Experimental and Analytical Results on H_2SO_4 and SO_3 Decomposer for IS Process Pilot Plant

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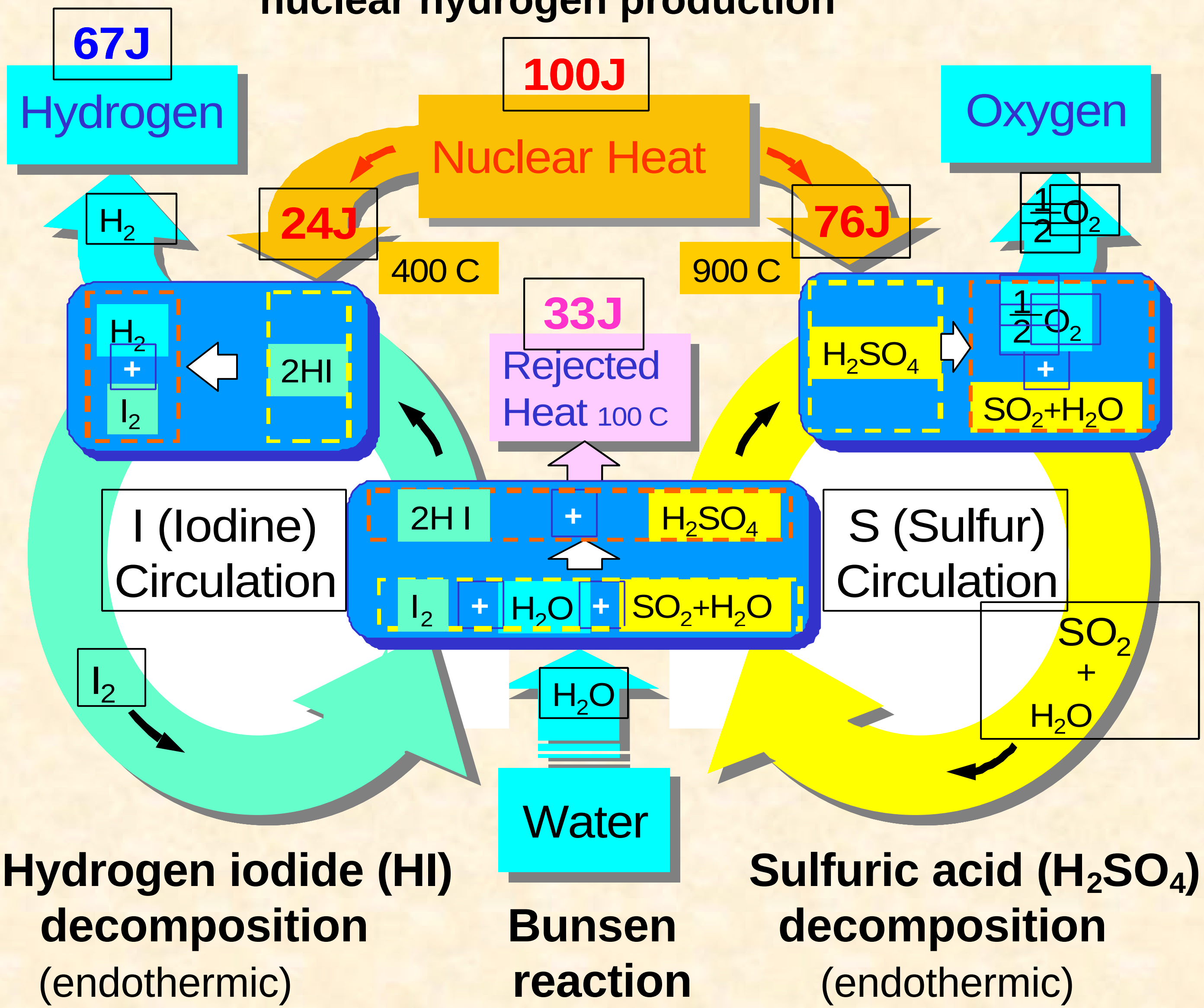
Thermochemical Iodine-Sulfur (IS) Process

developing IS process aiming to realize nuclear hydrogen production



IS Process

- ***H_2 is produced by thermal decomposition of HI at ca. 400℃, and O_2 is produced by thermal decomposition of H_2SO_4 below 900℃. (Pyrolysis of water; Heat more than 4000℃)***
- ***Iodine and sulfur compounds are used as recycling materials under thermochemical close cycle***

