SOLPS-ITER simulations of large power handling in the divertor for CFETR with full drifts

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In recent years, a lot of efforts have been made by the Chinese fusion community to push forward Chinese Fusion Engineering Testing Reactor (CFETR), which aims to bridge the gap between International Thermonuclear Experimental Reactor (ITER) and the demonstration power plant (DEMO). It has a major radius R = 7.2 m and a minor radius a = 2.2 m, plasma current Ip = 14 MA and the toroidal magnetic field Bt = 6.5 T at the major radius. According to the physics design of CFETR, it will produce a fusion power up to 1 gigawatt (GW), which requires about 200 MW from the core region into scrape-off layer (SOL) to be exhausted. Therefore, it is one of the biggest challenges for the design and operation of CFETR to control the huge heat flux onto the plasma-facing components (PFCs), especially the divertor target. It is essential to explore the potential solutions to dissipate power efficiently in the SOL and divertor region to ensure the maximum steady-state power load at the divertor target below 10 MWm^{-2}. One way to reduce the power load is to increase the radiation losses by seeding impurity, such as argon (Ar), neon (Ne) and nitrogen (N), which have been widely used in the present tokamaks and foreseen for ITER. The other way is to optimize divertor geometry for better power dissipation, such as improving divertor closure or increasing divertor volume. Increasing the poloidal length from the divertor X point to the divertor target (divertor leg length) has been used for JA DEMO in order to increase power radiation.

In the present work, the effects of seeding radiation impurities, such as argon (Ar) and neon (Ne) and increasing divertor leg length in CFETR are systemically investigated to evaluate the efficient reduction of the maximum steady-state power load at the divertor target to an engineering design level (less than 10 MWm^{-2}) by the SOLPS-ITER code package with full drifts. The modeling results show clearly that increasing radiation impurities Ar and Ne seeding rate with the fixed D_2 fueling gas injection rate $4.0 \times 10^{22}\,\mathrm{atom\,s^{-1}}$ can significantly reduce the target electron temperature and heat flux density for the reference divertor geometry, which can be both reduced further with higher D_2 injection rate ($> 4.0 \times 10^{22}\,\mathrm{atom\,s^{-1}}$). Moreover, the radiation efficiency for Ar is better than that for Ne. However, higher impurity seeding rate will cause higher impurity concentration in the core region, which can be controlled well by selecting the proper D_2 fueling gas injection rate and impurity seeding rate. Based on the reference geometry in CFETR, increasing the divertor leg length from 1.7 m at present to 2.4m can also benefit reducing electron temperature and heat load at the target further. These results show that the divertor design with a longer leg and higher Z seeding such as Ar is appropriate to obtain the divertor scenario for CFETR divertor design.