§7. Plasma and Gas Driven Permeation of Hydrogen through the First Wall in Counter Directions

Hirooka, Y., Ashikawa, N., Muroga, T.

In most of the recent magnetic fusion reactor designs [1] the first wall is not only intended to maintain high vacuum but to serve as a surface component of the blanket structure. The first wall is thus facing the edge-plasma on the one side and is wetted with a coolant or tritium breeder on the other side. For liquid breeders such as $Li_{17}Pb_{83}$, the dissociation hydrogen pressure of which is relatively high, one predicts that plasma-driven and gas-driven permeation through the first wall can occur simultaneously in counter directions. This is particularly important when the first wall is thin and the blanket operation temperature is high e.g. the first wall is only 5mm thick and the operation temperature is ~800K in the case of FFHR[1]. It follows from these that plasma-driven permeation would dilute the recovery efficiency of tritium from the breeder and gas permeation would affect edge plasma characteristics, and even core confinement performance.

Despite its critical importance, simultaneous plasma and gas driven permeation through the first wall has not yet been addressed clearly as a technical issue in the magnetic fusion research community. In the present work, these permeation fluxes have been calculated under some of the reactor relevant conditions using the DIFFUSE-code [2], and comparative experimental investigation using the VEHICLE-1 facility [3] is also under way.

The DIFFUSE code solves one-dimensional diffusion equation for hydrogen to migrate in a material with trapping sites. Only thermal de-trapping is taken into account although collision-induced de-trapping might occur as well near the surface. The initial profile of hydrogen atoms is imported from TRIM.SP-code [4] calculations under conditions relevant to the edge plasma characteristics such as electron temperature to determine the implantation energy, E, via $E\sim -3k_BT_e$, where T_e is the electron temperature.

The basic equations used in the DIFFUSE-code are:

$$\frac{\partial C_m(x,t)}{\partial t} = D\{T(t)\}\frac{\partial^2 C_m(x,t)}{\partial x^2} - \frac{\partial C_t(x,t)}{\partial t} + G(x,t)$$

$$\frac{\partial C_t(x,t)}{\partial t} = D\{T(t)\}\{C_T^o(x) - n_t C_t(x,t)\}/\lambda^2 - C_t(x,t)\nu_o \exp(-Q_t/kT(t))$$

where C_m and C_t are mobile hydrogen and trapping site concentrations, respectively, D is the diffusion coefficient, G is the source term, i.e., the initial implantation profile and Q_t is the de-trapping energy. The most commonly used boundary condition is "surface recombination", i.e.:

$$D\{T(t)\}\frac{\partial C_m(x_s,t)}{\partial t} = K_r C_m(x_s,t)^2$$

where K_r is the recombination rate constant.

The DIFFUSE-code has been run to compute the permeation fluxes in counter directions along with a temperature ramp through the first wall, assuming the following conditions: (1) a 5mm thick first wall made of F82H, simplified by pure α-Fe; (2) an edge plasma bombarding flux of $1x10^{16}H/cm^2/s$ at an energy of 100eV; and (3) a molecular hydrogen pressure of 10Torr at 800K, simulating a $Li_{17}Pb_{83}$ breeder, the plasma-driven and gas-driven permeation fluxes at steady state are calculated to be of the order of 10^{12} $H/cm^2/s$ and 10^{14} $H/cm^2/s$, respectively, the latter of which dominates the overall flow.

Shown in Fig. 1 is the implantation profile calculated by the TRIM.SP-code. The plasma-driven and gas-driven permeation fluxes are shown in Fig. 2 and Fig. 3, respectively. One extends these data such that the hydrogen in-flow from the blanket amounts up to 100Torr liter/s for a reactor with a first wall area of $2300m^2$, which would no doubt disturb plasma density control.

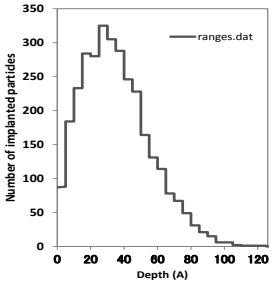

Fig. 1 Implantation profile of H in Fe at E=100eV.

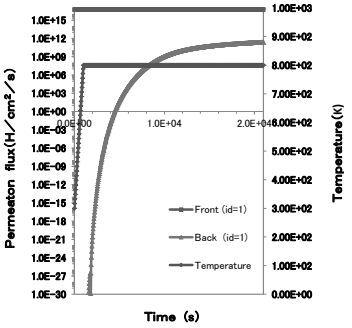

Fig. 2 Plasma-driven permeation flux at 800K.

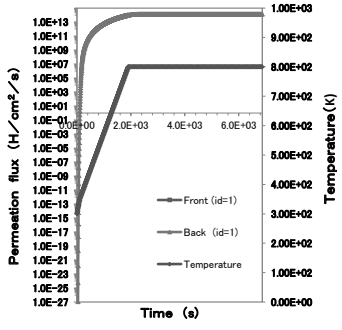

Fig. 3 Gas-driven permeation flux at 800K.

[1]Sagara A. et al., Fusion Technol. **39**(2001)753.
[2]Baskes M. I. "DIFFUSE83" Sandia Rep. SAND83-8231.
[3]Hirooka Y. et al., J. Nucl. Mater. **337-339**(2005)585.
[4]Eckstein W. and Biesack J., Nucl. Instr. & Meth.B2(1984) 550.