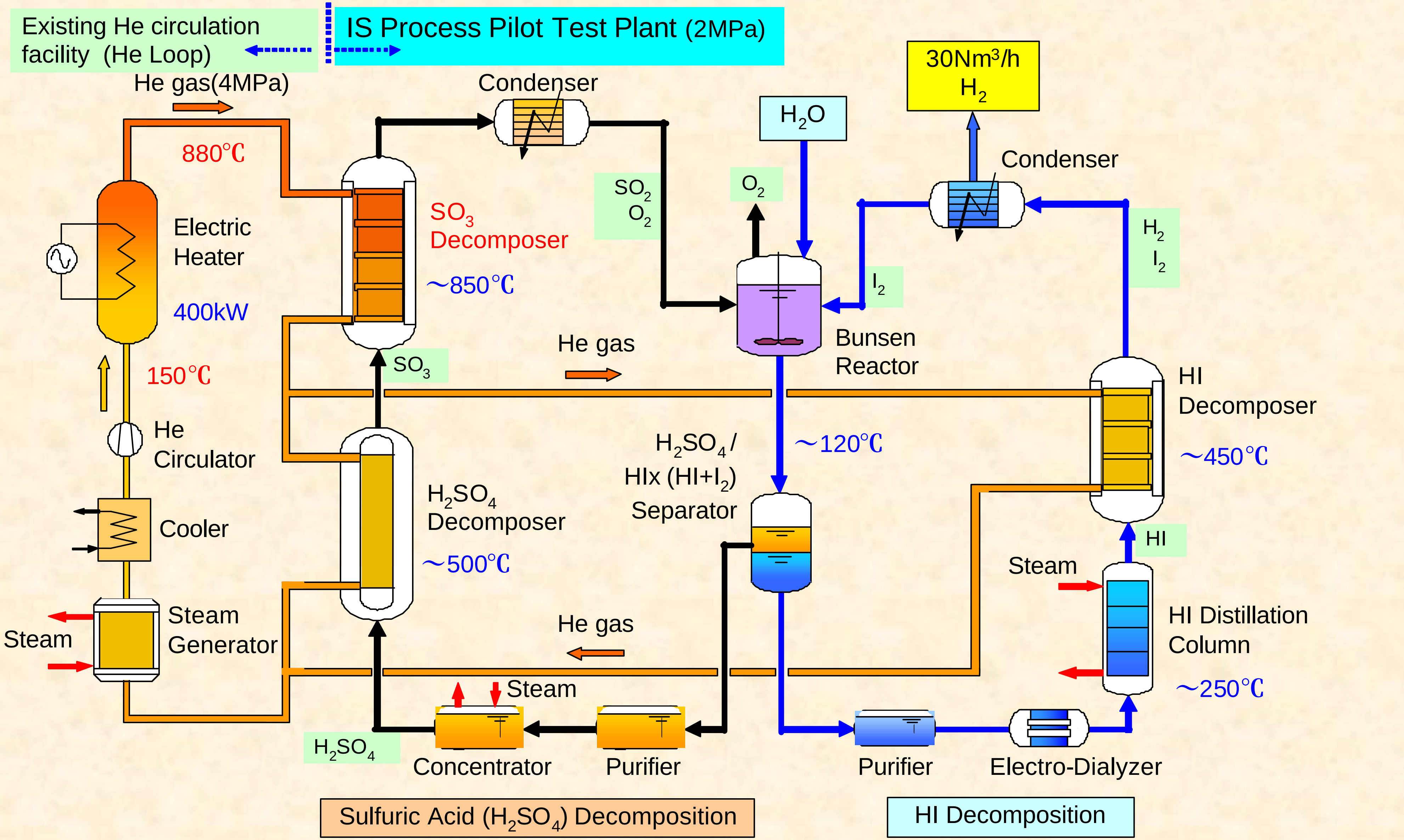
Next Step : Pilot Test (JAERI's Plan)

On the basis of the hydrogen production test results and know-how obtained with the bench-scale test apparatus and other R&Ds

	Bench-scaled Test	**Pilot Test**	HTTR Test nuclear demonstration
Hydrogen production rate	～ 0.03 m^3/h	～30 m^3/h	～1000 m^3/h
Heat supply	Electrical heater	Heat exchanger with helium gas (Electrical heater 0.4MW)	Heat exchanger with helium gas (Nuclear heat 10MW)
Material of chemical reactors	Glass	Industrial material (SiC, coated)	Industrial material
Pressure of chemical process	Atmospheric pressure	High pressure (up to 2MPa)	High pressure (up to 2MPa)
Time	FY 1999 - 2004	FY **2005** – 2010 (under planning)	FY 2009 – 2014 (under planning)

To confirm continuous hydrogen production under simulated HTGR operations and fabricability of components, and to establish technology base for realizing high thermal efficiency more than 40%.

Flow Diagram of IS Process Pilot Plant (tentative)

