Numerical Imaging of Edge Plasma Characteristics in the High-Recycling Scrape-Off Layer of the KSTAR Tokamak

Jin-Seok Ko, Ki-Hak Im, Deok-Kyu Kim, and Sang Hee Hong

***Abstract*—Edge plasma characteristics of a high-recycling divertor operation regime of the Korea Superconducting Tokamak Advanced Research (KSTAR) tokamak are presented. The results were obtained by numerical simulation using a two-dimensional (2-D) two-fluid edge plasma transport code coupled with a 2-D Monte Carlo recycling neutral transport code. The simulations successfully display the two major characteristics of a scrapeoff layer in a high-recycling regime: a parallel temperature gradient and parallel pressure conservation. The results of the simulation can be utilized to provide guidelines for future operation of the KSTAR tokamak regarding the relation between upstream plasma properties and divertor operation regimes.**

***Index Terms*—Edge plasma, high-recycling divertor operation, KSTAR tokamak, Monte Carlo neutral transport.**

HIGH-RECYCLING operation of a tokamak has the advantage of not only retaining hot plasma near the core and cold plasma near the divertor, but also keeping the tokamak from the risk of reaching the density limit where a plasma disruption usually occurs [1]. In this work, numerical images of edge plasma properties are presented to investigate plasma conditions in the high-recycling divertor operation regimes of the Korea Superconducting Tokamak Advanced Research (KSTAR) tokamak. The images were obtained using a two-dimensional (2-D) two-fluid edge plasma transport code, EDGETRAN [2], and a 2-D Monte Carlo recycling neutral transport code, NTRAN [2]. The fluid code employs Braginskii's transport equations in an orthogonal magnetic flux coordinate system for an actual scrapeoff layer (SOL) configuration shown in Fig. 1. The source terms for particles, momentum, and energy required by the edge transport equations in the fluid code are provided by the Monte Carlo code. The two major interaction mechanisms for recycling neutrals, electron impact ionization, and charge exchange, are taken into account in the Monte Carlo code. The coupling of these two codes has been successfully tested through various simulations for single-null and double-null divertor configurations [2] as well as limiter configurations of TEXTOR and TEXT tokamaks [3].

Numerical simulations for the KSTAR tokamak with an input power of 6.5 MW and an edge density of 5.1×10^{19} m^{-3}

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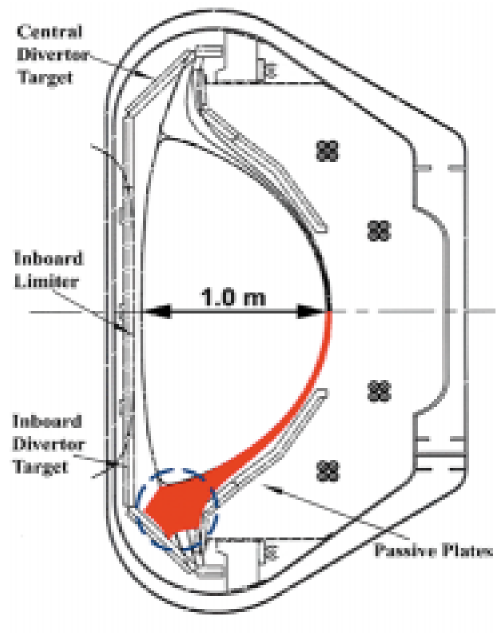

Fig. 1. Calculated domain (red-colored area) in the edge region of the KSTAR tokamak. Recycling neutral transport is considered in the dashed circle of this domain.

