한국핵융합에너지연구원
KOREA INSTITUTE OF FUSION ENERGY

Transactions of the Korean Nuclear Society Autumn Meeting, Oct. 21-22, 2021

사단법인 한국원자력학회
KOREAN NUCLEAR SOCIETY

Preliminary Hydrogen Cryo-sorption and Desorption Test using Molecular Sieve Bed

M.-Y. Ahn[1], S. C. Park[1], S. K. Son[1], S. Cho[1], Y.-H. Park[1], Y. Lee[1]

[1] Korea Institute of Fusion Energy (KFE), Daejeon, Rep. of Korea

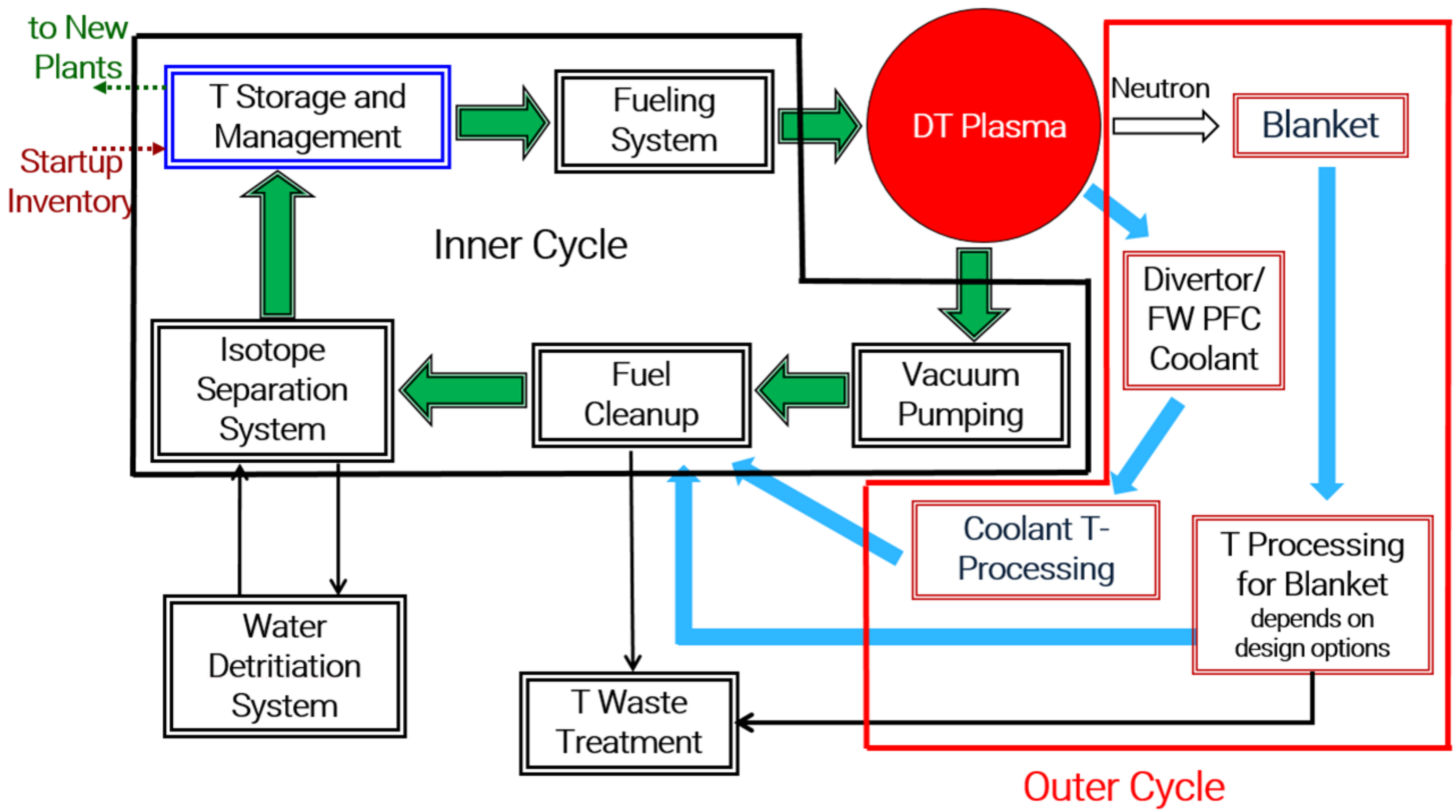
과학기술정보통신부
Ministry of Science and ICT

KOREA DOMESTIC AGENCY

Outline

1. Introduction
2. Experimental Description
3. Results on Hydrogen Adsorption
4. Results on 2 Cycles of Hydrogen Adsorption/Desorption
5. Summary

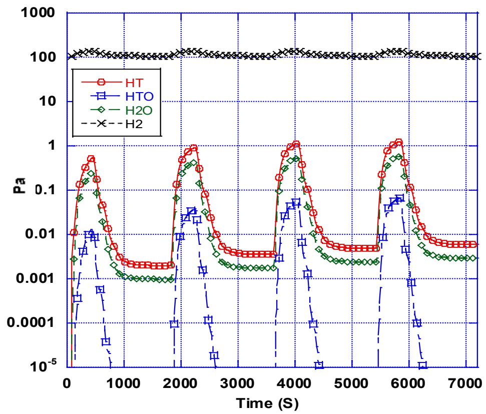
Overall Fuel Cycle

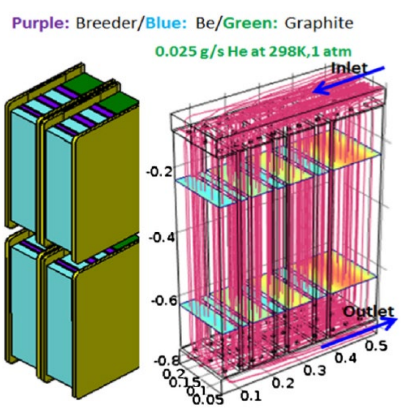


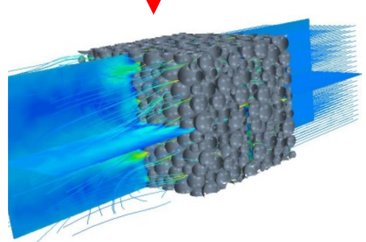
- Inner fuel cycle represents systems for supplying tritium to tokamak, and recycling and purifying the un-burnt tritium
- Outer fuel cycle primarily composes processing lines and systems to extract tritium produced from blankets, and to deliver it to inner fuel cycle

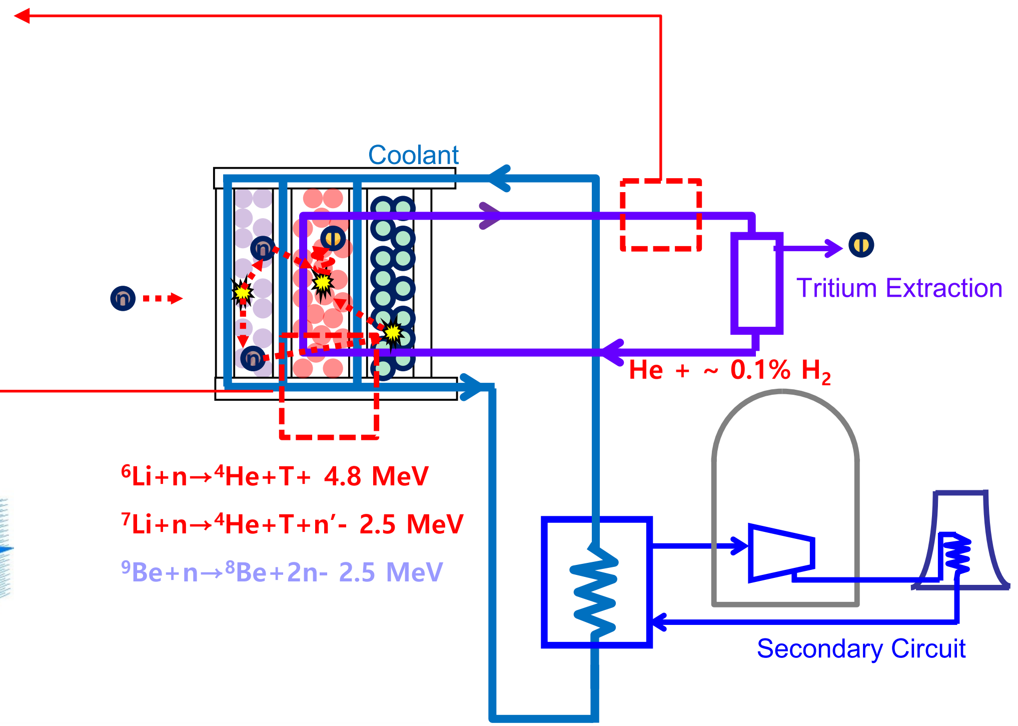
Tritium Production and Extraction in Outer Fuel Cycle

- Tritium produced in the blanket is extracted by purge gas
  - The helium purge gas flows around the pebbles to extract produced tritium
  - Small fraction of hydrogen is added to the purge gas to facilitate tritium release
  - Low concentration hydrogen isotopes exist in the purge gas, which need to be separated from helium before routing to the inner fuel cycle



