, electron density
$V$: velocity
$T$: temperature
$\kappa_{e,\parallel}=3.16\frac{nT_e\tau_e}{m_e}$: electron heat conductivity along the field line
$\tau_e=\frac{6\sqrt{2}\pi^{3/2}\varepsilon_0^2\sqrt{m_e}T_e^{3/2}}{ne^4\ln\Lambda}$: collision time

■Boundary condition

Stagnation point・・・$\frac{dT}{dx}=0, V=0$ Divertor plate・・・Bohm condition

■Recycling model

- Recycling particle flux

$$S_{ionization}(t+\Delta t)L_{DIV}=Recy(S_{core}L_{SOL}\times S_{ionization}(t)L_{DIV})$$

Particle flux from CORE — Previous Recycling particle flux

Where, $S_{ionization}$=const.

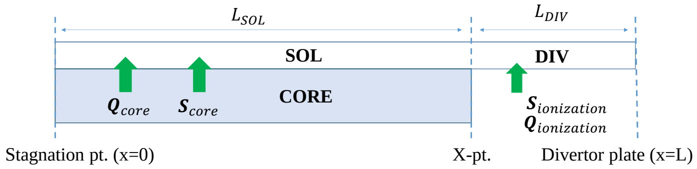
$$S_{ionization}=S_{core}\times\frac{R_{recy}}{1-R_{recy}}\frac{L_{SOL}}{L_{DIV}}$$

- Energy of recycled ion at ionization (and $T_e=T_i$)

$$Q_{ionization}=2\varepsilon_{FC}\times S_{ionization}$$

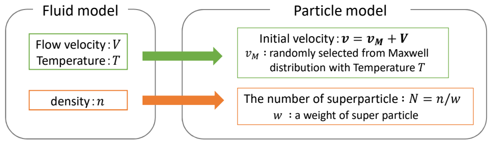
- Ionization position

Ionization occurs placed at random position between X-pt. and wall




## Particle model

■Data transformation (Fluid→particle)




■Collision model

We treated collisions as a binary collision, and used Symmetric model[3]

■Particle motion model

We Use PARASOL-like model. Guiding center model for electron, Gyro motion model for ion

■Electric field

Electron momentum balance without electric current

$$E_\parallel=-\frac{0.71}{e}\frac{\partial(kT_e)}{\partial x_\parallel}-\frac{1}{en}\frac{\partial p_e}{\partial x_\parallel}$$

Values obtained from fluid simulation results are used in all steps. No self-consistent calculation is taken. ➡ Reduction of calculation cost

■Boundary condition

Stagnation point・・・$V(t+\Delta t)=-V(t)$ Divertor plate・・・Simple sheath model

**Simple sheath model**

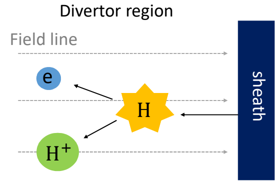
Incident high energy particle: $m_e v_{e,\parallel}^2/2\geq e\phi_s(t)$
Reflective low energy particle: $m_e v_{e,\parallel}^2/2\leq e\phi_s(t)$

$$\phi_s(t+\Delta t)=\phi_s(t)-\alpha T_e/e$$

Potential control parameter $\alpha=(N_i-N_e)/(N_i+N_e)$

- ions : always penetrating sheath
- Electrons : penetration or reflection is judged by its incident energy compared with the sheath potential $\phi_s(t)$

■Recycling model




- Number of recycled neutral particles

[number of incident particle]×[Recycling rate]
Rest of incident particles are returned as plasma flux from CORE.
The particles are returned as a pair of electron and ion.

- Particle energy after ionization

Franck-Condon energy is used. (same as the fluid model.)

- Recycled position

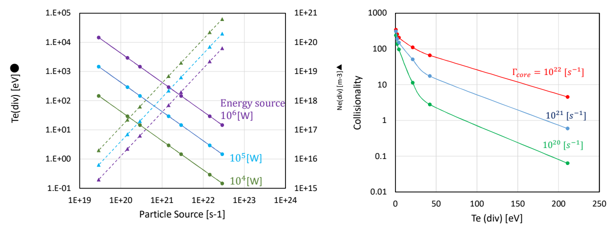
Recycled particles are placed at random position between X-pt. and wall

## Numerical result (collisionality dependence)

■In order to investigate the dependence of the collisionality, we changed the variance value in the binary collision calculation in eq.(11) of Ref. [4].
(variance value determines magnitudes of the scattering angle)

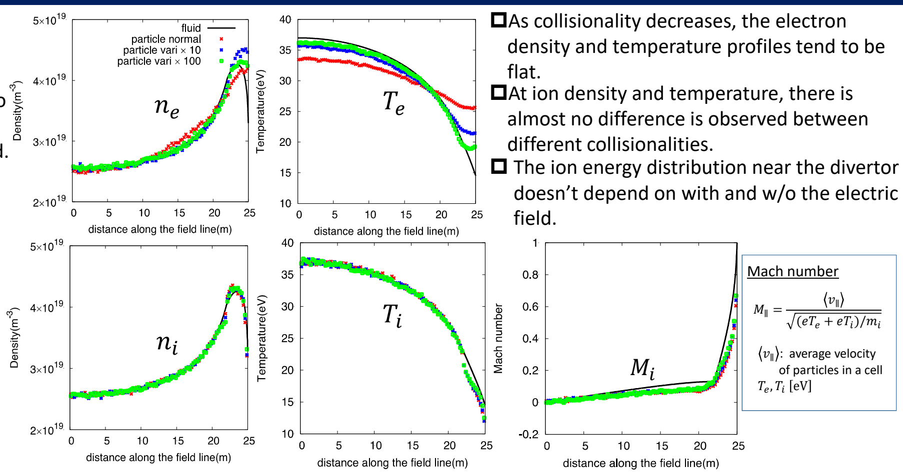
■Calculations with × 10 and × 100 variance values are performed in order to increase the collisionality artificially.

■Results of the fluid model and the fluid/particle hybrid model are compared.




2-point model to estimate the calculation parameter

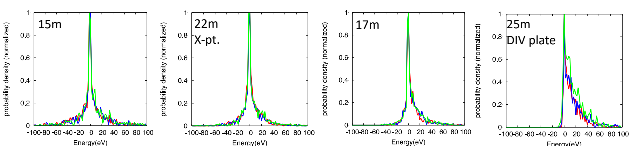
Collisionality $\nu_{SOL}^*=10^{-16}nL_{SOL}/T_e^2$




□As collisionality decreases, the electron density and temperature profiles tend to be flat.

□At ion density and temperature, there is almost no difference is observed between different collisionalities.

□ The ion energy distribution near the divertor doesn't depend on with and w/o the electric field.




Ion energy distribution at a distance from each stagnation pt.

■ Calculation parameter

| | electron | Ion |
|---|---|---|
| mass[kg] | $9.11\times10^{-31}$ | $1.67\times10^{-27}$ |
| charge[C] | $-1.6\times10^{-19}$ | $1.6\times10^{-19}$ |

| | |
|---|---|
| dt [s] | $1.0\times10^{-8}$ |
| fluid iteration | 300,000 |
| particle iteration | 2,000 |

| | |
|---|---|
| Energy source from core [W] | $1.0\times10^{6}$ |
| Particle source from core [$s^{-1}$] | $1.0\times10^{22}$ |

## Reference


[1] A.V Chankin, D.P. Coster Journal of Nuclear Materials 390-391 (2009) 319-324
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