TRITIUM MODELING FOR ITER TEST BLANKET MODULE

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HCPB (Helium Cooled Pebbles Bed) Test Blanket Model (TBM) is based on solid breeder. Tritium has to be extracted using Helium purge gas flowing through breeder pebbles bed. He-stream must be cooled down and processed and all these steps are carried out in TES (Tritium Extraction System). A modeling work has been performed to study the behavior of the TES of the HCPB TBM and for Molecular Sieve 5A as adsorbent material. The result is the capability to model the extraction process of gaseous tritium compounds and to estimate the breakthrough curves of two main tritium gaseous species (H_2 and HT).

I. INTRODUCTION

TES (Tritium Extraction System) is a fundamental auxiliary system of blanket using solid breeder like HCPB (Ref. 1-3). Tritium generated inside solid lithium isotopes is extracted using a low pressure helium purge-gas which is processed inside TES in order to recover all tritium compounds. TES also checks physical properties and chemical composition of purge gas, and to remove oxygen and other possible impurities.[3]

Main chemical form of tritium are gaseous tritium and tritiated water. Their production and total amount depend on quantity of hydrogen or water contained in the helium stream.

Molar fraction equal to 0.1% in H is typically added to He to facilitate tritium release by isotopic exchange from solid breeder. This process is described by the reaction.

$$H_2 + HTO \rightarrow HT + H_2O$$

Different techniques are available to process He-flow inside TES, but the most important is adsorption that is performed at different temperatures. Cryo-sorption is defined as an adsorption on porous media at very-low temperature (less than -100 °C).

Extraction technique influences the layout of TES and different configurations have been proposed. Parameters of TES 2008 design has been selected for our calculations.

Results are described using breakthrough curves, representing the evolution of adsorbate concentration in the gas flow at the outlet of absorbed bed over time: they are characterized by a typical "S" shape.

II. TES 2008 MAIN PARAMETERS

This system has been designed by ENEA in 2008. (Ref. 2-3) Tritium extraction is performed through two steps: one to extract HTO/H2O in vapor form and one for gaseous tritium compounds. Extraction of vapors has been improved by replacing cold trap by an adsorption column which can operate at room temperature. CMSB (Cryogenic Molecular Sieve Bed) has been used for gaseous tritium like in previous designs. This component is a column containing pebbles of adsorbent material. Among many available materials, Molecular Sieve 5A (Zeolite) has been used.[4] Since these materials must be regenerated, two identical components have been foreseen to avoid unavailability during regeneration phase.

Also, this system is able to operate under two possible operating conditions: High Duty DT phase and Low Duty DT phase. In this last case, operations can be performed because a by-pass line and a Q_2 Getter Bed have been introduced. These components are able to process the total flow rate when irradiation regime is based on isolated pulses.

Geometrical parameters and main physical properties needed to simulate extraction process inside CMSB are listed in Table I.

TABLE I. Data on 2008 TES Adsorption Column

Parameter	Symb	Value
Column internal diameter [m]	r_D	0,2
Column height [m]	Z_B	0,6
Bulk density [kg/m3]	ρ_b	660
Particle diameter [m]	d_P	$2{,}0\times10^{-3}$
ExternalPorosity of the bed	E	0,51

Adsorption process is performed at 77,4 K and 0,1013 MPa. Helium stream enters adsorption column from the bottom and it is considered uniformly distributed over whole column cross section. After extraction process, He flow is taken off from the top of the column.

Results of calculations obtained using COMSOL Multiphysics 4.3 (Ref. 5) are going to be shown.

Preliminary results for model testing were shown in Ref. 6.

Species transport in porous media is a complex phenomenon and for this reason it is described by many equations. The most important is the time dependent mass balance equation:

$$P_{1,i}\frac{\partial c_i}{\partial t} + P_{2,i} + \nabla \cdot \Gamma_i + u \cdot \nabla c_i = R_i + S_i$$

Time dependent equation has been used since the breakthrough curve is defined as the change in the concentration of the adsorbate at the outlet of the bed with time. On the left-hand side of the equation, since c_i is the concentration of species i in the gas phase, first term represents its behavior during time. Second term describes accumulation of chemical species i in solid phase (porous matrix). Last term, containing velocity u, represents convection due to directional velocity u itself. On right-hand side, the two terms describe production and consumption of chemical species. First one can account reaction rate in solid or gas phase, while second one is a source term that can describe fluid flow source or sink.

