§13. Particle Exhaust Experiment with Superpermeable Membrane in Fusion Devices

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The superpermeable membranes are available for hydrogen pumping in various places in fusion devices. The most attractive application is to employ metal membranes for pumping and the separation of D/T fuel and He ashes in exhausting. Another possible application is to install the membranes into the divertor for strong active pumping of hydrogen. In this case, it is not necessary to have the generator of energetic hydrogen (the atomizer) because the divertor plasma itself is a source of such energetic hydrogen particles.

We designed a prototype of membrane pumping system to evacuate deuterium particles in the JFT-2M tokamak divertor and investigated the outcoming flux of deuterium atoms from the divertor plasma. As a result, a deuterium pumping with superpermeable membrane has been demonstrated for the first time in fusion devices. The amount of exhausting particles depends on the type of plasma discharges (Ohmically heated, with NBI, with additional gas puffing). The maximum pumping flux of 2.8 x 10^{17} D/s was obtained in the discharge with a strong gas puffing into the divertor chamber. Figure 1 shows the dependence of the pumping flux on the divertor pressure measured by a Penning gauge. One can see that the pumping flux increases in proportion to the divertor pressure, which is closely related to the divertor particle flux from the plasma.

By measuring the permeation flux through the membrane, we can estimate the outcoming atomic flux from the divertor plasma. In order to discuss the permeation probability through the membrane, we must consider the reflection of incident deuterium atoms and the release rate of the absorbed ones at both sides of membrane surface. Assuming a plane source of thermal deuterium atoms with the density n_0 and the temperature T_0 in the divertor region, the permeation flux density Γ_D through the membrane can be estimated as

$$\Gamma_D = n_0\left(\frac{kT_0}{2\pi m}\right)^{1/2} \times f_g \times (1 - f_R) \times f_s$$

where m is the mass of deuterium atom. The geometrical factor f_g with respect to the acceptance solid angle for the plane source assumption is about 0.33. The reflection coefficient f_R may be supposed to be 0.4 ~ 0.6 for low energy particles (E = 2 ~ 5 eV) from the recent data in the experiment where the deuterium reflection coefficient was measured with a compound ion beam (ArD^+) and a Nb target covered with the impurity oxygen [1]. The factor f_s due to the membrane asymmetry is defined as a part of total desorption flux escaping from the down stream side and it can be calculated to be 0.67 from the experimental result on the desorption rate at both sides of membrane. From our measurements, the permeation flux density of the membrane can be estimated to be 7.3 x 10^{19} D/m^{2}s for the discharge with a maximum divertor pressure of 0.032 Pa, assuming that the effective membrane area equals to half of the surface area for each tubular membrane (S_{eff} = 38 cm^2). Thus, for this discharge, we can find that the atomic deuterium density in the divertor region is 0.9~2.1 x 10^{17} D/m^3. This atomic density is the same order of magnitude as that evaluated by computer simulations where a two dimensional fluid code coupled with a Monte Carlo method for neutral gas behavior was applied to the closed divertor configuration [2]. Consequently, it is found that our membrane is in the superpermeation regime and the outflux of deuterium atom at the divertor plasma surface is estimated to be 5.6~8.4 x 10^{20} D/m^{2}s for the discharge with a strong gas puffing. This neutral flux density is larger than that from the main plasma region by orders of magnitude. This indicates that the closed divertor is essential in applying the membrane pumping to fusion devices.

Reference

1) A.A. Evanov et al., in Workshop on Hydrogen Recycle at Plasma Facing Materials (Tokyo, 1998)
2) H. Kawashima, S.Sengoku et al., Proc. 24th Europ. Conf. on Contr. Fusion and Plasma Phys., Berchtesgaden, 21A-II (1997) 705.

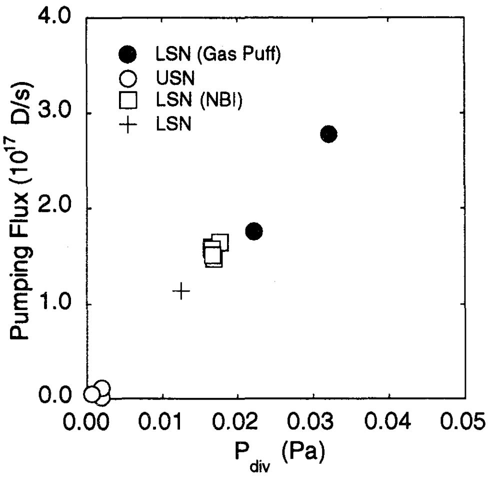

Fig. 1. Dependence of permeation flux on divertor pressure. LSN and USN represent the lower and upper single null divertor configurations, respectively. The membrane pumping system is placed in the lower divertor region.