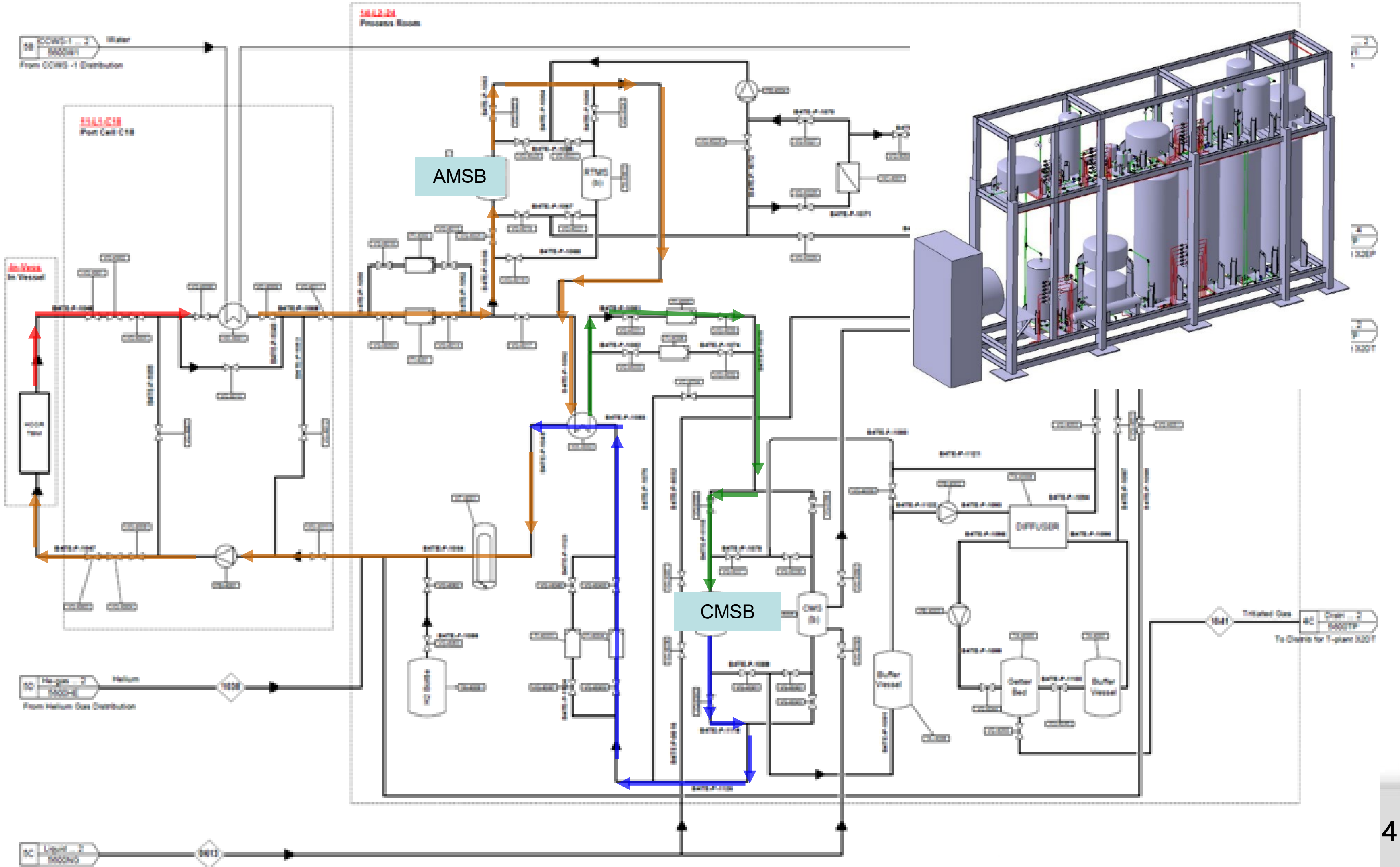






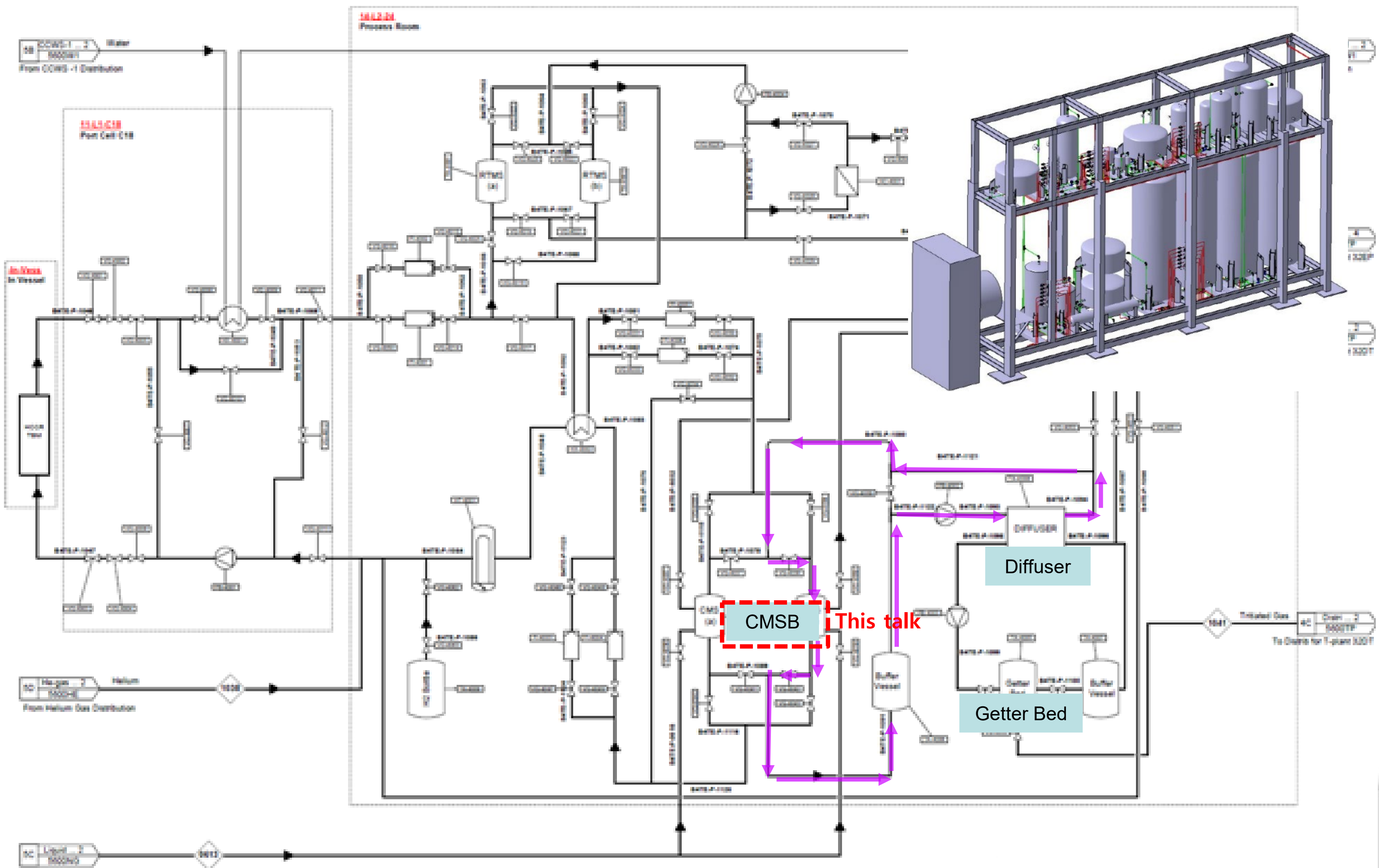
Technology for Separation of Hydrogen Isotopes

- Main processes adopted for the Tritium Extraction System (TES) of HCCR-TBS
  - During adsorption phase, Q_2 & Q_2O are adsorbed by Cryogenic Molecular Sieve Beds (CMSB) & Ambient Molecular Sieve Beds (AMSB), respectively



Technology for Separation of Hydrogen Isotopes

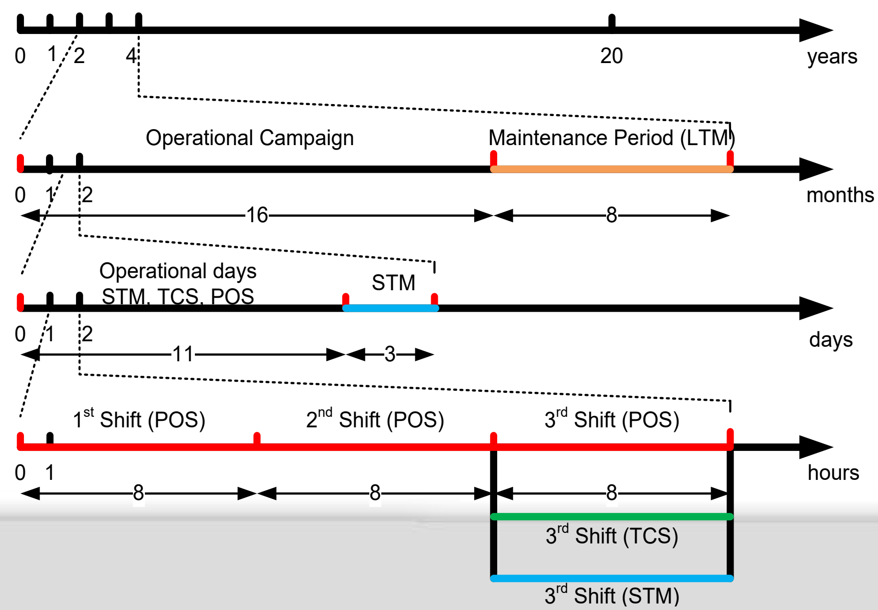
- Main processes adopted for the Tritium Extraction System (TES) of HCCR-TBS
  - During desorption phase regenerated hydrogen isotopes are purified at the diffuser and stored in the getter bed



