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Simulations and pre-experiment uncertainty analyses for a hydrogen diffusion experiment using a “two side purged membrane” setup

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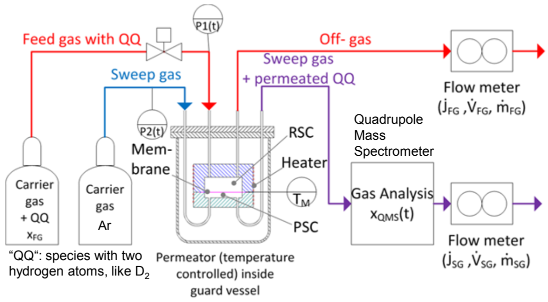
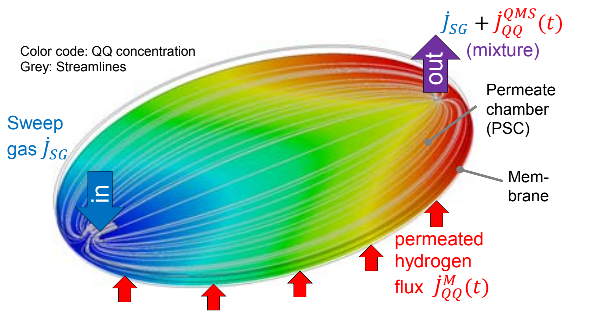
Background and Objective

*An experiment **“Q-PETE”** representative for the situation in the **Helium Cooled Pebble Bed** breeding zone and suitable for **validation of relevant tritium transport codes** is planned.*
In a temperature controlled setup a hydrogen loaded feed gas is directed over a steel membrane into which it can permeate.
*On the other side of the membrane **a sweep gas flow collects the permeated hydrogen** and transports it to a gas analysis **(QMS)** for quantitative **time resolved detection**.*

➔ ***Methods to handle time resolved permeation experiments with sweep gas***, considering the ***residence time distribution*** of the sweep gas are introduced.



Schematic flow and instrumentation diagram of Q-PETE



Flow and concentration field in the purged permeate chamber

Issue

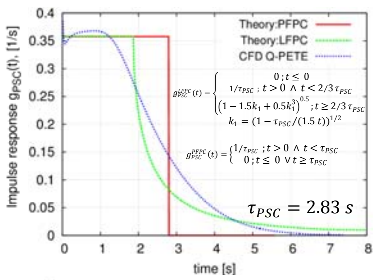
- The ***time resolved*** permate flux signal over the membrane $j_{QQ}^{M}(t)$ is of interest for code validation and material parameter (Diffusivity D, Sieverts constant K_S) determination
- The purge flow ***residence time distribution*** in the permeate chamber (PSC) and the piping effects a ***lag*** and a ***dispersion*** in the measurable concentration signal $x_{QMS}(t) = j_{QQ}^{QMS}(t)/j_{SG}$

➔ **The difference between $j_{QQ}^{M}(t)$ and $x_{QMS}(t)$ must be described !**

Simulation methodology

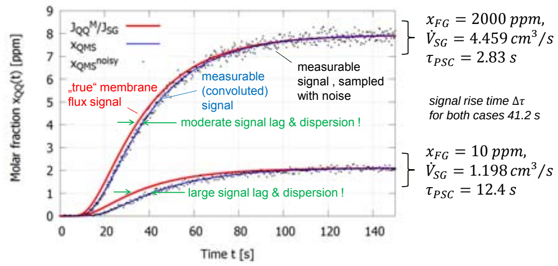
- System response $j_{QQ}^{QMS}(t) = j_{QQ}^{M}(t) * g(t) = \underbrace{\int_{u=0}^{t} s(u)\cdot g(t-u)\,du}_{\text{convolution integral}}$
- Impulse response function $g(t)$ is residence time distribution
- Convolution integral $j_{QQ}^{M}(t) * g(t)$ is numerically solved
- Further model for QMS sampling and noise applied

➔ **Complete system signal simulation (prediction) implemented .**



Residence time distributions can be obtained by analytic formulae (abstracted cases) or by CFD calculation for a specific geometry and flow boundary conditions.

They differ by the effected signal dispersion.

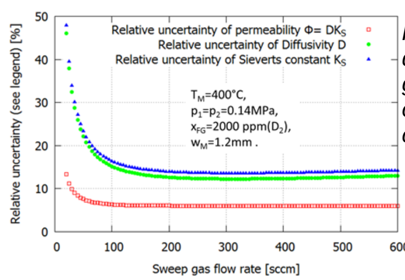


Simulated signals for two experimental conditions
x_{FG}: feed gas hydrogen content. $\dot{V}_{SG}$: Sweep gas flow rate

Uncertainty estimation

- As figure of merit, propagated uncertainties to D and K_S are estimated for a simplified analytic evaluation method.

  (1) $D \approx 0.16877 \cdot w_M^2 / \Delta\tau$, (2) $\phi = D\,K_S = \frac{2\,w_M}{A_M}\cdot\frac{x_{QMS}(t\to\infty)\cdot j_{SG}}{\sqrt{p_{QQ,1}}-\sqrt{p_{QQ,2}}}$
- Experimental setpoints can be optimized. For example: large flow rate and/or large membrane thickness: ➔ good time resolution *but* low signal level (and vice versa).



Predicted uncertainties depending on the sweep gas flow rate show an optimum range (in this case, ~300 sccm)

➔The residence time distribution in the permeation setup volume before the analysis station has ***significant*** effect and can be predicted by appropriate methods.
➔Experimental **uncertainties of ~ 15%** for the derived Sieverts constant for breeder zone typical conditions are expected for the Q-PETE purged permeation experiments.

EUROfusion
This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euratom research and training programme 2014-2018 under grant agreement No 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.