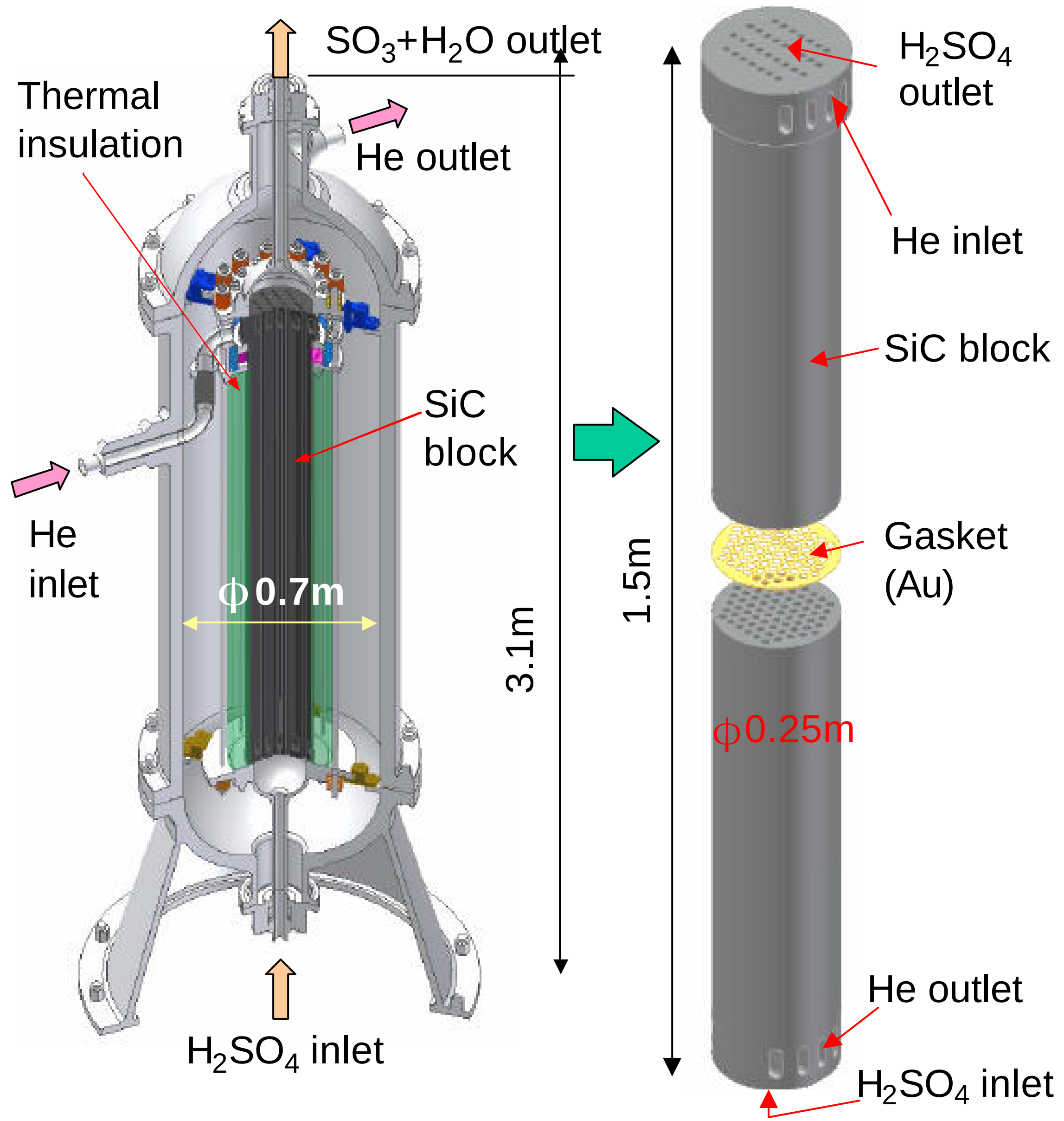


Conceptual design (system, components) : taking into account of effective heat recovery including efficient HI concentration by using electro-dialysis, so as to increase system efficiency.