Objectives of the Study

- **Demonstration of large-scale cryogenic adsorption performance**
  - Cryogenic adsorption is known to be an efficient method to separate low concentration hydrogen isotopes from helium
  - The adsorption characteristic and performance has been investigated by previous studies in small-scale apparatus with adsorbent from several grams to two kilograms
  - The required adsorbent is estimated exceeding several tens of kilograms for the TES of HCCR-TBS, and it will required more for beyond if adopted

- **Investigation on the large-scale CMSB operability**
  - Impact of desorption are explored on operation of tritium circuit in breeding blankets, in particular the TES of HCCR-TBS, with focus on transition between adsorption and desorption phases



Outline

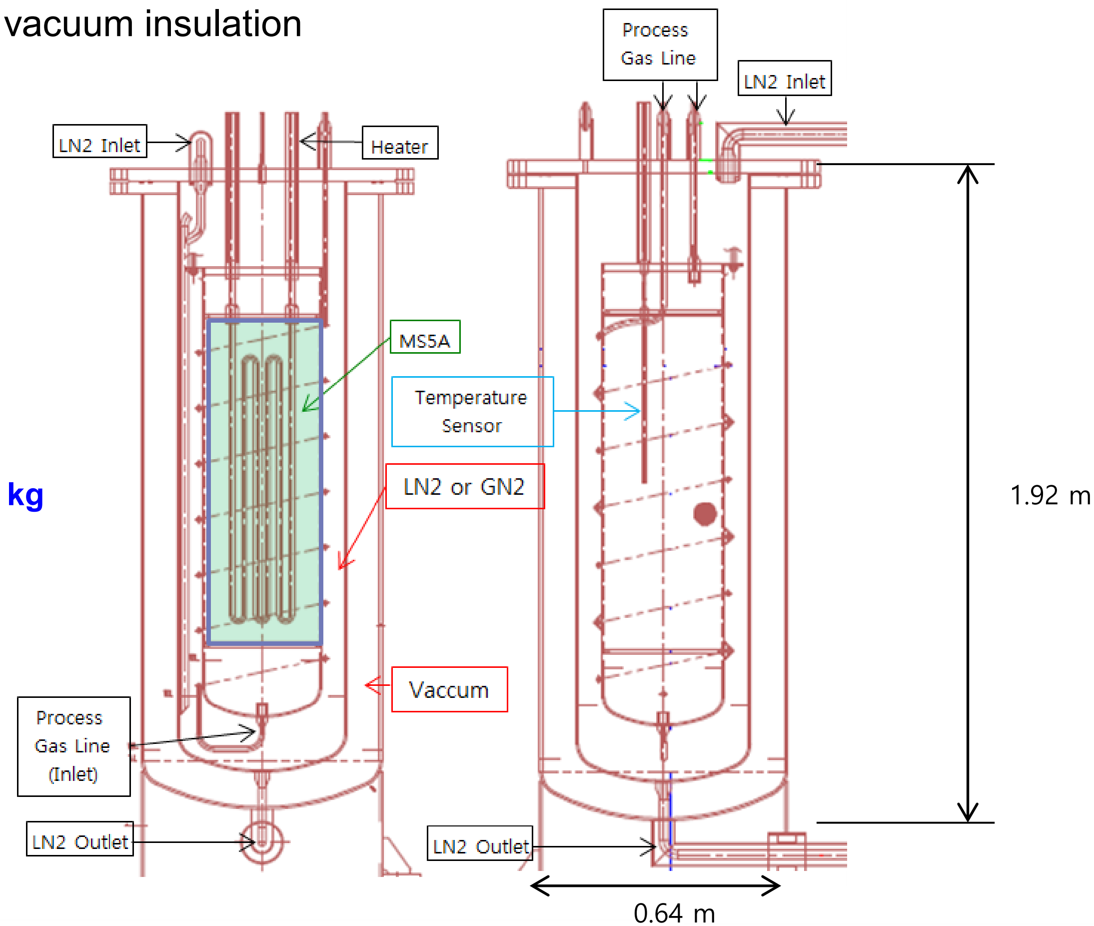
PGLoop

- PGLoop facility is in operation in NFRI
  - Basic tests for unit process, and integral test for adsorption and desorption envisaged for the TES of HCCR-TBS
  - Gas circulation module, gas control module, AMSB module, CMSB module, diffuser & storage module, vacuum module, etc.

CMSB Module

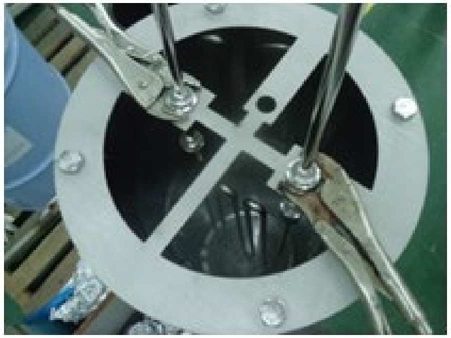
- The experiments for this study were performed using PGLoop CMSB module
  - Large-scale CMSB
    - Inner vessel to contain MS5A
    - Mid vessel for LN2
    - Outer vessel for vacuum insulation

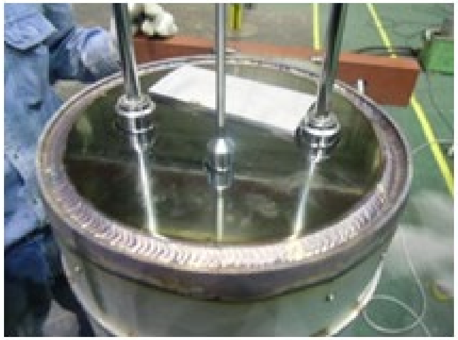
MS5A: ZEOCHEM Z5-01 50.7 kg



CMSB Module

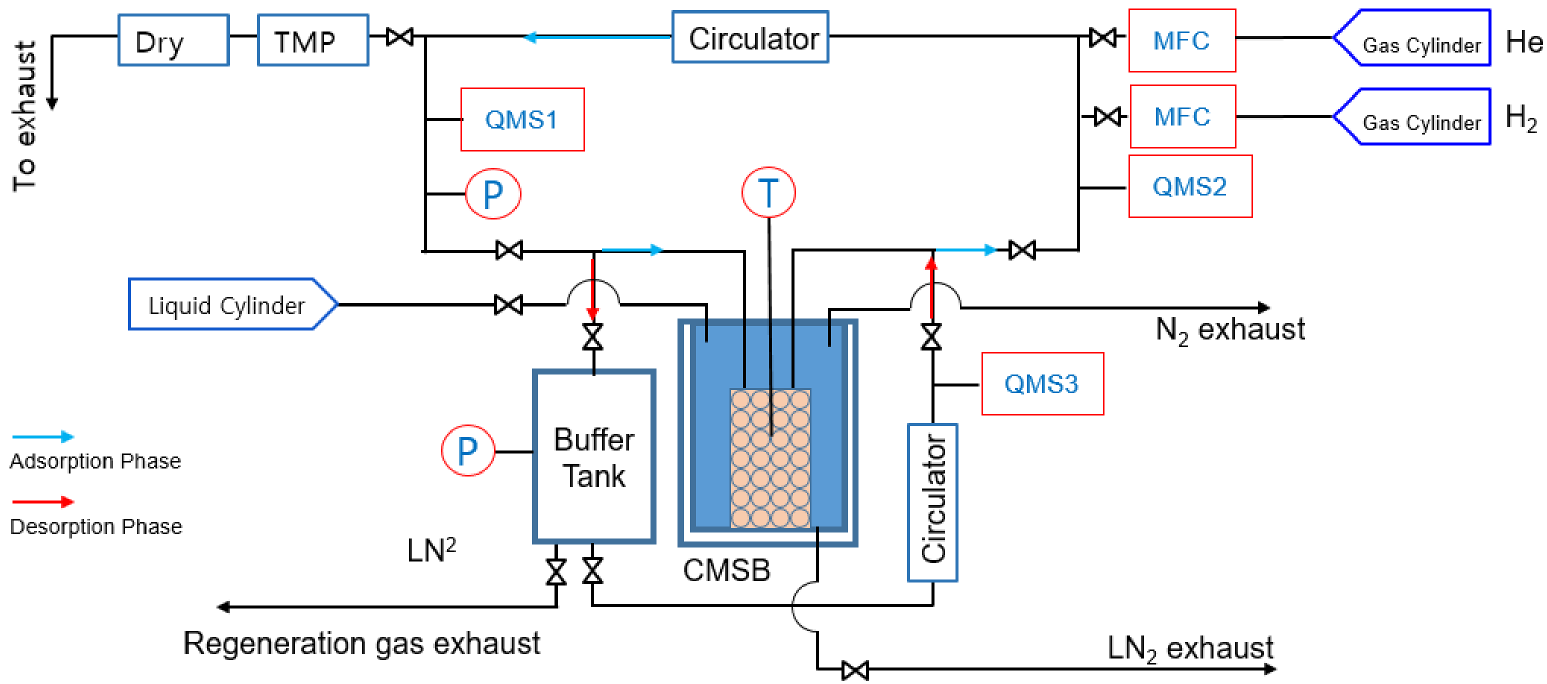
- The experiments for this study were performed using PGLoop CMSB module
  - Large-scale CMSB
    - Inner vessel to contain MS5A
    - Mid vessel for LN2
    - Outer vessel for vacuum insulation





