中国科学技术大学
University of Science and Technology of China （USTC）

Third IAEA Technical Meeting on Divertor Concepts
ID: 28

Simulation study of the radiative quasi-snowflake divertor for CFETR

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Abstract

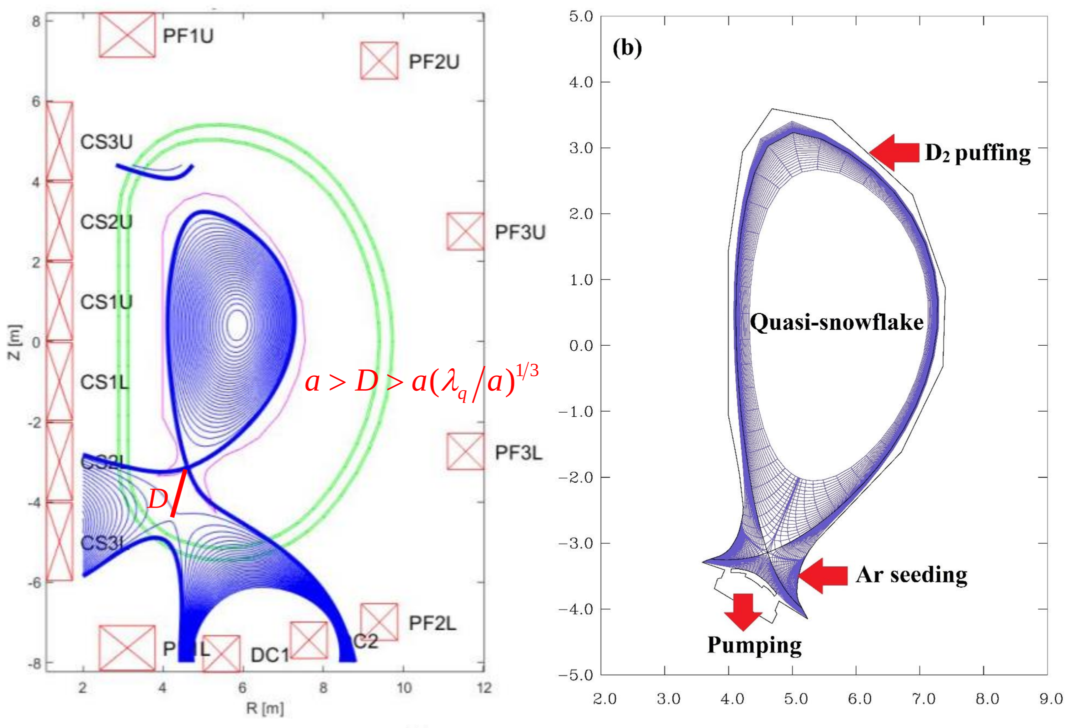
- The radiative quasi-snowflake (QSF) divertor is studied by SOLPS simulation for CFETR with argon seeding.
- The dependence of Z_{eff} with the plasma density and radiation power is fitted according to the Matthews' law.
- The asymmetry of plasma detachment in the inner and outer divertor is found different under low and high density.
- The QSF has better performance under high density.

Background

- Power exhaust is one of the critical issue for the fusion reactor.
- Snowflake divertor[1] is proposed as an advanced divertor configuration which has larger flux expansion and longer connection length compared with LSN.
- To dissipate the heat power before landing on the divertor target, radiative impurity seeding is indispensable when no intrinsic impurity exists.
- Therefore, it is important to understand the performance of radiative SF divertor, especially for the detachment and impurity screening.
- For CFETR, the quasi-SF divertor is simulated with argon seeding using SOLPS.[2]

Simulation Settings

- For CFETR, the divertor coils are introduced to create SF equilibrium.
- In the simulation, argon impurity are seeded from the outer divertor. D_2 are puffed from the top of the main chamber to adjust the separatrix density.