have produced the images of edge plasma characteristics of the high-recycling divertor operation as shown in Fig. 2. Since the KSTAR program has set such moderate values of input power and plasma density for its initial research campaign, the KSTAR tokamak during this period is expected to be operated in this unique divertor operation regime. In Fig. 2(a), plasma density buildup is observed in front of the divertor plate due to the high recycling of neutral particles. This, in turn, has effects on rapidly reducing the ion and electron temperatures near the divertor plate as seen in Fig. 2(b) and (c). The two major features of high recycling, the parallel temperature gradient and the plasma pressure conservation along the flux tubes, can be seen in Fig. 2(b)–(d), respectively. Recycling neutral transport is calculated only near the divertor. Most of the neutrals are ionized by electron impact during their travel to the upstream, thereby decreasing their density, while those which are not ionized experience charge exchange with ions. The ion energy exchange processes shown in Fig. 2(e) and (f) indicate that energy exchange between ions and neutrals are localized in a region adjacent to the divertor where the recycling process dominantly takes place. Although strong charge exchange takes place ad-

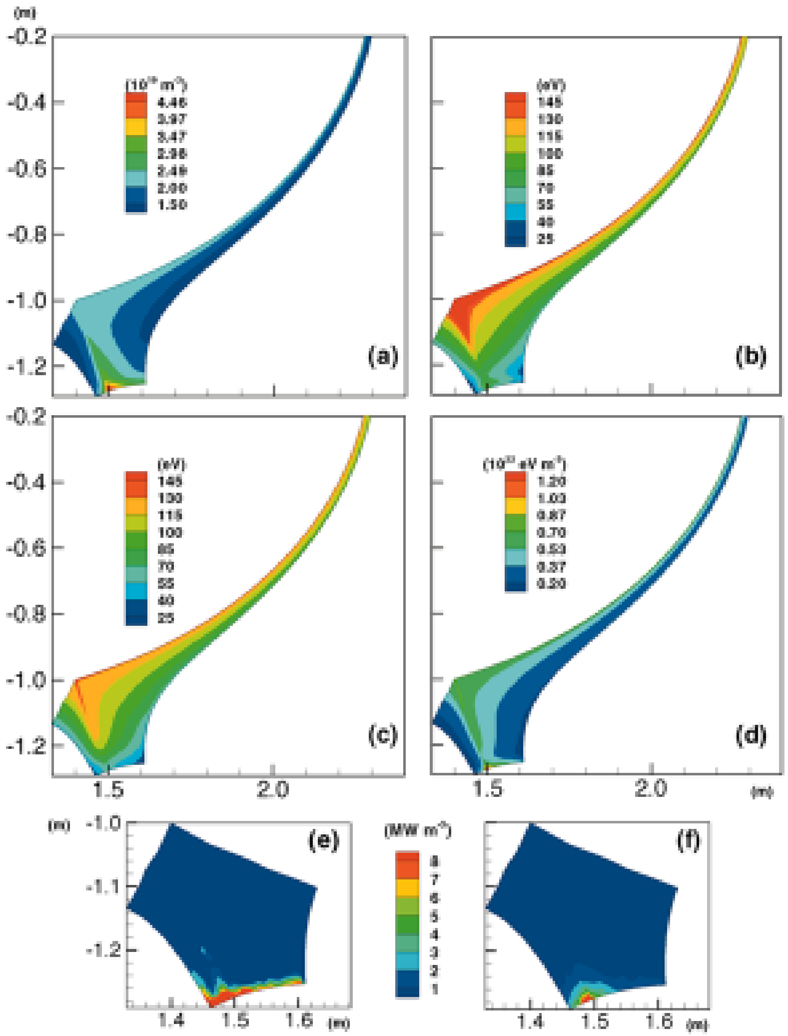

Fig. 2. Numerical images of (a) plasma density, (b) ion temperature, (c) electron temperature, (d) total pressure, (e) ion energy loss rate by charge exchange with neutrals, and (f) ion energy gain rate by electron impact ionization of neutrals.

jacent to the plate, the overall effect of ionization is dominant, thus making a pressure loss small.

The present simulations can provide information on the operating ranges for a high-recycling divertor in terms of upstream density and auxiliary input power, and can predict the expected divertor heat loads for a given operation. As one can see from these results of simulation, the KSTAR divertor in the high-recycling regime is too hot to retain the divertor material within the engineering limit. Other extrinsic mechanisms, such as impurity injection, to lower the divertor temperature are necessary so that the significant pressure loss and radiative recombination process can take place.

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