Schematic Diagram

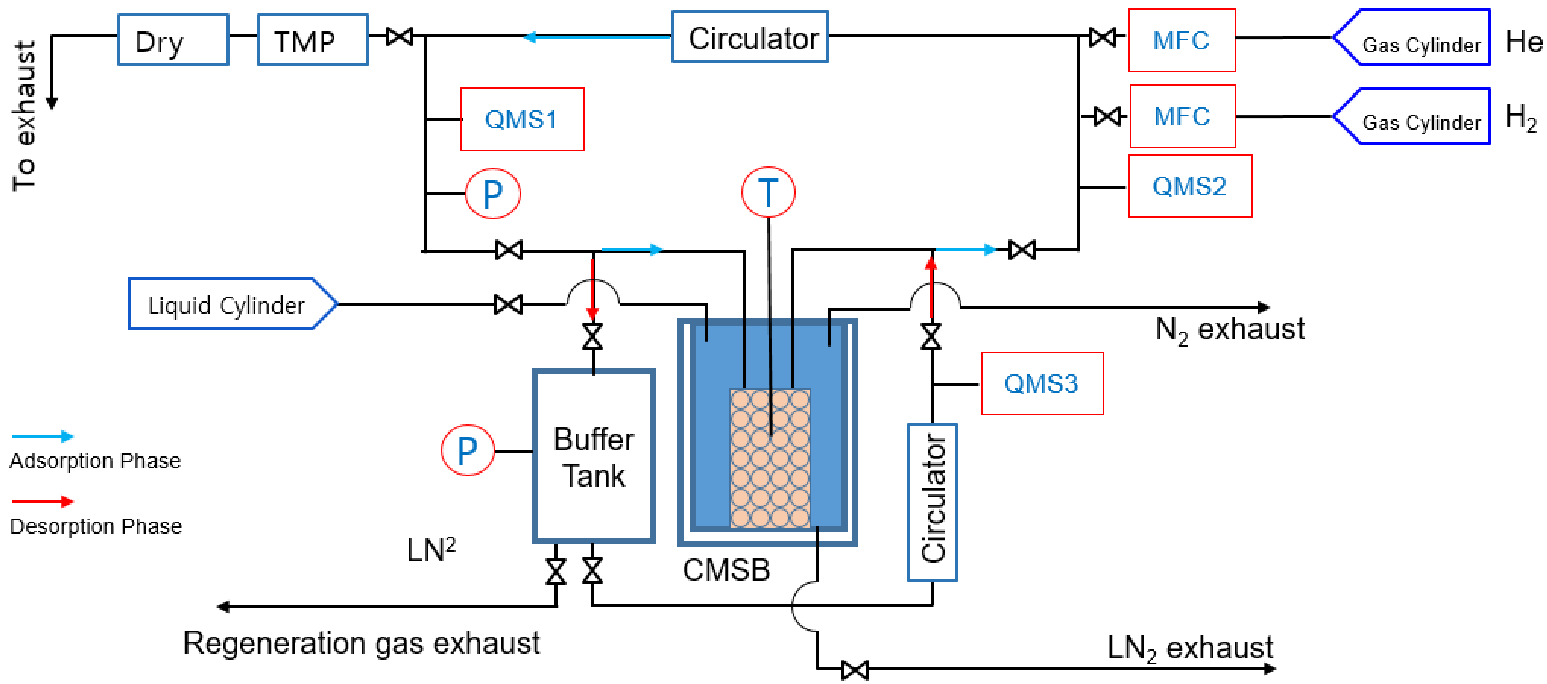
- The experiments for this study were performed using PGLoop CMSB module



- Evacuation of the loop and the CMSB regeneration with helium purging several times
- LN2 supply to the CMSB in order to cool down to 77 K
- Helium gas is circulated at process conditions
- Hydrogen is introduced by controlling mass flow controller set to the purge gas conditions
- H2 concentration measurement at the inlet and outlet of the CMSB using QMS1 & QMS2
- Stop supplying H2 when the breakthrough achieved

Schematic Diagram

- The experiments for this study were performed using PGLoop CMSB module



- The main circulation loop is closed and the desorption loop is opened
- LN2 is evacuated and carrier gas (helium) flows in the desorption loop at process conditions
- H2 concentration measurement at QMS3
- Stop flowing the sweep gas and preparation of the next adsorption

Outline

1. Introduction
2. Experimental Description
3. Results on Hydrogen Adsorption
4. Results on 2 Cycles of Hydrogen Adsorption/Desorption
5. Summary

Experimental Parameters

- The experimental conditions were chosen to include the blanket relevant parameters
  - The purge gas pressure targeted 120 kPa and 160 kPa
  - Hydrogen concentration ranged from 0.1% to 0.6%
  - Flowrates 70 SLPM and 100 SLPM

* Based on QMS2 measurement after the breakthrough

	Parameters				Results	
No.	Pressure at CMSB inlet [kPa]	H2 concentration* [%]	H2 partial pressure	Flowrate [SLPM]	H2 adsorbed [stand. L]	H2 adsorption capacity [mol/g]
1	120	0.090	103	70	382	3.367E-4
2	120	0.120	154	70	497	4.378E-4
3	121	0.248	311	70	747	6.576E-4
4	125	0.602	696	70	1099	9.675E-4
5	155	0.211	310	70	745	6.559E-4
6	159	0.439	636	70	1050	9.244E-4
7	158	0.245	316	100	753	6.629E-4
8	165	0.408	660	100	1100	9.684E-4

S. C. Park et al, Fusion Eng. Des., Vol. 146 (2019), 1863-1867

Effect of Parameters

- The effect of total pressure and flowrates is shown to be negligible for large-scale adsorption, and amount of H_2 adsorbed depends on hydrogen partial pressure as reported by small-scale experiments
- This means that diffusion of hydrogen gas in the purge gas is dominant than convection for the current CMSB design
  - The purge gas speeds for all conditions are sufficiently low
  - Mesh structure located at the bottom of the inner vessel seems to enhance distribution of the flow

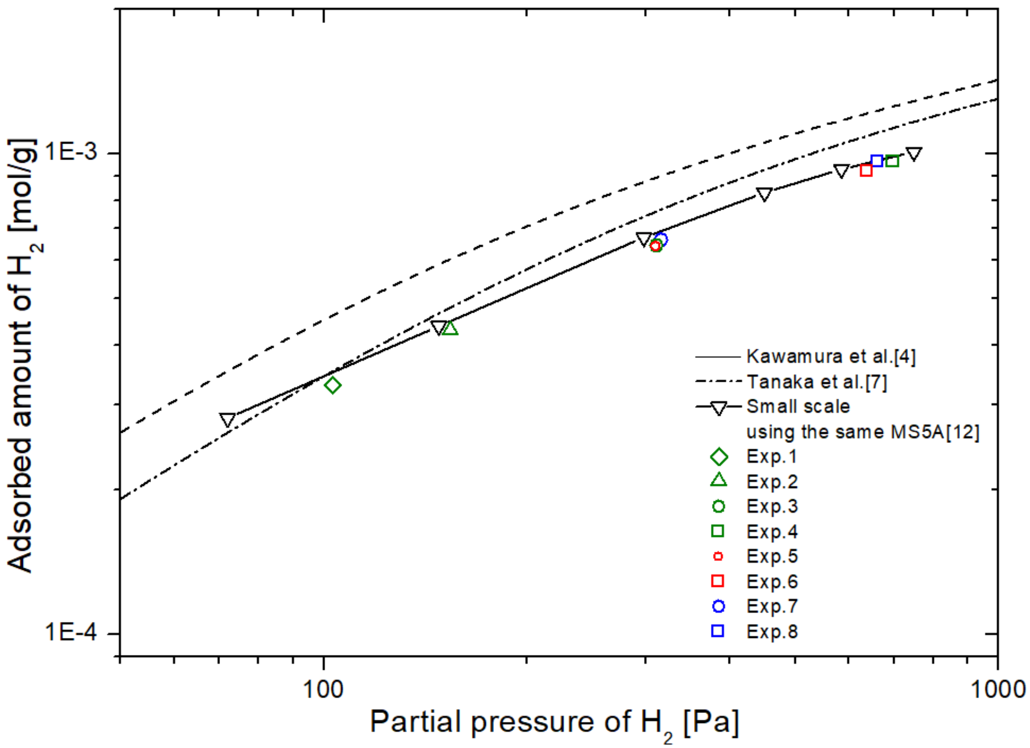
* Based on QMS2 measurement after the breakthrough

	Parameters				Results	
No.	Pressure at CMSB inlet [kPa]	H2 concentration* [%]	H2 partial pressure	Flowrate [SLPM]	H2 adsorbed [stand. L]	H2 adsorption capacity [mol/g]
1	120	0.090	103	70	382	3.367E-4
2	120	0.120	154	70	497	4.378E-4
3	121	0.248	311	70	747	6.576E-4
4	125	0.602	696	70	1099	9.675E-4
5	155	0.211	310	70	745	6.559E-4
6	159	0.439	636	70	1050	9.244E-4
7	158	0.245	316	100	753	6.629E-4
8	165	0.408	660	100	1100	9.684E-4

S. C. Park et al, Fusion Eng. Des., Vol. 146 (2019), 1863-1867

Adsorption Performance

- The adsorption performace of the present study shows on average 74% and 87% compared to small scale experiments [4] and [7]
- However, compared to small scale experiment [12] which used the same MS5A product, the present experiment shows 96% adsorption performance



[4] Kawamura et al., Fusion Technology 37 (2000), 54-61.