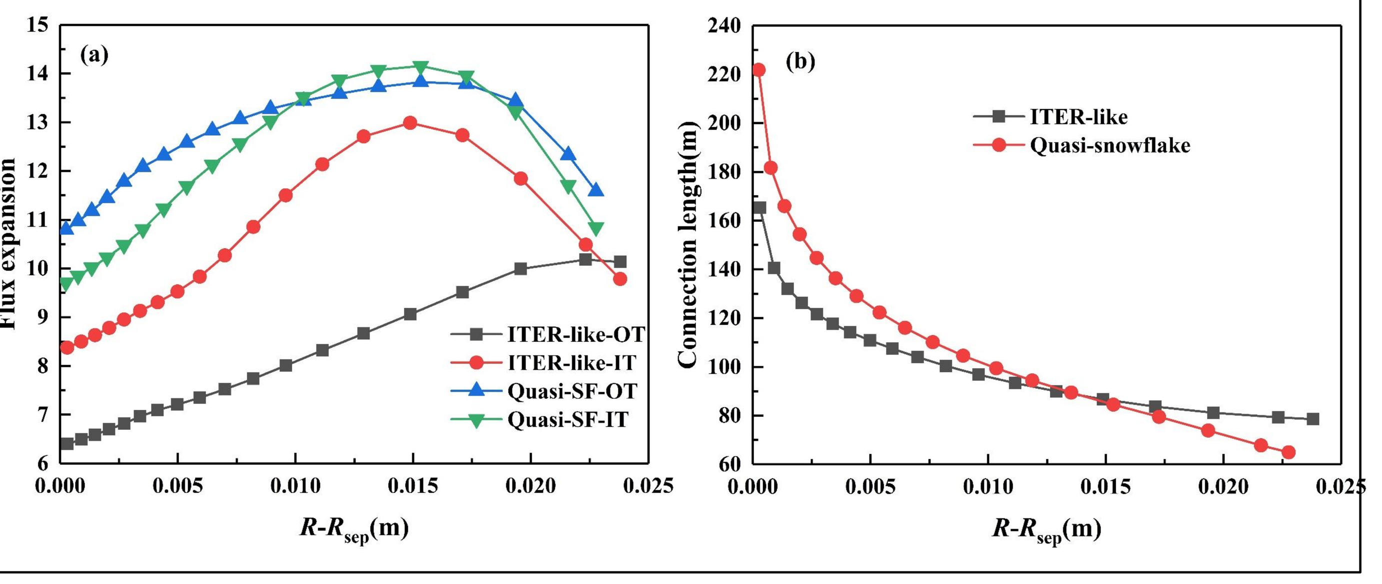
Boundary conditions (ρ = 0.9):

- $P_e = P_i = 50$ MW
- $\Gamma_{D^+} \sim 1.7\times10^{22}\ s^{-1}$
- $\Gamma_{He^{2+}} \sim 8.0\times10^{20}\ s^{-1}$

Other settings:

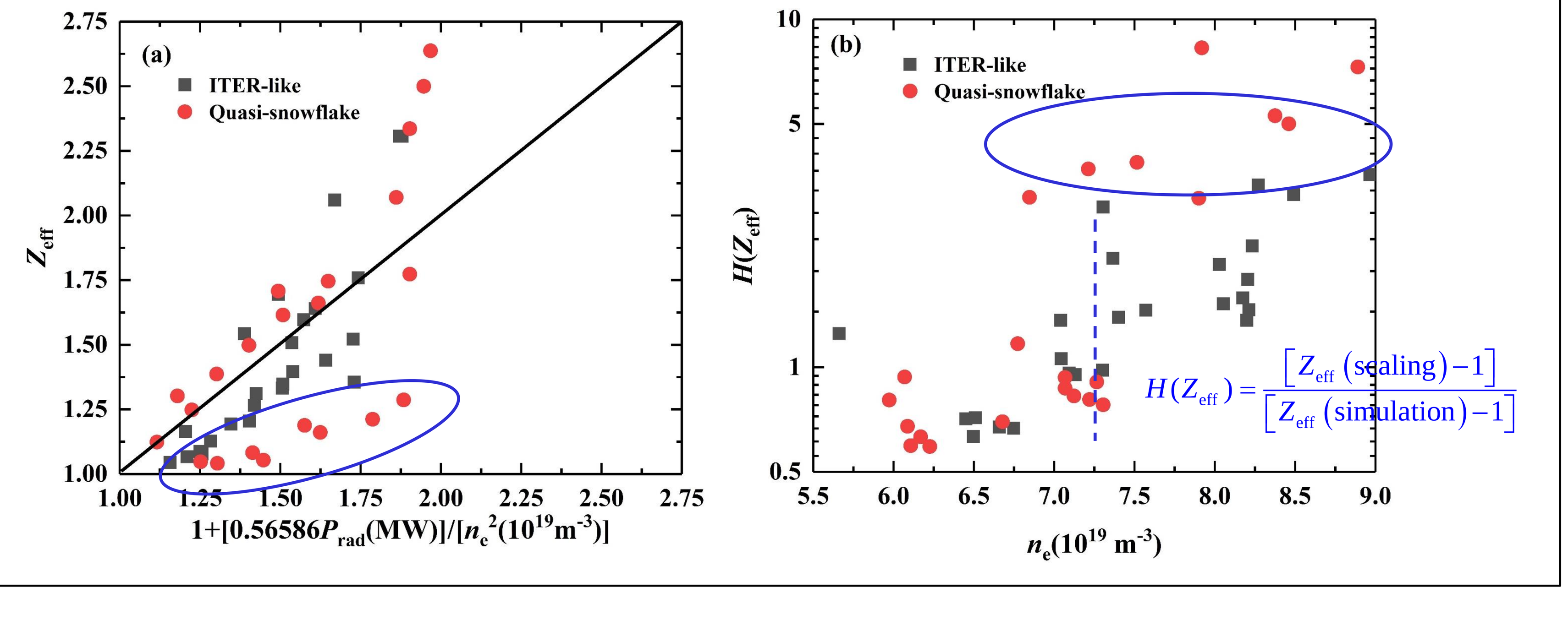
- no sputtering
- **no drifts**
- recycling rate is 100%:
- density scan by D_2 puffing
- radiation fraction by Ar puffing
- constant transport coefficients ($D_\perp = 0.3\ m^2/s$; $\chi_i = \chi_e = 1.0\ m^2/s$)

