Numerical Simulation on H-mode Transition Powers in KSTAR Tokamak

Jin Myung Park, Ki Min Kim, Ei-Sung Yoon, and Sang Hee Hong
Department of Nuclear Engineering, Seoul National University

The high confinement mode (H-mode) is a baseline operation mode of Advanced Tokamak (AT) scenario targeted in the KSTAR (Korea Superconducting Tokamak Advanced Research) tokamak. The H-mode is characterized by good plasma confinement of energy and particle caused by a transport barrier near the plasma edge and occurs when heating power is deposited in the core plasma above some threshold value [1]. It is essential for the numerical modeling to predict how much auxiliary heating powers are needed for the H-mode transition in the experimented tokamaks.

In this numerical work, the threshold power for the H-mode transition in the KSTAR Tokamak has been estimated using an integrated simulation code, C2 (Coupled 2-dimensional), newly developed in the authors' laboratory [2]. Based on the modified Braginskii's multi-fluid equations with a unified 2-D description, the C2 code calculates the time evolutions of plasma temperature, density and parallel flow in the core, edge pedestal and scrape-off layer (SOL) regions by reflecting strong couplings among these three regions in the tokamak. The radial electric fields are self-consistently calculated by the neoclassical theory with an ambipolar constraint. The MHD equilibrium calculation with toroidal and/or poloidal rotations is coupled to the transport simulation inside the separatrix at each time step. The transport of recycling and gas-puffing neutrals is considered self-consistently using a transmission-escape-probability (TEP) method. Various plasma heating and current drive modules of NBI, ICRH/FWCD, and LHCD are integrated into the C2 code. In this simulation, the transport coefficients from turbulent diffusions of electron and ion are calculated in the edge pedestal region by a 3-D direct numerical simulation (DNS). The transport coefficients from DNS are tabulated in the multidimensional parameter space including the external electric field and gradients of plasma density and temperature.

A set of numerical simulations has been carried out for the baseline operating scenario of KSTAR H-mode discharges with systematic parameter scans of the toroidal magnetic field, plasma current and averaged plasma density. Figure 1 (a) shows the time evolution of the total heat flux (P_{sep}) across the separatrix and the gas puffing rate (Γ) required for maintaining an average plasma density of $5.0\times10^{19}\mathrm{m}^{-3}$. If NBI heating of 4 MW starts just after the current ramp up to 2 MA, P_{sep} and Γ abruptly fall down at t = 2.625 sec by $\boldsymbol{E}\times\boldsymbol{B}$ shear suppression of turbulent transports near the edge, which indicates the H-mode transition. At this transition moment, the steep gradient of ion temperature is formed just inside the separatrix as appeared in Fig. 1(b). The transition power dependency on the main operating parameters of the KSTAR tokamak are illustrated in Fig. 2. The transition power increases with toroidal magnetic field and plasma density. However, it does not change significantly with plasma current, which agrees well with the experimental observations. In Fig. 2 (b), the threshold powers obtained in this work are compared with an experimental scaling law [3], $P_{th}^{exp} = 2.84\, M_i^{-1} B_t^{0.82}\, n_{e20}^{0.58}\, R_m^{1.0}\, a_m^{0.81}$ [MW], where M_i is the hydrogenic mass in amu, B_t the toroidal magnetic field in Tesla, n_{e20} the line average density in units of $10^{20}\ \mathrm{m}^{-3}$, R_m and a_m are the major and minor radii in meter, respectively. Since this scaling law was obtained from single-null divertor tokamaks, the transition power is considered to be twice as much as P_{th}^{exp} expected from KSTAR tokamak with a double-null configuration. The calculated transition powers are reasonably in good agreement with the experimental ones.

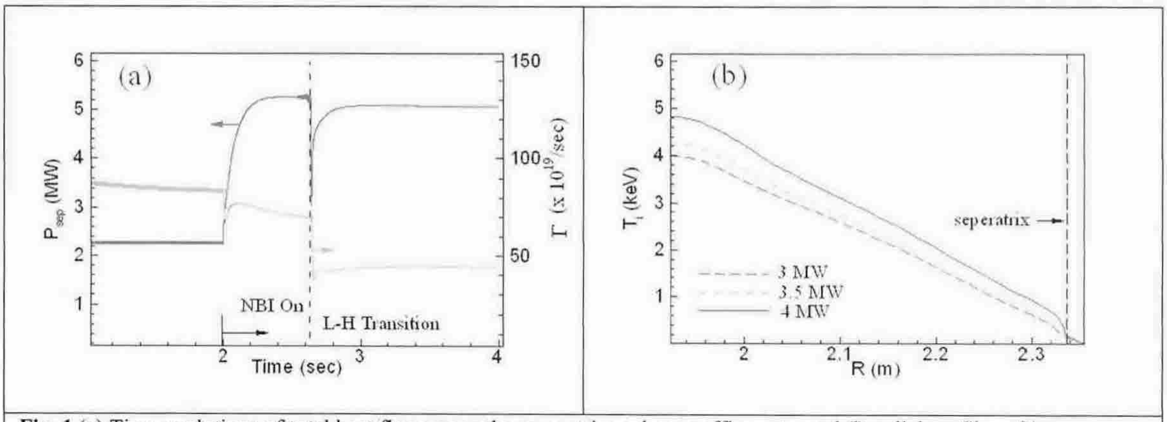

Fig. 1 (a) Time evolutions of total heat flux across the separatrix and gas puffing rate, and (b) radial profiles of ion temperatures with different heating powers

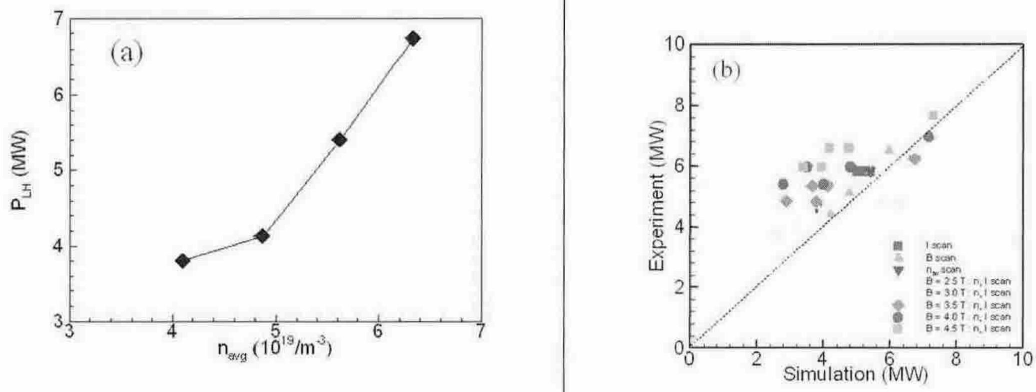

Fig. 2 (a) Dependency of H-mode transition power on toroidal magnetic field, and (b) comparison between the calculated and experimental transition powers

[1] F. Wagner *et al.*, Phys. Rev. Lett. **49**, 1408 (1982)

[2] J. M. Park *et al.*, 45th Annual Meeting of Division of Plasma Physics, Albuquerque, NM, USA, 27-31 Oct. 2003

[3] Y. Shimomura *et al.*, in Proceedings of the 18th IAEA Fusion Energy Conference, Sorrento, Italy, 4-10 Oct. 2000