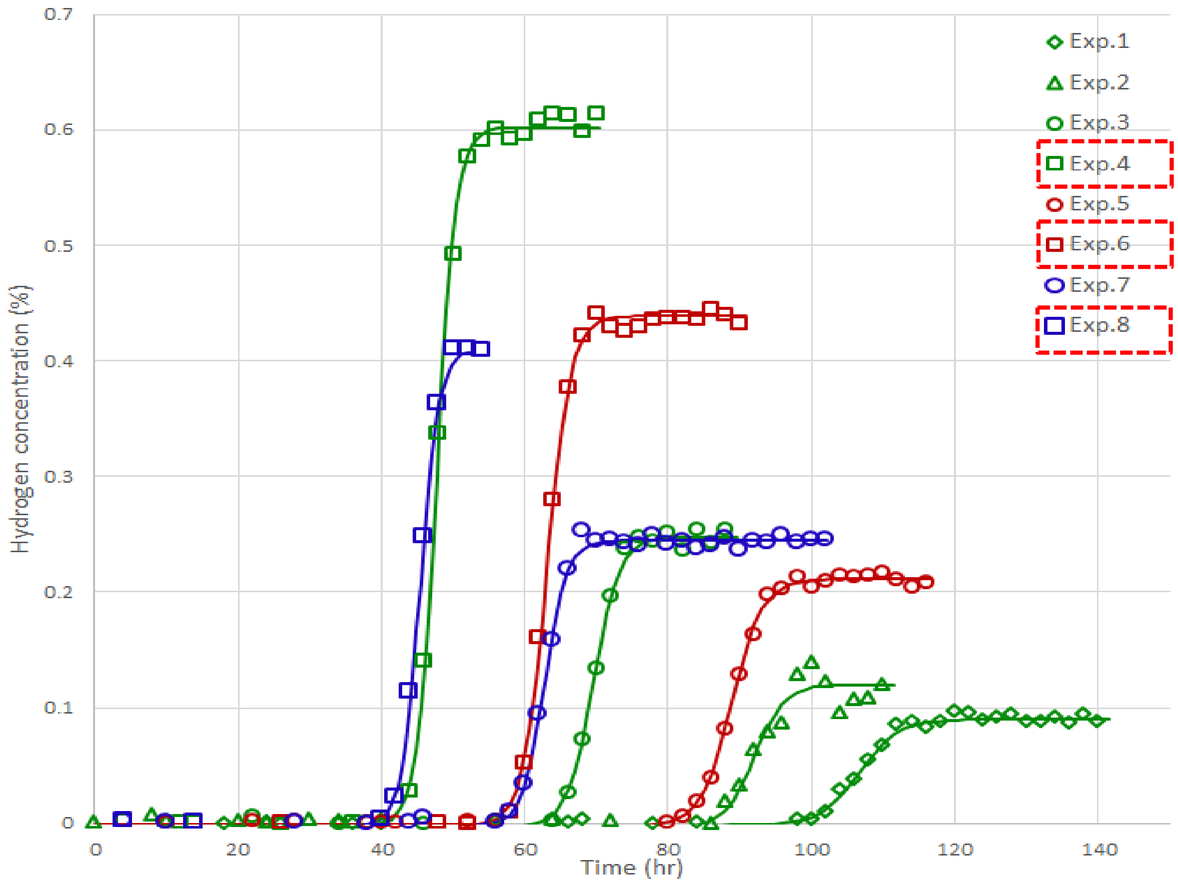
[7] Tanaka et al., Journal of Nuclear Science and Technology 33 (1996), 492-503

[12] Crogenic Research Institute of DAESUNG Industrial Gases Co. Ltd, personal communication

S. C. Park et al, Fusion Eng. Des., Vol. 146 (2019), 1863-1867

Breakthrough Curves

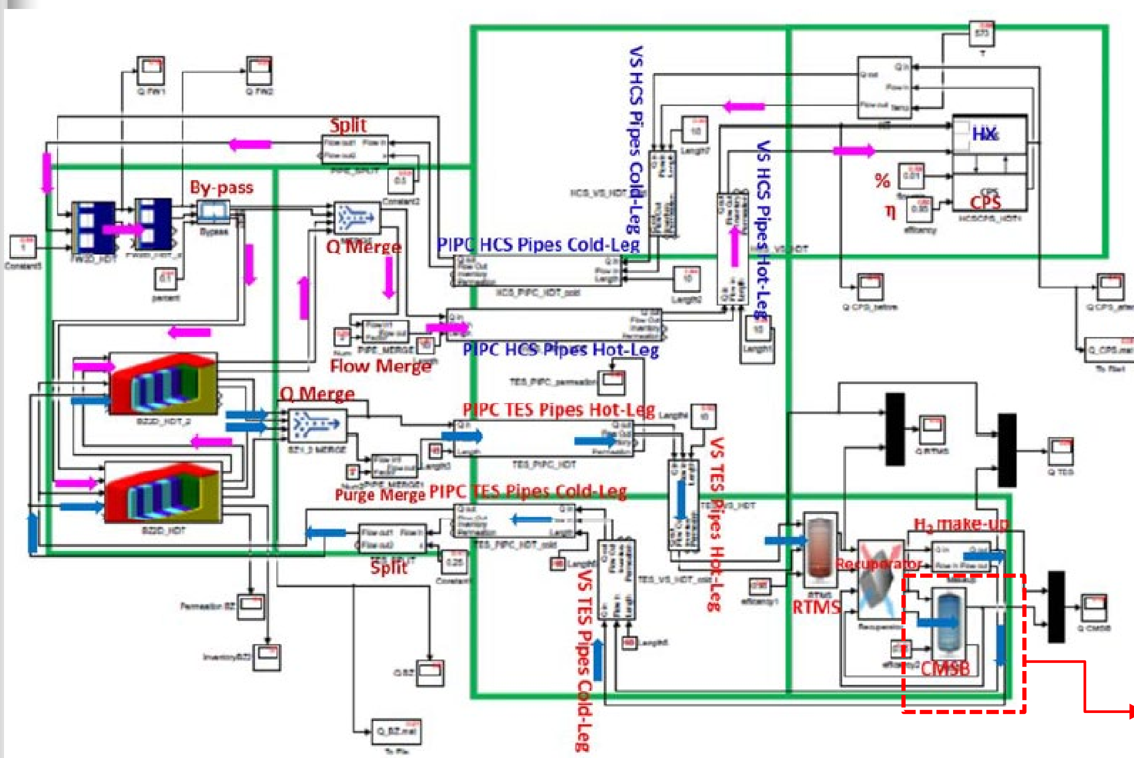
- Relatively fast transition of breakthrough occurs for all cases showing favorable adsorption characteristics of MS5A as reported by literature for small-scale experiments
- Steeper gradients are observed for higher hydrogen flowrates



S. C. Park et al, Fusion Eng. Des., Vol. 146 (2019), 1863-1867

Tool for Computation

- Numerical computation was performed for comparison
  - Dynamic modeling tool which has been developed for predicting tritium retention, removal and permeation for HCCR-TBS under KO-US FNST/blanket collaboration was used



$$u\frac{\partial C_{B,H_2}}{\partial z} + \gamma\frac{\partial q_{A,H_2}}{\partial t} + \varepsilon\frac{\partial C_{B,H_2}}{\partial t} = D_{Z,H_2}\frac{\partial^2 C_{B,H_2}}{\partial z^2}$$

$$\gamma\frac{\partial q_{A,H_2}}{\partial t} = K_{F,H_2} a_v (C_{B,H_2} - C^*_{H_2})$$

In a constant temperature adsorption process, the concentration of the adsorbate in the gas phase in equilibrium with the concentration in the adsorbed phase, C, is expressed in the form of Langmuir equation. For the calculation, Langmuir constants from Tanaka et al. [7] was used*

$$q_{A,H_2} = \frac{a_{1,H_2} P^*_{H_2}}{1 + b_{1,HT} P^*_{HT} + b_{1,H_2} P^*_{H_2}} + \frac{a_{2,H_2} P^*_{H_2}}{1 + b_{2,HT} P^*_{HT} + b_{2,H_2} P^*_{H_2}}$$

For modeling details, refer followings:

A. Ying et al., Fusion Science and Technology 68 (2015), 346-352

A. Ying et al., Fusion Engineering and Technology 109-111 (2016), 1511-1516

A. Ying et al., https://doi.org/10.1016/j.fusengdes.2018.04.093

Comparison to the Computational Result

- Numerical computation was performed for comparison
  - Performance of the experiments is around 90% compared to the computation
  - The difference between experiments and computation can also come from modeling details (ex. Packing fraction of MS5A, temperature distribution, velocity distribution, etc.)