Concept of H_2SO_4 Decomposer for Pilot Test Plant

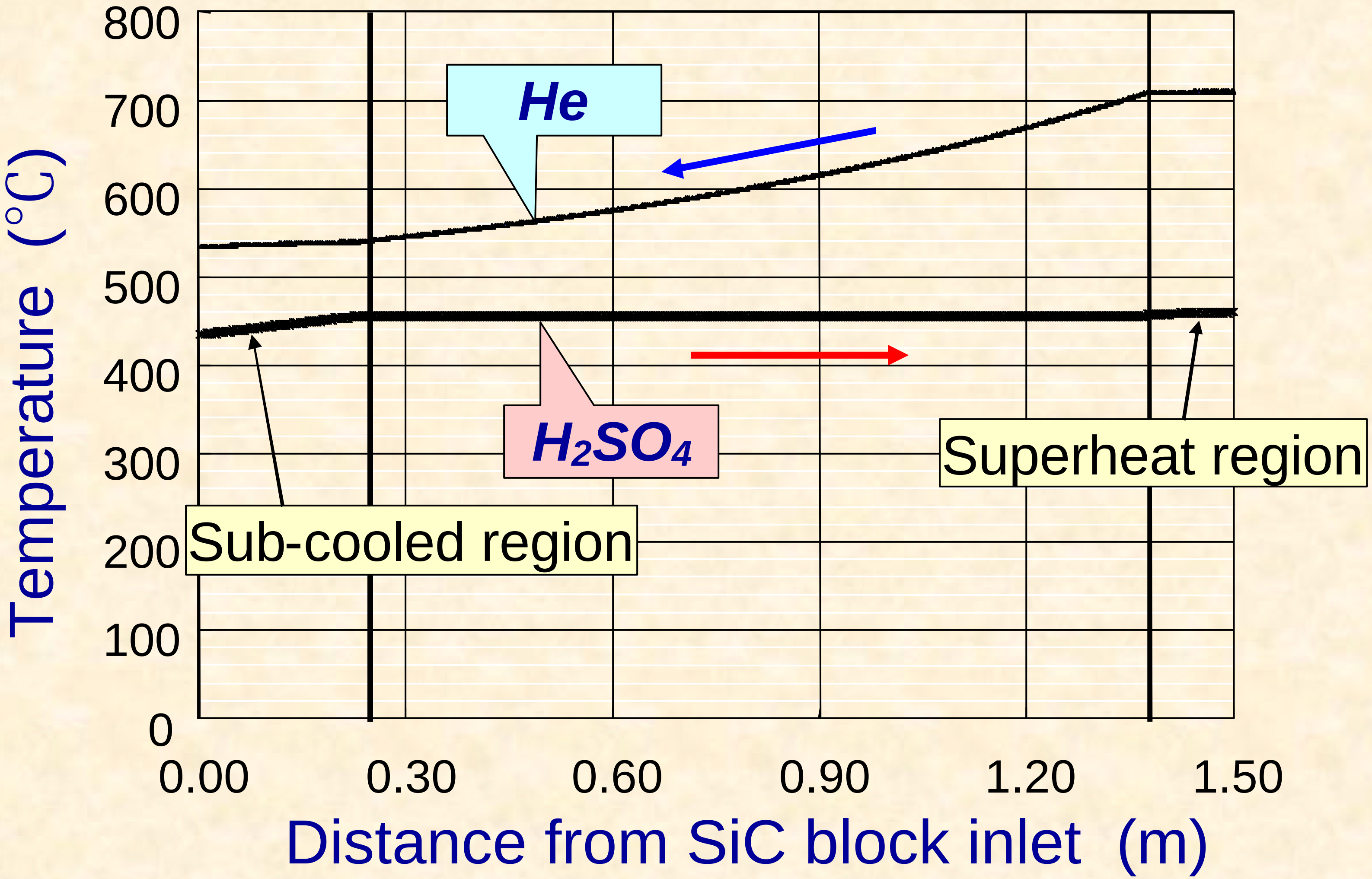
The concept of the H_2SO_4 decomposer is a counter-flow type heat-exchanger made of SiC, which works as an H_2SO_4 evaporator.

Items	Conditions
Thermal Rating	82.7 kW
He Inlet / Outlet Temp.	710 / 535 ℃
Process Inlet / Outlet Temp.	435 / 460 ℃
He Pressure	4 MPaG
Process Pressure	2 MPaG
He Flow Rate	0.091 kg/s
Process Flow Rate	0.066 kg/s



Ref) H. Ota et al., 13th Int. Conf. Nuclear Engineering (ICONE13), Beijing, China, May 16-20, 2005, ICONE13-50494
H. Ota et al., 2005 Ibaraki Meeting of the Japan Society of Mechanical Engineers, Hitachi-taga, Ibaraki, Japan, September 9, 2005.

Structure Analysis of H_2SO_4 Decomposer (1/2)

