Tritium extraction from liquid breeding blankets based on the vacuum sieve tray technology

L. Frances*, D. Demange, D. E. Diaz, D. Hillesheimer, A. Muñoz

Introduction

- Tritium self-sufficiency of fusion reactors has to be ensured
- Tritium produced in the breeding blanket has to be extracted
- Vacuum Sieve Tray: T₂ extraction from liquid breeding blankets

Vacuum Sieve Tray (VST) principle

- PbLi droplets fall in a vacuum chamber
- Tritium atoms diffuse towards their surface
- They recombine: T₂ is extracted
- Droplets undergo oscillations (up to 200 Hz)
- Mass transport enhanced [1]

Diffusion coefficient \( \eta = \frac{\eta_0}{M_{\alpha}} \) Mass transport coefficient \( \frac{2 \times 10^{-9} \text{ m}^2 \text{s}^{-1}}{3 \times 10^{-7} \text{ m}^2 \text{s}^{-1}} \)

The vacuum sieve tray project at TLK

MNVST: \( \text{D}_2 \) multi-nozzle
- Quantify and model disturbances
- Preliminary experiment (prior to \( T_3 \))
- \( * \text{D}_2 \) reabsorption

SNVST: \( T_2 \) single-nozzle
- Proof of operation with \( T_2 \)
- DEMO relevant (\( T_2 \) pressure...)

Modelling and scaling up multi-nozzle VST
DEMO tritium extraction systems

Multi-nozzle set-up

Upper chamber:
- Favor dissolution
- Limit permeation

Lower chamber:
- High extraction efficiencies
- Observation windows
- Flexible pumping configuration
- PbLi transfer by He pressurization
- 8 geometries to be tested

Single-nozzle model [3]

\[ \eta = \frac{M_{\alpha(t)}}{M_{\alpha(0)}} = 1 - \frac{6}{\pi^2} \sum_{n=1}^{\infty} \frac{1}{n^2} \exp \left( -\frac{D \times n^2 \times \pi^2 \times t_{\text{fall}}}{r^2} \right) \]

\( t_{\text{fall}} \) calculated (iterations) taking into account:
- Flow velocity (temperature, geometry...)
- Changes in hydrostatic pressure
- Pressure losses (five contributions)

- Follow-up any single nozzle experiment

Multi-nozzle model

Distillation \( \sum p_{XY} = \eta_{\text{calculated}} - \eta_{\text{experimental}} \)

Dissolving pressure: 50 mbar
Nozzle diameter: 0.6 mm
Falling height: 0.56 m
Falling time: 0.154 s
\( \eta_{\text{calculated}} \): 86.5 %

Disturbance parameter
\( \begin{align*}
\dot{p}_{XY} &= X \times \frac{y(\beta)}{x(\beta)} \times \frac{\beta}{\beta(\beta)} \\
\end{align*} \)

Nose mitochondria:
- \( t \) droplets disturbed
- \( d \) droplets disturbing
- \( s \) droplets in the surroundings of the disturber

Support activity analysis of multi-nozzle experimental results
- Six types of disturbances identified \( (p_{X3}, p_{X4}, p_{X5}, p_{X3}, p_{X4}, p_{X6}) \)
- Number of occurrences predictable (depends on the geometry)

Conclusions

- Two complementary experiments developed (SNVST & MNVST)
- Single-nozzle model: accurate calculation of the pressure losses
- Multi-nozzle model: support the analysis of MNVST experiments and of the impact of the geometry

References


This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the Euroatom research and training programme 2014-2018 under grant agreement No 633553. The views and opinions expressed herein do not necessarily reflect those of the European Commission.