Experimental study of helium purge flow in pebble bed for solid breeder

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Outlines

- Background and objectives
- Experimental study of pressure drop in the breeder pebble bed
- Analysis of behavior of He purge gas in breeder pebble beds
- Verification test of hydraulic performance of purge gas
- Conclusions
Background and objectives

Toward the Tritium Recovery System

Tritium behavior in the blanket is a complex phenomenon which consists of tritium generation, tritium release from the breeder pebble, purge gas thermo-hydraulics and tritium permeation.

Final goal of this study is to construct the total tritium behavior simulation taking into account all essential tritium transfer process.

Integrated simulation of heat and mass transfer in blanket

Objectives

\begin{itemize}
\item to estimate generated tritium and its transport
\item to contribute to the design of blanket
\end{itemize}
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Experimental study of pressure drop of the purge gas

The pressure drop of the purge gas in the breeder pebble bed experimentally has been studied, using pebble bed with comparably-size of the TBM. Two containers with different cross-sectional shape are applied.

A cross-section area and a flow length of two different containers are the same, 3864 mm$^2$ and 500 mm, respectively. Breeder pebbles ($\text{Li}_2\text{TiO}_3$, diameter of 1 mm) which will be used in our TBM were packed in the containers. The packing factors were obtained as 65.4% for the simple rectangle and as 64.4% for the rectangle-shaped with pipe-array one. The range of the flow rate of helium purge gas in room temperature is set to be up to 60 L/min.
As for the trend of the pressure drop with increasing the gas flow rate, the pressure drop of simple rectangle became slightly larger than that of the rectangle-shaped with pipe-array due to its higher packing factor. On the other hand, few effect of pressure drop on the different geometrical cross-section was found. It is demonstrated that the Ergun's equation can be applied to predict the pressure drop in the breeder pebble bed of our TBM.
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Analysis of behavior of He purge gas in breeder pebble beds

The effect of thermo-hydraulics of the purge gas stream in the breeder pebble bed was studied numerically. The purge gas stream was calculated by 3D thermo-hydraulic simulation code “FLUENT”.

By taking into account the distribution of the tritium generation rate and nuclear heating rate distribution in the radial direction of the blanket, the purge gas stream and tritium concentration were calculated by the 2D numerical simulation. In this calculation, the tritium release mass transfer conductance is assumed to be negligible.

Tritium production and temperature of pebble bed obtained by one-dimensional nuclear and thermal analyses are put into FLUENT as source terms.
Numerical simulation for Darcy flow in porous media

Computational configuration

- porosity: 0.35
- Reynolds number:

\[ Re_p = \frac{u_m D_p}{\nu} = 0.3 \]

\( u_m \): Bulk mean velocity
\( D_p \): Sphere Diameter (1mm)
\( \nu \): kinematic viscosity

Shapes of inlet and outlet

Porous Type

- First Wall (346°C)
- Membrane Panel (347°C)
- He + T
- 5.5 [L/min]
- 50 [°C]
- 0.1 [MPa]

Velocity of Darcy flow

- Inlet: 10 cm/s
- Outlet: 2 cm/s

Concentration of T

- 2.3 \times 10^{-2} \text{ mol/m}^3
- 1.1 \times 10^{-2} \text{ mol/m}^3

Convective diffusion → small
Molecular diffusion of T₂ → small

Especially, the high concentration of T₂ stays near the first wall and the membrane panel.

It is necessary to further investigate the effect of near-wall packing fraction. An experiment has been started to demonstrate a flow distribution near the wall and at the center of pebble bed.
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Verification test of hydraulic performance of purge gas

Flow in the pebble bed is simulated by the flow in the porous media. → Difference between porous media and pebble bed is to be clarified.

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High speed CCD camera
PIV measurement
Transparent material pebble bed
Acrylic container
Near Wall: large porosity
Bulk Pebble Bed: small porosity

The pebble made of MEXFLON® that imitates a breeder pebble was adopted because of similar refraction index between MEXFLON® and water.

Practical pebble Li₂TiO₃
Sheet-like laser
H₂O

Preliminary test for visualization of flow in the MEXFLON® pebble bed has been performed by particle image velocimetry (PIV).
MEXFLON® pebble has a characteristic of transparent in water. Refractive index identical to water prevent loss of tracer particle caused by reflection of light and adapts to PIV measurement.

In past PIV measurement, corrosive sodium iodide solution was used to match refractive index of fluid to that of acrylic. Using MEXFLON® pebble made PIV measurement easier available without strong corrosive of a sodium iodide solution.
Experimental equipment for PIV in pebble bed (1)

Experimental setup

A sphericity of pebble needs to have high level of quality for anti-halation.

The wall has a small hole to introduce tracer particles for visualization.

MEXFLON® pebble

The wall has a small hole to introduce tracer particles for visualization.
YAG sheet laser is generated by a continuum source of a laser diode pumped solid-state laser with a wavelength of 532nm, a power of 200mW.

The structure of pebble bed can also be captured by controlling contrast of 2D monochrome image obtained by the laser. As a future plan, 2D monochrome image will be translated to 3D graphic data by image processing. It will be applied as a boundary condition for numerical simulation of flow in the pebble bed.
Visualization of flow phenomena in pebble bed (preliminary)

The Reynolds number of water based on the diameter of pebble and the mean bulk velocity is set to be identical to that of helium purge gas.

Flow goes upward with small influence of flow dispersion.
Conclusions

- Experimental study of pressure drop in the breeder pebble bed
  - The pressure drop of the purge gas in the breeder pebble bed has been studied experimentally, using pebble bed with comparably-size of our TBM.
  - Two containers with different cross-sectional shape are applied. In both cases, Ergun's equation can fit the pressure drop results obtained from the experiment. It is demonstrated that the Ergun's equation can be applied to predict the pressure drop of the purge gas in the breeder pebble bed of our TBM.
  - On the other hand, an effect of geometrical cross-section was found to be negligible in the pipe-array case.

- Verification test of hydraulic performance of purge gas
  - Preliminary visualization of flow phenomena in pebble bed by using PIV and MEXFLON® was successfully performed.
  - The preliminary result of the flow visualization in the pebble bed showed small effect of dispersion of the fluid near the wall. This means that the tritium concentration near the wall could be twice as much as average concentration in the purge gas as predicted by numerical simulation.

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