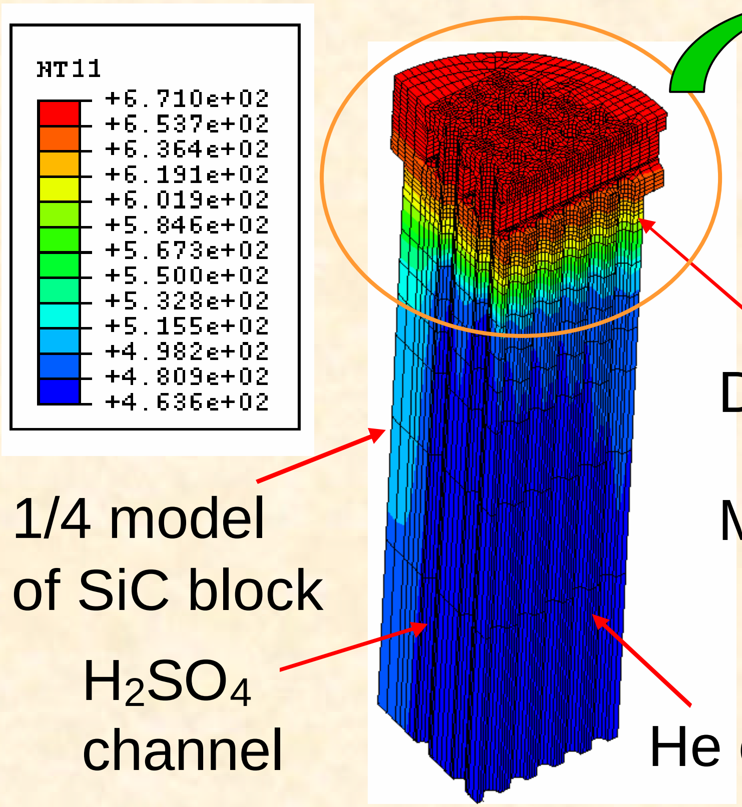


Axial Temperature Distribution

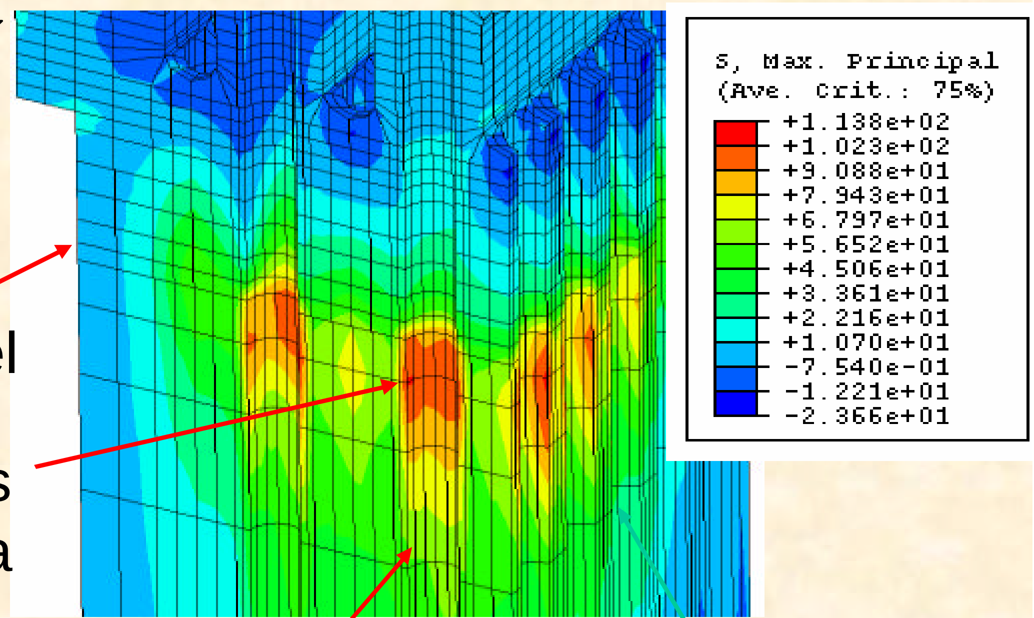
Ref) H. Ota et al., 13th Int. Conf. Nuclear Engineering (ICONE13), Beijing, China, May 16-20, 2005, ICONE13-50494

Structure Analysis of H_2SO_4 Decomposer (2/2)

- **Heat Transfer and Stress Analysis of SiC Block**
  - Max. ΔT=250℃ and ΔP=2MPa ： Max. stress=114MPa
  - Average tensile strength of SiC = 250 MPa



Temperature distribution



Stress distribution
(thermal stress + static stress)

Test Fabricated SiC Block Assembly - Mock-up Model-

Upper SiC block
(ϕ0.25×0.75 m)

We confirmed fabricability of the SiC block assembly.

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H. Ota et al., 2005 Ibaraki Meeting of the Japan Society of Mechanical Engineers, Hitachi-taga, Ibaraki, Japan, September 9, 2005.

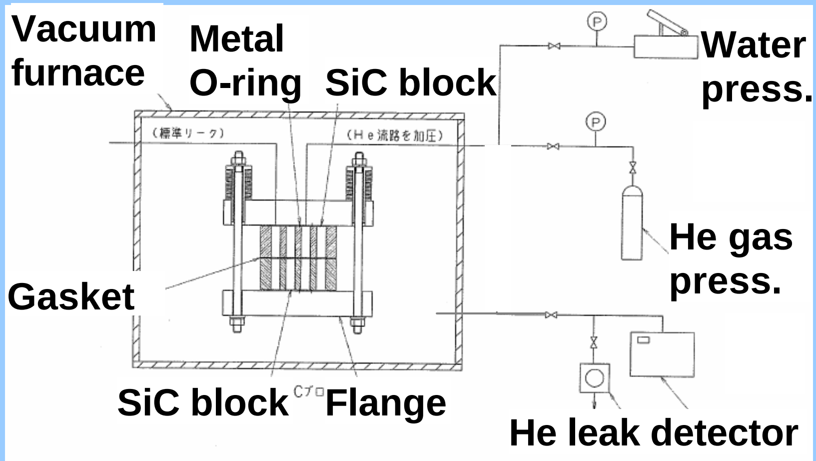
Seal Performance Test with Mock-up Model of H_2SO_4 Decomposer

- Objectives

To confirm applicability of a gold seal for boundary between sulfuric acid (liq. or gas) and helium

- Test method

Seal performance test

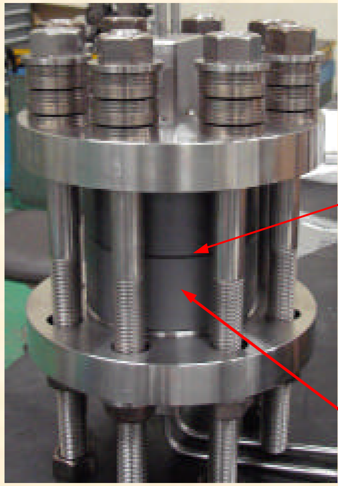


Test condition：

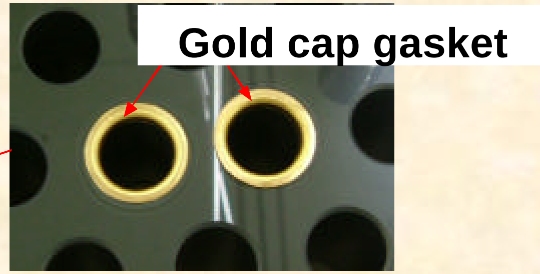
3 heat cycle up to 500℃

Outer press. :Vacuum

Inner press. :4MPa



Leak test model



Attachment of gold cap gaskets (19mmφ)

SiC block (120mmφ 50mmt)

- Test results

Helium leak rate was 7.5×10^{-8} Pa･m^3/s at the connection of SiC blocks, which was much less than the LWR rubber seal standard of 1×10^{-4} Pa･m^3/s.