Flux expansion and connection length at the strike points is increased by a factor of 1.2 – 1.8, respectively.



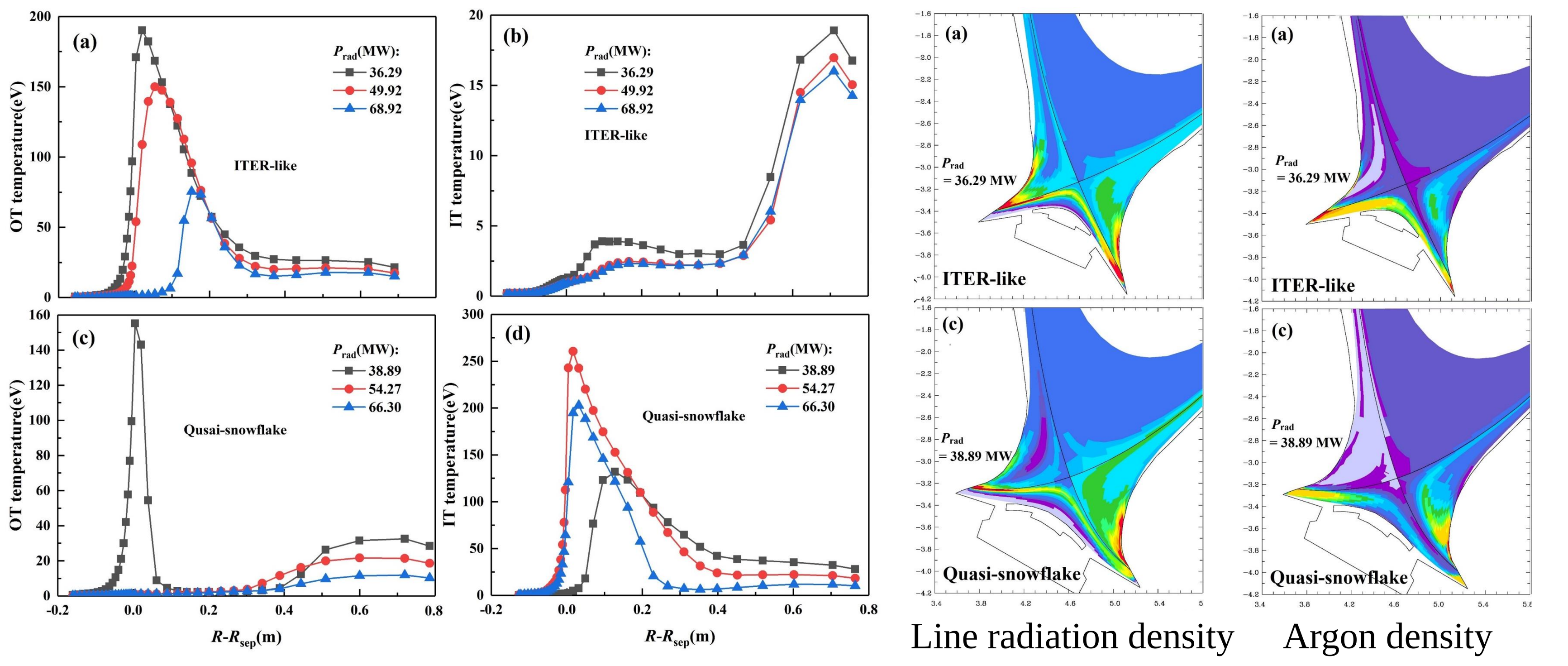
Overall performance

- Simulated Z_{eff} is fitted according to the Matthews' law[3] $Z_{eff} \propto P_{rad}/n_e^2$



Low density case ($n_{e,sep} \sim 2.3\times10^{19}\ m^{-3}$)

