§19. Hydrogen Isotope Transport through the First Wall of a Magnetic Fusion DEMO Reactor

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In a number of recent DEMO reactor studies such as FFHR,[1] the breeder serves as a coolant as well in the blanket structures. The first wall is defined as the plasma-facing surfaces of the blankets, which are required to operate at elevated temperatures for an efficient heat exchange. Also, to reduce thermal stresses, the thickness of the first wall is often limited to less than 1 cm. In the case of FFHR, molten salt FLiBe has been employed as a self-cooled breeder and the tritium overpressure is $\geq 10^4$ Pa. Under these conditions, the first wall will be subjected to bi-directional permeation of hydrogen isotopes: [1] one surface is to be exposed to the plasma, leading to plasma-driven permeation (PDP) of deuterium as well as tritium into blankets; and [2] the other surface is to be exposed to bred tritium in blankets, depending upon its dissociation pressure, which can result in significant gas-driven permeation (GDP) of tritium back to the edge plasma. If plasma-driven permeation dominates, deuterium flowing into the blanket will hinder the recovery of tritium and will probably necessitate isotope separation as well. On the other hand, if the opposite is true, gas-driven permeation will result in an increase in first wall recycling. Due to their critical importance to steady state reactor operation, these technical issues must be clearly addressed.

Plasma-driven permeation and gas-driven permeation experiments have been conducted, using a steady-state laboratory-scale plasma device: VEHICLE-1 for F82H and SUS304.[2-4] The thickness of the membrane varies between 0.5 and 5 mm. In the PDP experiments, the plasma density is of the order of 10^{10} cm^{-3}, the electron temperature is 2-4 eV, and the net implantation flux is estimated to be of the order of 10^{16} H·cm^{-2}·s^{-1}. The ion bombarding energy is controlled by a negative bias applied to the membrane. Resistive heater radiation from the downstream side is added as needed to reach desired temperatures. In the GDP experiments, an absolute gauge has been used to measure the H_2 pressure at the upstream side, while penetrating hydrogen is detected by a quadrupole mass spectrometer (QMS).

Both plasma-driven permeation and gas-driven permeation have been found to be essentially diffusion-limited. The steady-state PDP flux is affected by the upstream surface condition of the membrane, typically the surface roughness. However, there is a possibility that surface oxide may affect the recombination, which warrants more detailed investigation. Figure 1 shows the temperature dependence of permeability for GDP and permeation ratio for PDP through a 1 mm thick F82H membrane. Some literature data are also shown for a comparison in which one can find that our data is in good agreement with Serra's. From the Arrhenius plot the activation energy of permeability is estimated to be 0.49 eV, which is very close to the result obtained from PDP experiment, suggesting that the rate-limiting steps in these PDP and GDP experiments could be the same. Shown in Fig. 2 is a comparison between PDP and GDP on a 5 mm thick F82H membrane at ~500 ℃. The upstream hydrogen pressure for the GDP experiment is ~100 Torr. The steady-state GDP flux has been measured to be ~1.1×10^{15} H·cm^{-2}·s^{-1}, which is about one order of magnitude larger than that of PDP. These data suggest that GDP can dominate the hydrogen isotope transport through the first wall under Flibe-blanket conditions and possibly increase first wall recycling.

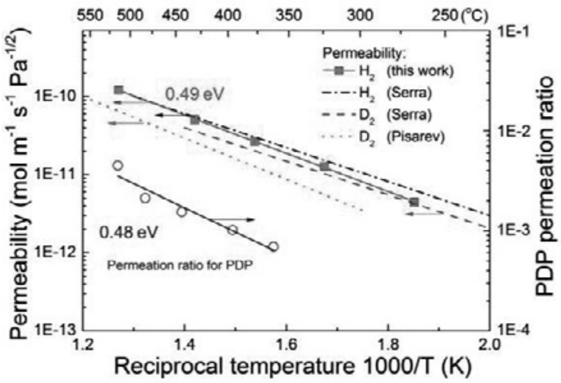

Fig. 1. Permeability for GDP and permeation ratio for PDP through a 1 mm thick F82H membrane.[4]

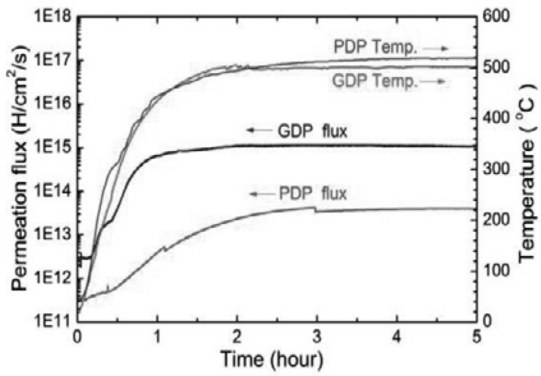

Fig. 2. Comparison between PDP and GDP on a 5 mm thick F82H membrane at ~500 ℃.

1) Sagara, A. et al.: Fusion Technol. **39** (2001) 753.
2) Hirooka, Y. et al.: "Plasma- and gas-driven hydrogen isotope permeation through the first wall of a magnetic fusion power reactor", Fusion Sci. Technol. **63** (2013) in press.
3) Zhou, H. et al.: "Hydrogen plasma-driven permeation through a ferritic alloy F82H", Fusion Sci. Technol. **63** (2013) in press.
4) Zhou, H. et al.: "Bi-directional hydrogen permeation through F82H under DEMO-relevant conditions", Plasma Fusion Res. **8** (2013) in press.