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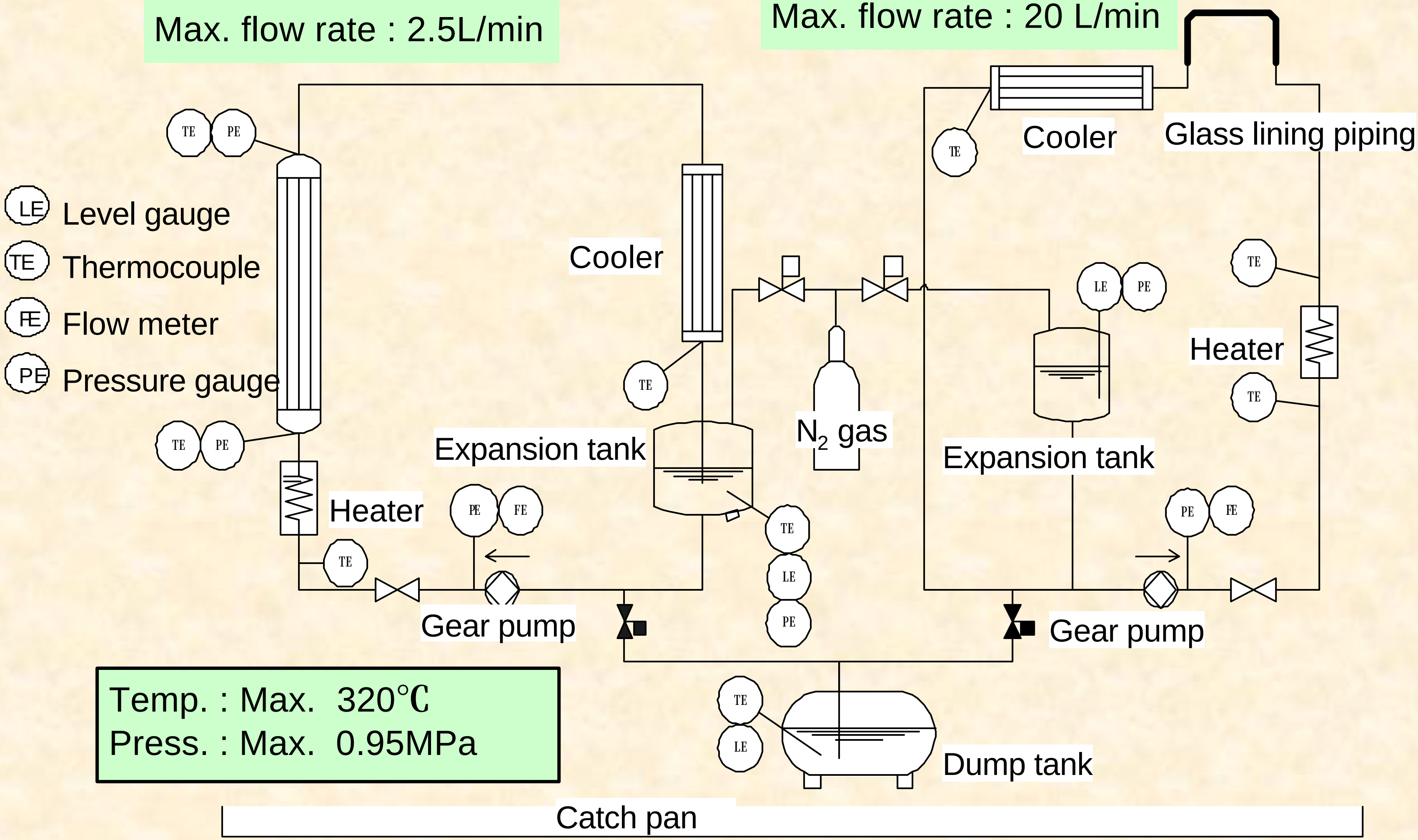
H_2SO_4 Thermal-Hydraulic Test Loop

Boiling heat transfer test loop
(Heat transfer measurements and flow-visualization)

Component test loop
(Performance & integrity of H_2SO_4 components)