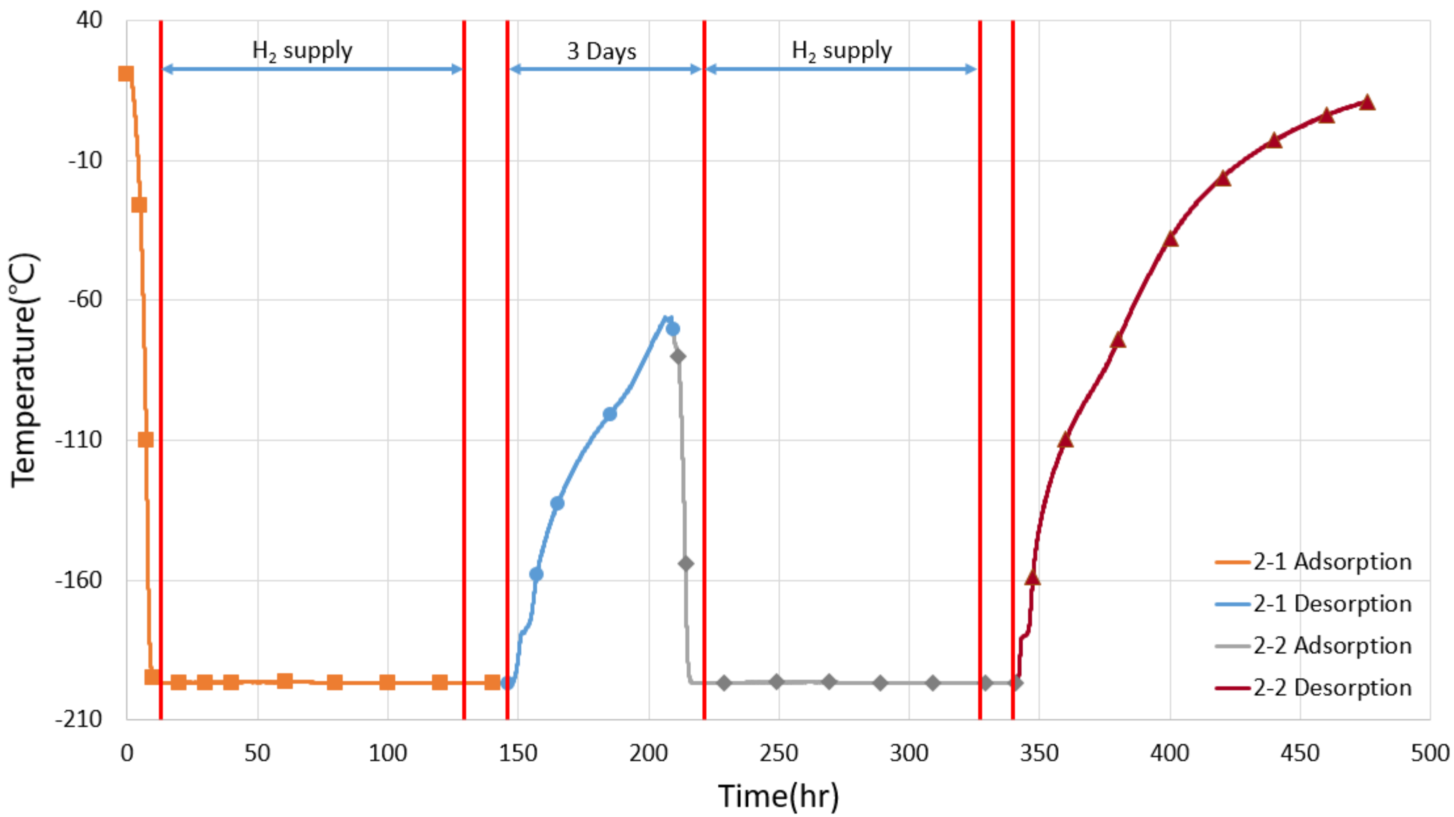
	Parameters				Experiments	Computation	
No.	Pressure at CMSB inlet [kPa]	H2 concentration* [%]	H2 partial pressure	Flowrate [SLPM]	H2 adsorbed [stand. L]	H2 adsorbed [stand. L]	Ratio [%]
1	120	0.090	103	70	382	389	98.1
2	120	0.120	154	70	497	534	93.1
3	121	0.248	311	70	747	847	88.2
4	125	0.602	696	70	1099	1247	88.1
5	155	0.211	310	70	745	847	88.0
6	159	0.439	636	70	1050	1206	87.1
7	158	0.245	316	100	753	834	90.3
8	165	0.408	660	100	1100	1220	90.2

S. C. Park et al, Fusion Eng. Des., Vol. 146 (2019), 1863-1867

Outline

Experimental Scenario

- Hydrogen adsorption and desorption for 2 cycles were carried out
  - Cryogenic adsorption until complete breakthrough
  - In the first cycle, desorption conducted with 20 SLPM flowrate for ~ 2.5 days and preparation of the next adsorption for ~ 0.5 day
  - In the second cycle, desorption conducted with 40 SLPM until room temperature



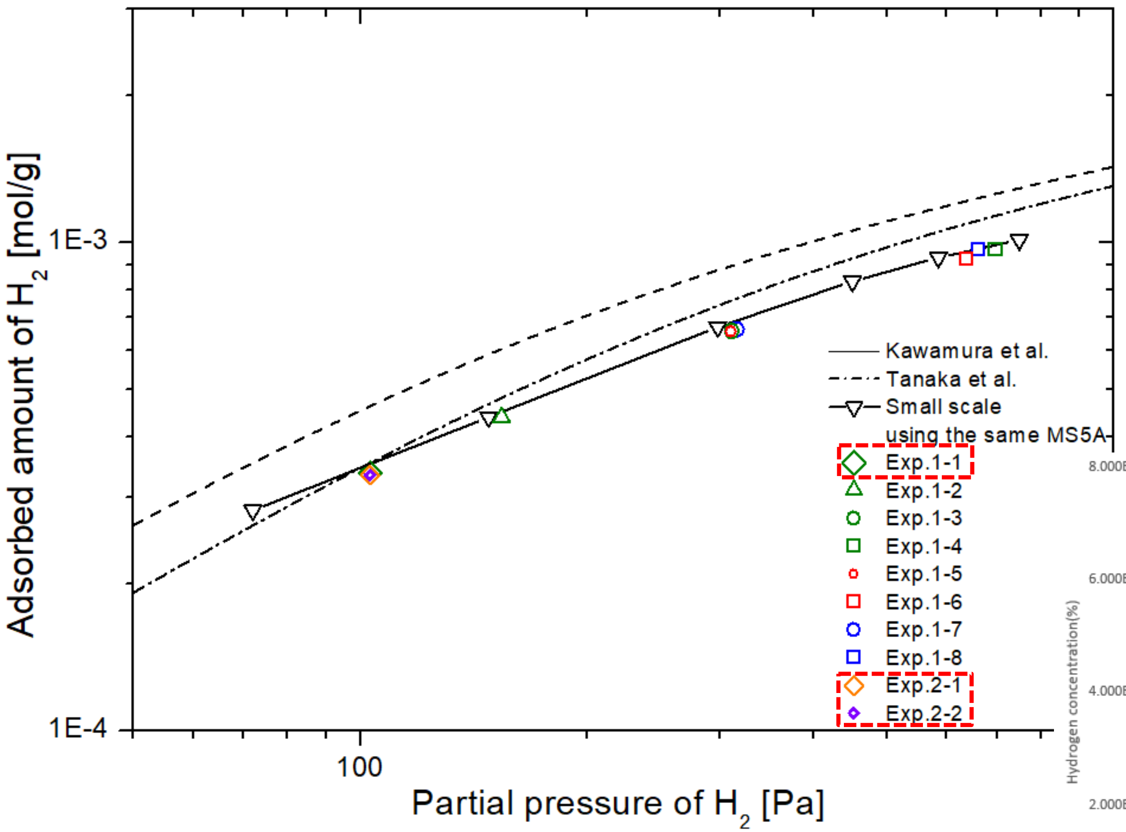
Adsorption Parameters

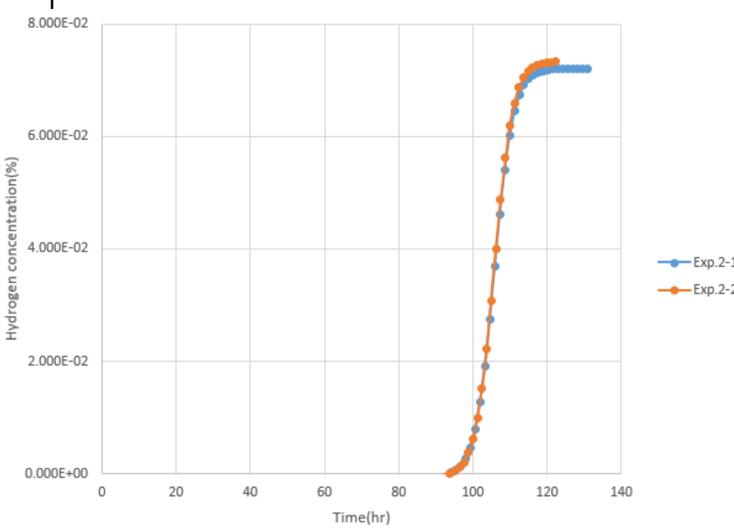
- The adsorption parameters for Exp. 1-1 were chosen