III. RESULTS

Calculations have been carried out considering two cases:

- Constant porosity, permeability and velocity;
- Profile of porosity, permeability and velocity.

Permeability of a packed bed measures the ability of a specific porous material to allow a fluid to flow through it under certain conditions. This quantity is directly linked to the bed porosity, but it is affected by other parameters too. In particular, in case of single-sized beds, the main variables are: both particle size and shape, and geometric factor.

The operative conditions considered for the simulation are the following: total stream mass flow-rate 60 dm^3/h, HT molar fraction 1 ppmv, pressure 1 bar, temperature inlet 773 K

Breakthrough curves for both chemical species (H_2 and HT) are displayed below.

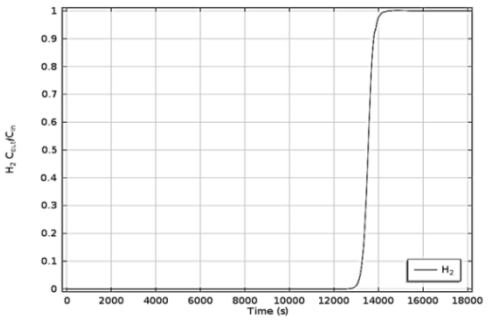

Fig. 1. H_2 breakthrough curve, constant velocity.

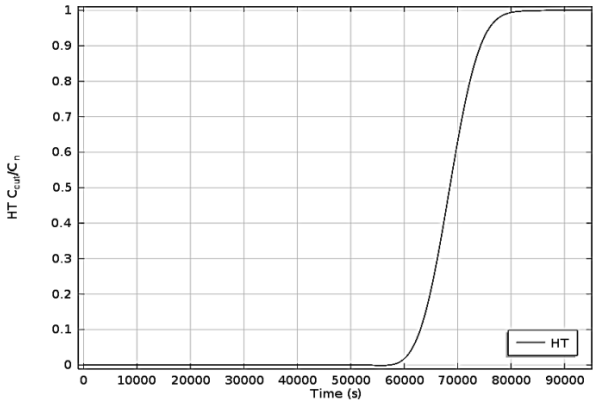

Fig. 2. HT breakthrough curve, constant velocity.

Here, saturation occurs after about 14800 seconds.

Here, saturation is reached after 85500 seconds. The difference is due to the very different partial pressure of H2 and HT, with different derivative values in the adsorption isotherms that, being proportional to the adsorption front axial velocity, explain the different breakthrough curves for H2 and HT. A profile of porosity and permeability inside adsorption column has been adopted in order to approach real operating conditions. These profiles lead to get a profile of velocity too. Its shape is described in Fig. 3.

Flow channeling region is placed in a small area near the wall because of high aspect ratio (well-packed bed). Largest part of the column is characterized by a constant velocity. Also, ratio between peak and bulk velocity is around 2,55 - a typical value for porosity around 0,5 in the center of the bed. Three points were identified to describe breakthrough curve: #1 on column centerline, #2 on the wall and #3 in the middle. Figure 4 shows the breakthrough curves for H_2. Saturation in #1 and #3 occurs at the same time since velocity is the same. Saturation time on the column centerline is longer than in case of constant velocity, while it is shorter on the wall because of higher velocity.

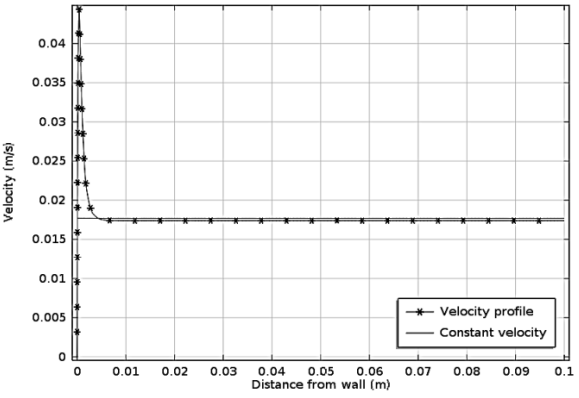

Fig. 3. Profile of velocity.