Max. flow rate : 2.5L/min

Max. flow rate : 20 L/min



Temp. : Max. 320℃
Press. : Max. 0.95MPa

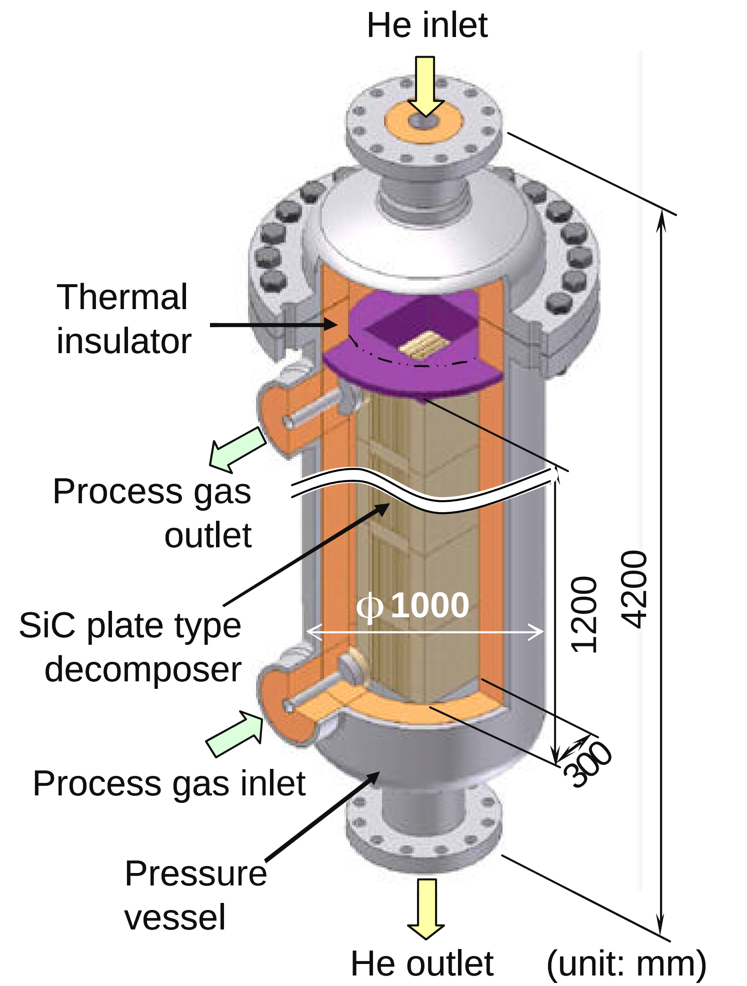
Ref) H. Ota et al., 2005 Ibaraki Meeting of the Japan Society of Mechanical Engineers, Hitachi-taga, Ibaraki, Japan, September 9, 2005.

Outer View of H_2SO_4 Thermal-Hydraulic Test Loop

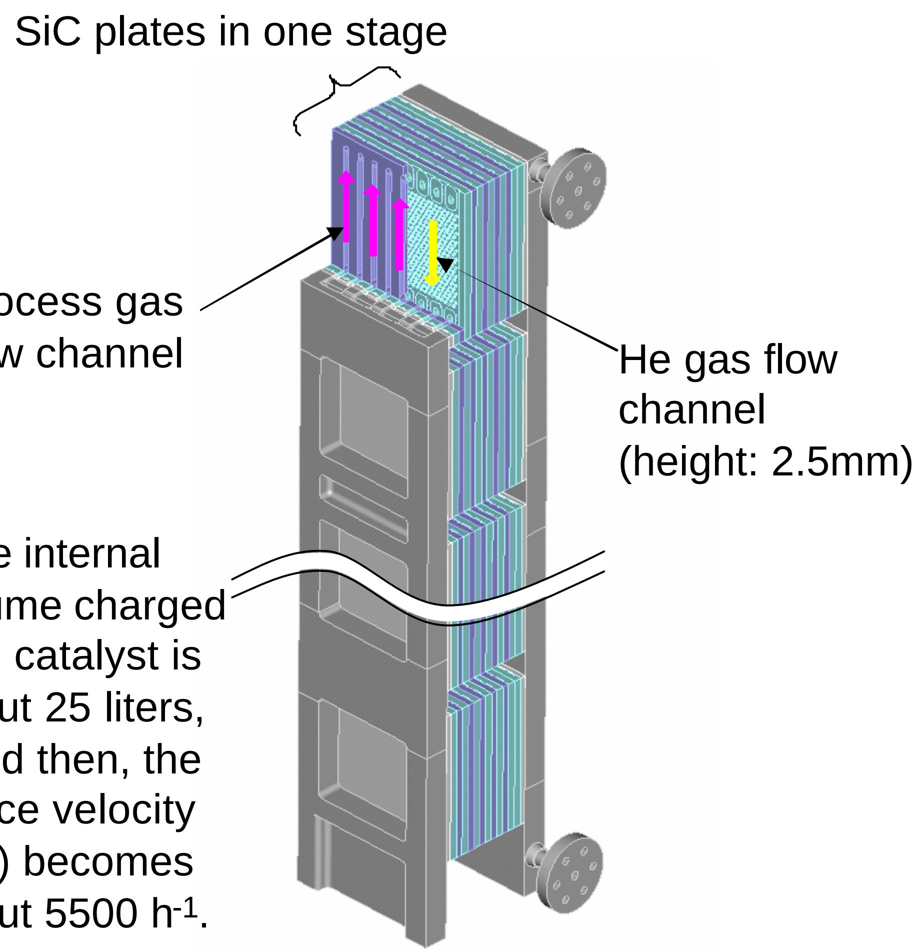
Ref) H. Ota et al., 2005 Ibaraki Meeting of the Japan Society of Mechanical Engineers, Hitachi-taga, Ibaraki, Japan, September 9, 2005.