	Parameters				Experiments
No.	Pressure at CMSB inlet [kPa]	H2 concentration* [%]	H2 partial pressure	Flowrate [SLPM]	H2 adsorbed [stand. L]
1	120	0.090	103	70	382
2	120	0.120	154	70	497
3	121	0.248	311	70	747
4	125	0.602	696	70	1099
5	155	0.211	310	70	745
6	159	0.439	636	70	1050
7	158	0.245	316	100	753
8	165	0.408	660	100	1100

Adsorption Results

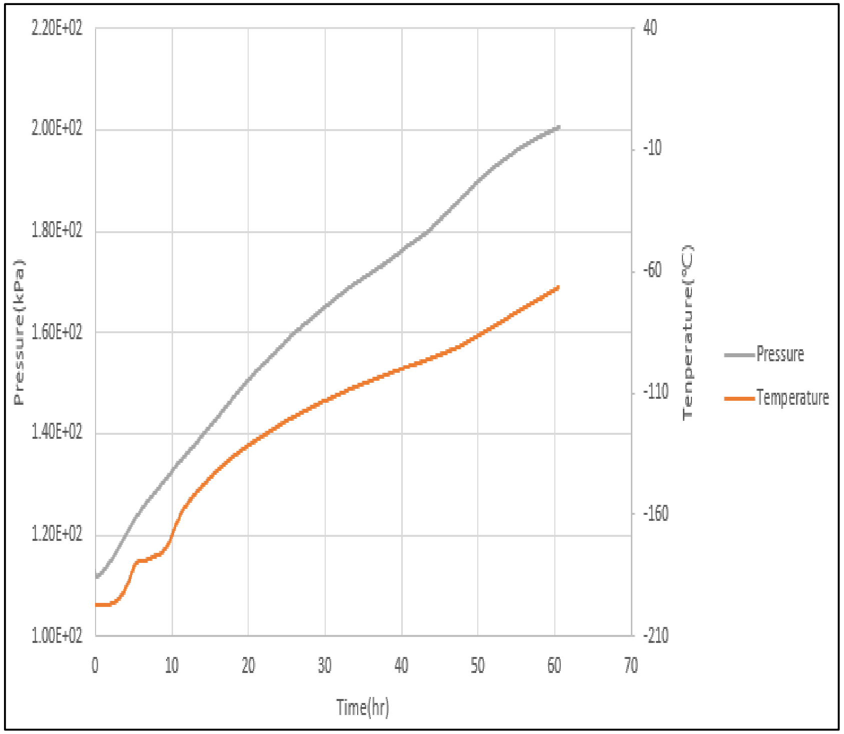
- The adsorption results demonstrate good repetition of the performance
  - It looks like sufficient desorption took placed during 2.5 days desorption after full adsorption of the CMSB

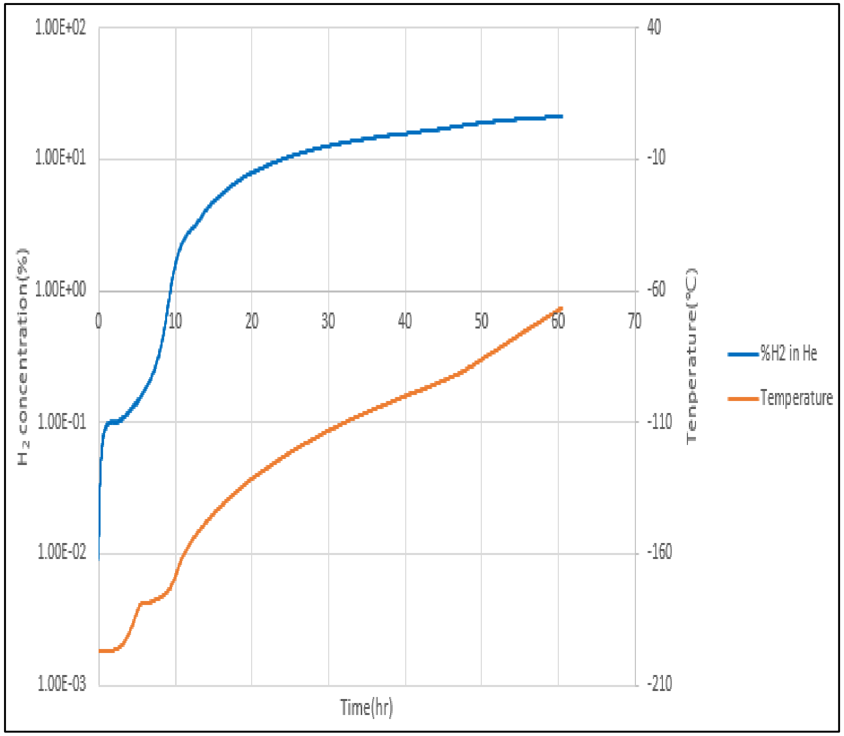




Desorption Results

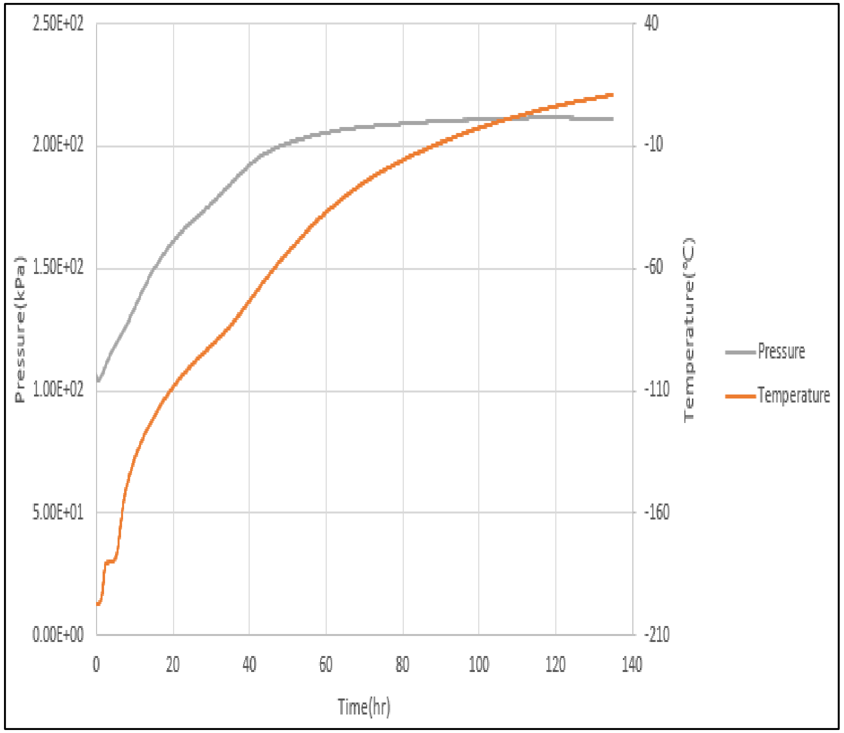
- Desorption performance for the first cycle with 20 SLPM carrier gas