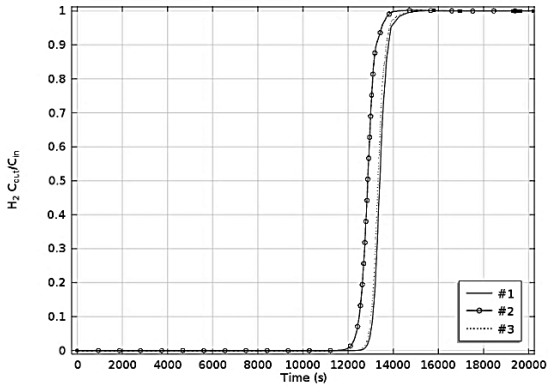

Fig. 4. H_2 breakthrough curves (velocity profile).

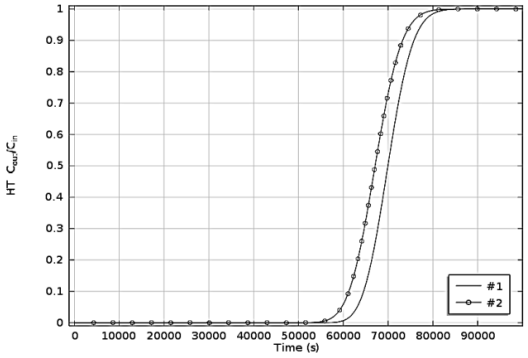

Fig. 5. HT breakthrough curves (velocity profile).

HT breakthrough curves are shown in Fig. 5. Same behavior is verified in this case too.

So far, an exponential profile of porosity has been used to compute velocity of helium inside column. However, the real profile is not exponential, but with oscillations: a new profile described by Klerk correlation has been introduced.

This model applies for mono-size spheres with a bed-to-pebble diameter ratio equal or larger than 2.

Oscillations of porosity and permeability generate oscillations in velocity profile as well. Figure 6 shows this profile.

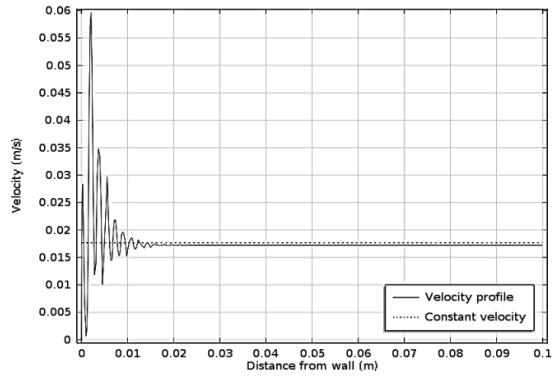

Fig. 6. Oscillating profile of velocity (Klerk).

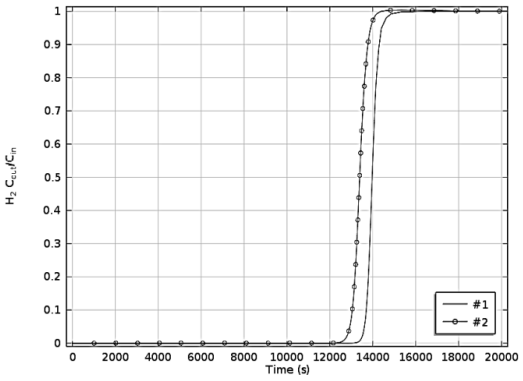

Fig. 7. H_2 breakthrough curves (Klerk profile).

Resulting breakthrough curves for H_2 are displayed in Fig. 7.

Column saturation occurs in 15200 seconds in point #1 and in 14400 seconds in #2. This means that breakthrough curves are not very affected by oscillating profile and porosity can be well approximated by exponential formulation too.

As mentioned above, all these calculations have been carried out assuming helium flow uniformly distributed over whole column cross-section. However, more realistic configuration can be considered introducing a perforated plate [7-8] at column inlet (see Fig. 8).