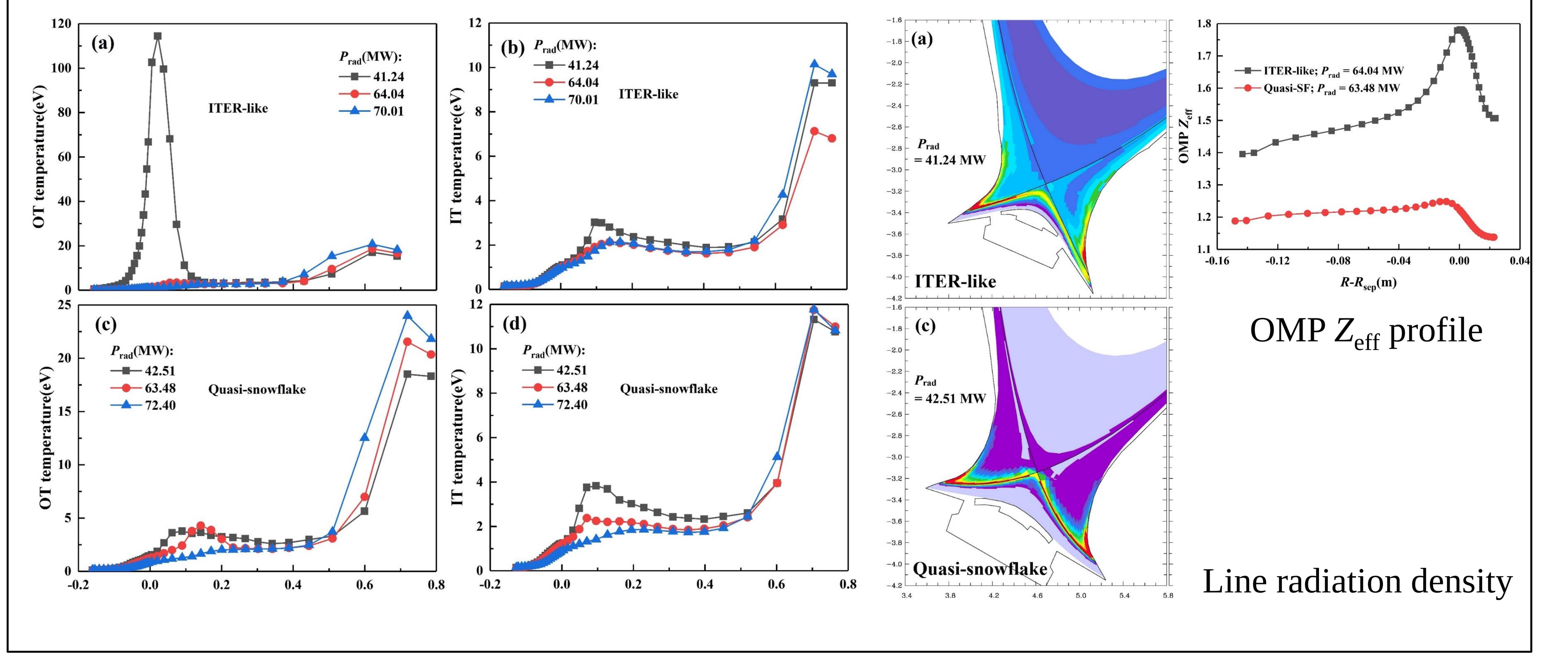
- The outer divertor is detached first due to the pronounced increasing of flux expansion in the LFS.
- The impurities are strongly compressed in the outer divertor, as well as the impurity radiation is concentrated there.



Line radiation density   Argon density

High density case ($n_{e,sep} \sim 4.5\times10^{19}\ m^{-3}$)

- Both targets are detached in the QSF when ~40 MW radiation power, while the outer target is still attached.
- The detachment is more symmetry in QSF under high density.
- The degrees of detachment is deeper in QSF than ITER-like divertor, as well as better impurity screening.



OMP Z_{eff} profile

Line radiation density

Conclusions

- Snowflake divertor (SFD) is thought as a possible candidate to solve the heat exhaust problem for future fusion reactor. A simulation study on the radiative quasi-SFD (QSF) is performed for CFETR with Ar seeding using SOLPS.
- The simulated Z_{eff}, P_{rad} and n_e are fitted according Matthews' law. Further comparison of the radiative efficiency between QSF and ITER-like divertor (ILD) shows better performance of QSF divertor under higher density.
- For low density case ($n_{e,sep} = 2.3\times10^{19}\ m^{-3}$), the outer divertor is found detached firstly due to the larger flux expansion in the outer divertor.
- While for the high density case ($n_{e,sep} = 4.5\times10^{19}\ m^{-3}$), both divertor targets are detached more symmetry for QSF. The degree of detachment is found deeper for QSF than ILD and the QSF also has better impurity screening.
- The flux expansion, in other words, the position of the secondary X point could be considered as a control parameter of divertor detachment (asymmetry).

Reference

[1] D.D. Ryutov, Phys. Plasma 14 (2007) 064502.
[2] M.Y. Ye et al., Nucl. Fusion 59 (2019) 096049.
[3] G. F. Matthews et al, J. Nucl. Mater. 241-243 (1997) 450.