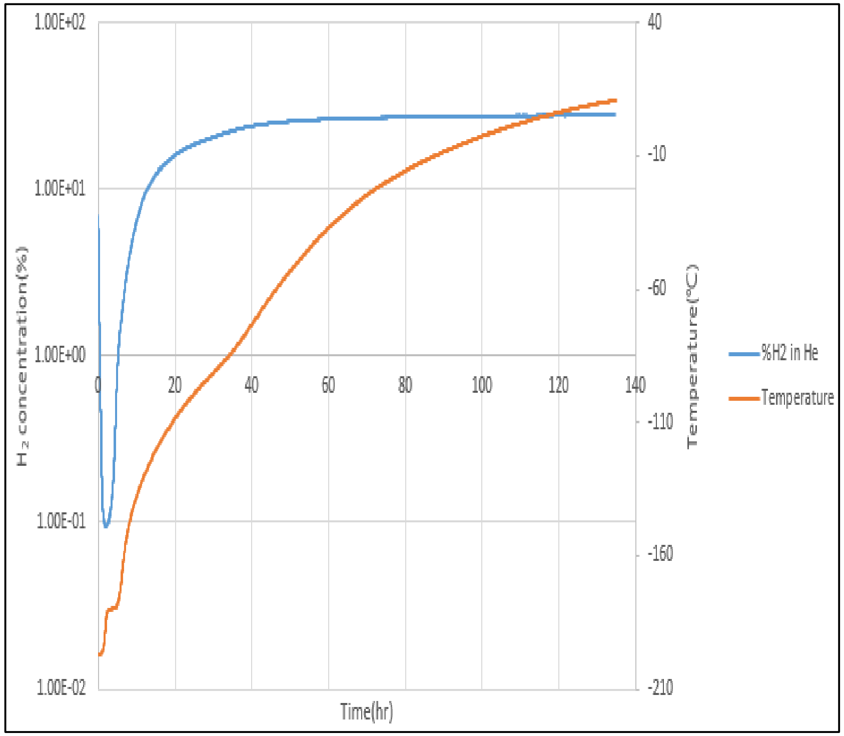




Desorption Results

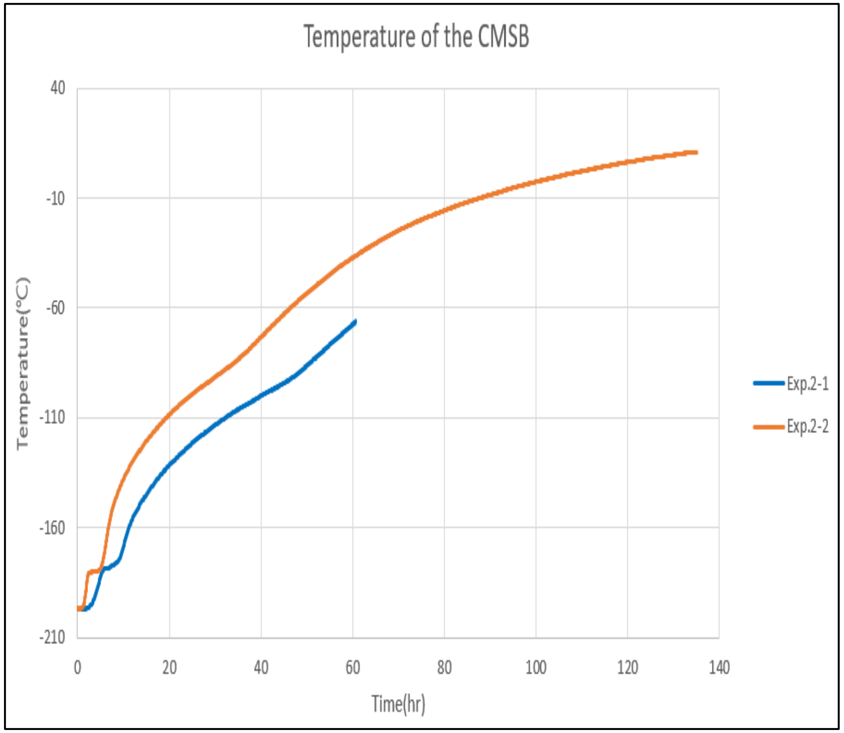
- Desorption performance for the second cycle with 40 SLPM carrier gas

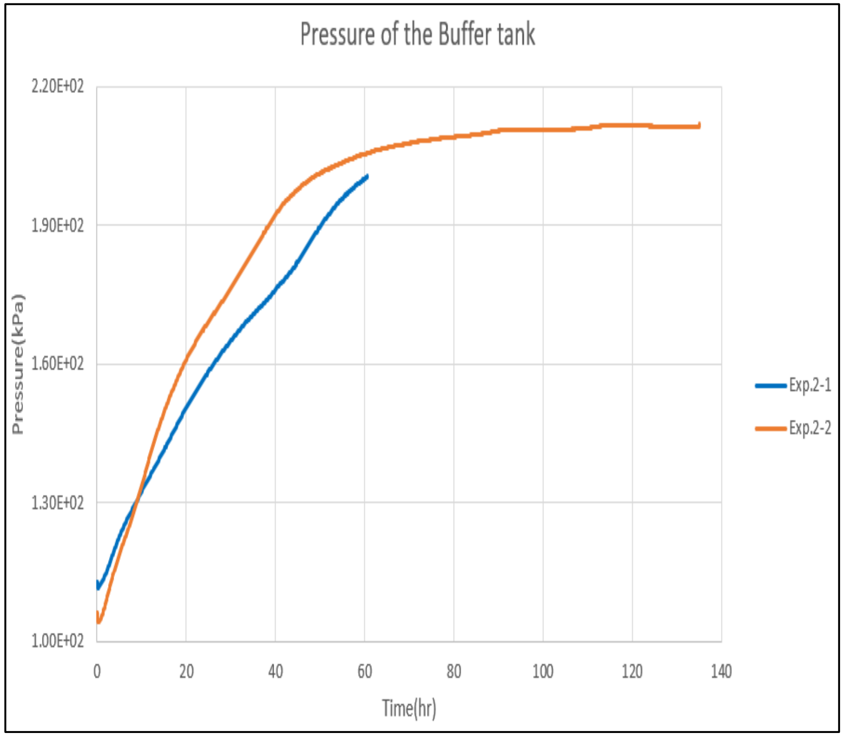




Desorption Results

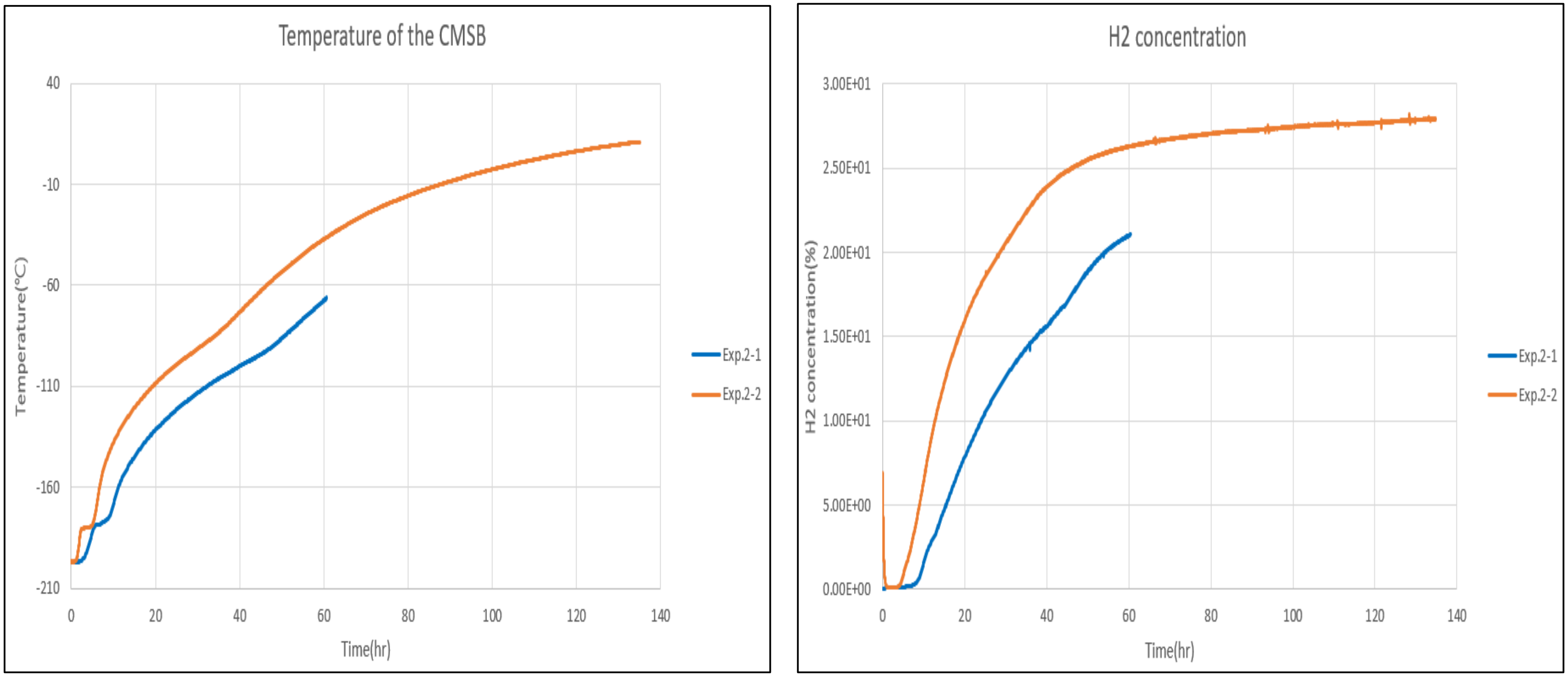
- Comparison between two desorption





Desorption Results

- Comparison between two desorption



Outline

1. Introduction
2. Experimental Description
3. Results on Hydrogen Adsorption
4. Results on 2 Cycles of Hydrogen Adsorption/Desorption
5. Summary

Summary

- Large-scale hydrogen adsorption and desorption experiments were conducted using CMSB module of PGLoop facility
- Adsorption performance of large-scale CMSB comparable to the TBS-relevant scale was demonstrated
  - Size effect on the adsorption is not large for the current CMSB design, and the adsorbed amount depends only on hydrogen partial pressure as reported by small-scale studies
  - Diffusion of hydrogen gas in the purge gas is the dominating factor in CMSB design
- Desorption performance was studied using the CMSB stand-alone testing
  - Although most of hydrogen seems to be desorbed by 2.5 days, time to reach full desorption is likely to require more than 2.5 days for the current CMSB design
  - Further study is required to establish operational parameters and scenarios for desorption
- In future, it is expected that desorption performance and switching to adsorption will be investigated in conjunction with the diffuser module

Thank you for your attention!