Study of the plasma driven permeation of hydrogen through a nickel membrane in RF and ohmic plasmas in the spherical tokamak QUEST

S. K. Sharma


1IGSES, Kyushu University, Kasuga, Fukuoka, 816-8580, Japan
2RIAM, Kyushu University, Kasuga, Fukuoka, 816-8580, Japan
3Department of Nuclear Engineering, Graduate School of Engineering, Kyoto University, Japan
4National Institute for Fusion Science, Toki, Japan
5Kyushu Tokai University, 9-1-1 Toroku, Kumamoto 862-8652, Japan
6Plasma Research Center, University of Tsukuba, Japan
7Department of Mechanical System Engineering, Graduate School of Engineering, Hiroshima University, Japan
8Hydrogen Isotope Research Center, Toyama University, Toyama 930-8555, Japan
9Graduate School of Frontier Science, The University of Tokyo, Ibaragi, Japan
Outline

1. Motivation
2. Plasma Driven Permeation
3. Schematic of Experimental System
4. Summary of PDP results
5. Parametric scan
6. Conclusion
Future fusion reactors have two key issues

- Recycling density control in steady state operation
- Safety Issues due to Tritium retention

Motivation

- Hα, CX measurement
- Neutral atomic Hydrogen
- Plasma Driven Permeation

Direct measurement of neutrals near plasma facing as well as non plasma facing components
Plasma Driven Permeation

Implant zone (absorbed layer)

Recycling

Permeation

\[
J(t) = k_d C^2(L, t) \approx D \left[ \frac{\partial C(x, t)}{\partial x} \right]_{x=L}
\]

\[
\frac{\partial C(x, t)}{\partial t} = D \frac{\partial^2 C(x, t)}{\partial x^2}
\]

Plasma facing wall

Incident atomic flux (eV and Sub eV range)

Recycling

\[
(H)
\]

\[
(H_2)
\]
Top View of Quest

- New PDP (#2)
- New PDP (#3)
- Fast camera
- 8.2 GHz µ-wave (CD/heating)
- Surface probe
- µ-wave reflectometer
- Probe/ Medium camera
- Pump
- Hα array /medium camera
- Multi channel spectrometer (200 - 900 nm)
- Spectrometer (Fulcher spectrum for \( I_{H2} \))
- Hα, OII spectrum

- 2.45 GHz
- 8.2 GHz µ-wave
- Hard X-ray
- Movable probe

VUV(Lyman)
PDP System
Schematic of the measurement of the Plasma Driven Permeation

- **Ni Baffle**
- **Ni membrane**
- **Magnetic Shield**
- **GV**
- **QMA**
- **Lamp**
- **Thermocouple**

**Graphs:**
- **Left Graph:**
  - Time (s) vs. \( I_{H_e} \) (a.u.)
  - Data points for different shots: H2_3188 - 3197

- **Right Graph:**
  - Time (s) vs. \( \Gamma_{pp}(H/m^2/s) \)
  - Data for different shots: H2_3188 (87.4 kW) - H2_3189 (4.65 kW)
Wall conditioning during the experimental campaign  
(2009/06/02 to 2009/07/24)
For more than 1200 discharges, $Q_{\text{PDP}}$ follows $H_\alpha$ fluence and shows a linear relationship with $H_\alpha$ fluence ($Q_\alpha$).

$Q_{\text{PDP}}$ is found linearly proportional to the incident atomic fluence.

Scattering from the linearity is to be studied in view of local plasma wall interaction as well as to understand its capabilities for measuring atomic flux near PFCs as well as far PFCs.
Reproducibility in $Q_{\text{PDP}}$ during discharge shots with similar operating parameters

- $Q_{\text{PDP}}$ is measured during plasma discharges having the similar operating condition
- $Q_{\text{PDP}}$ shows a variation of $\approx 3\%$
- The part of this variation in $Q_{\text{PDP}}$ may be due to the variation in the plasma discharges itself.
- $Q_\alpha$ however shows comparatively large variation.
Sensitivity of PDP against local PWI (Change in magnetic configuration)

- The $Q_{PDP}$ shows a variation of $\pm 13\% >$ standard
- However variation in $Q_{\alpha}$ is $\sim \pm 9\%$
- Large variation seems to be related to the change in neutrals by local PWI
**Variation in PDP measurements during gas puff scan**

$\Gamma_{H2}(H/m^2/s)$

- Shot. 3423 - 3429

$Q_{PDP}$ shows linear relationship with the Gas puff width. However the linearity with spectral fluences are relatively poor as compared to that with the gas puff times.
Effect of gas on plasma parameters i.e. Density and electron temperature

$Q_{PDP}$ increases linearly with the Gas puff width (chamber pressure).

However edge plasma density does not show such relationship with gas puff width.

It indicate that the permeation is mainly related with the dissociated atomic density (flux) but not due to the plasma density itself.
Variation in permeated flux, $\Gamma_{\text{PDP}}$ during a power scan

At 50 kW RF power, $Q_{\text{PDP}}$ shows a threshold value after which it rises more rapidly. Similar threshold can also be observed in $H_\alpha$ and molecular spectral fluences.
Effect of RF power scan on plasma density and electron temperature

At 50 kW RF power, $Q_{\text{PDP}}$ shows some threshold after which it rises more rapidly.

The similar threshold can be observed in the edge plasma density.
QPDP as a function of H$_\alpha$, Lyman-α, molecular fluence and Density

QPDP shows a offset linear relationships with different spectral fluences and also edge plasma density
PDP measurement during a discharge width scan

Permeate fluence increases linearly with the plasma discharge widths (> 5s)
Normalized PDP Flux for discharge pulse scan and gas puff scan

(Shot No. 3598 - 3602)

Rising or decay time constants of $\Gamma_{PDP}$ does not depend on the incident atomic fluence
Effect of the hydrogen releasing from the chamber walls

All the operating parameter have been fixed during these three shots.

A large difference in \( \Gamma_{PDP} \) is due to a rise of the incident atomic flux released from the wall as indicated by the \( H_\alpha \) and Molecular (Fulcher line) intensities.
Summary & Conclusion

• Permeated flux is found linearly proportional to the incident $H_\alpha$ fluence ($Q_\alpha$) during various types of plasma discharges.

• A long term working of the permeation probe without any cleaning procedure is observed.

• During gas puff scan the $Q_{PDP}$ shows a linear relationship with the gas puff width or chamber pressure. However, the linearity with spectroscopic fluences are relatively poor as compared to that with the gas puff width.

• During RF power scan, a threshold is observed at 50 kW in $Q_{PDP}$ as well as various spectroscopic fluence.

• The permeated fluence is linearly proportional to the discharge width.
The released gas from the walls (recycled flux) may highly affects the permeated flux $\Gamma_{\text{PDP}}$

The rising or decay time constants of $\Gamma_{\text{PDP}}$ does not depend on the incident fluence.

The PDP measurements seems to be a best estimates to know the atomic density near PFCs or far from PFCs as compared to the other spectral measurements.
Thanks for your kind attention