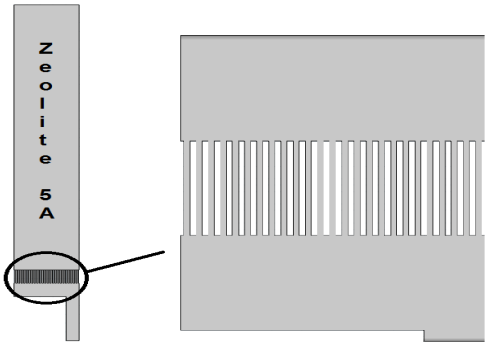

Fig. 8. New configuration of adsorption column.

TABLE II. Features of Perforated Plate[7-8]

Parameter	Value
Thickness of plate [m]	0,03
Diameter of holes [m]	0,002
Pitch [m]	0,004
Total number of holes	2270
Thickness of gap before the plate [m]	0,03
Inlet tube diameter [m]	0,04

Geometrical properties of the perforated plate are listed in Table II. Total number of holes was determined

through open area, assuming a triangular pitch for round holes.

Velocity profile near the plate is distorted by the plate itself, while at the column outlet, profile is unaffected. Thus, perforated plate doesn't modify profile once it is completely developed. Better results can be obtained decreasing diameter of holes and pitch.

Resulting breakthrough curves for H_2 and HT are displayed in Fig. 9 and 10. Saturation occurs in 14500 seconds in point #2 and in 15300 seconds on column centerline. Process is a little bit slower with respect to case without plate.

Slower saturation is verified in this case too, since 84800 seconds are required in point #2 and 86500 seconds in #1. This behavior is related to the velocity profile immediately after the plate.

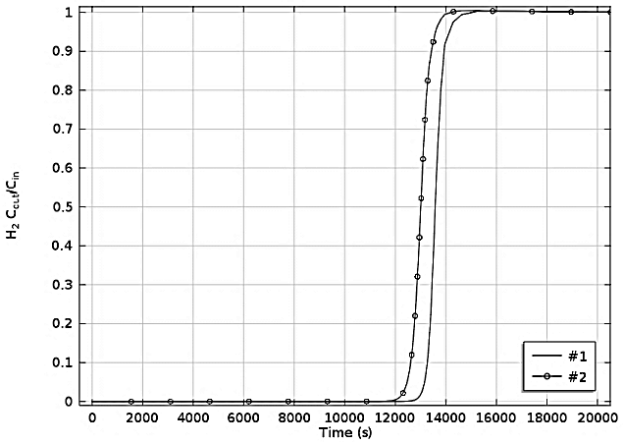

Fig. 9. H_2 breakthrough curves (perforated plate).

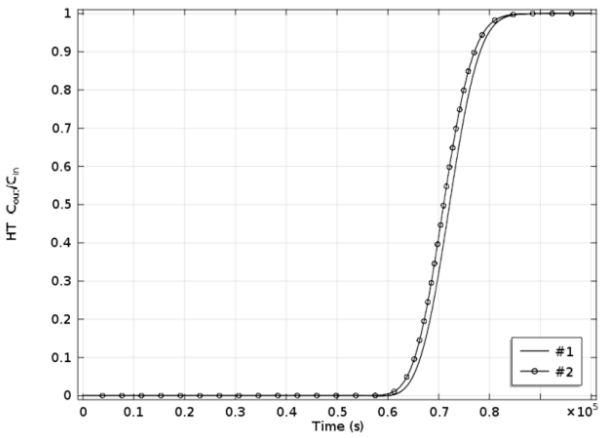

Fig. 10. HT breakthrough curves (perforated plate).

IV. CONCLUSION

Comparing breakthrough curves in Fig. 1 and 4, or in Fig. 2 and 5, it's evident that a certain profile of porosity must be introduced in order to get a more realistic model. Effects of porosity and permeability are not negligible.

Comparing results associated to exponential and oscillating profile of porosity, only minor differences are found. Thus, exponential formulation for radial porosity is a good approximation.

Finally, differences among cases with and without plate are negligible. This means that assumption of uniformly distributed flow over column cross-section is justified.

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