Concept of SO_3 Decomposer - counter flow type heat exchanger -

H_2SO_4 evaporates, and some amount of H_2SO_4 vapor is decomposed into SO_3 gas and water vapor by high temperature heat supplied from the existing helium gas loop.



Concept of the SiC plate type SO_3 decomposer for pilot test plant



- the internal volume charged with catalyst is about 25 liters,
- and then, the space velocity (SV) becomes about 5500 h^{-1}.

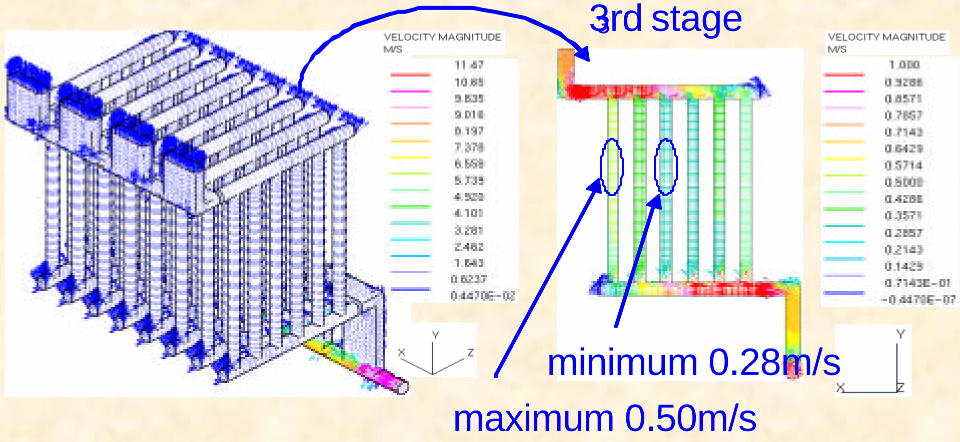
Structure of the SO_3 decomposer unit

(composed of 6 plate-type heat exchangers connected in series)

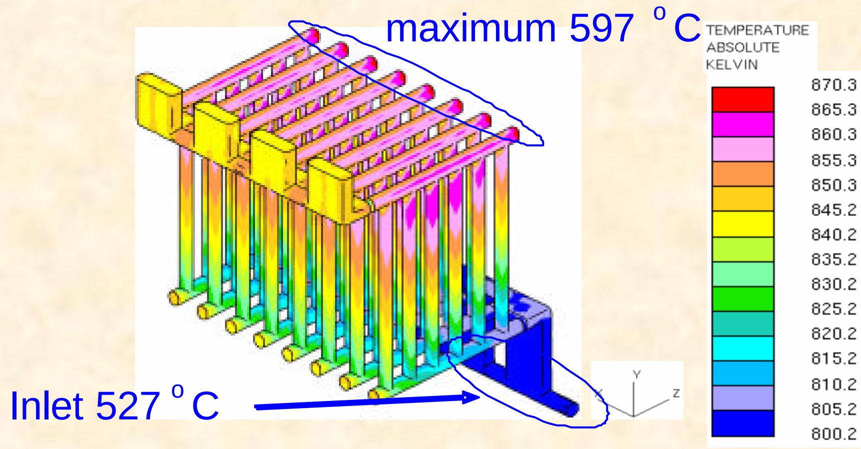
Ref) A. Kanagawa et al., 13th Int. Conf. Nuclear Engineering (ICONE13), Beijing, China, May 16-20, 2005, ICONE13-50451

Thermal-Hydraulic Analytical Results

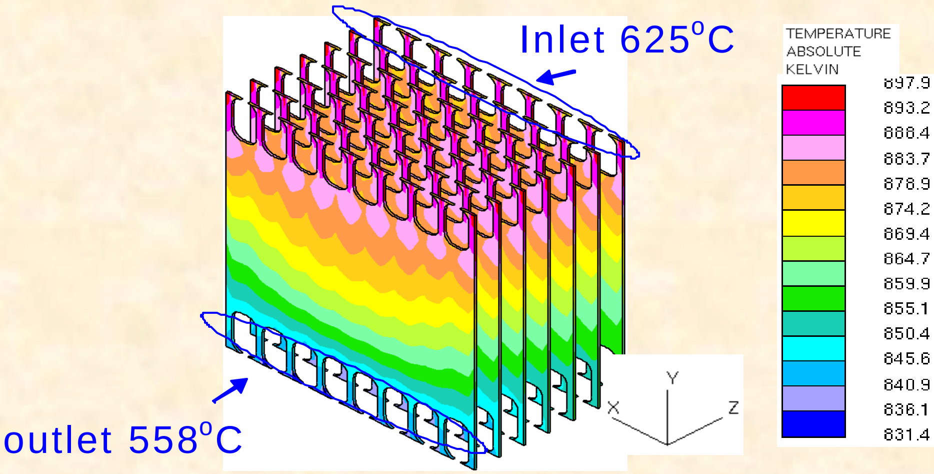
- middle stage of the decomposer -



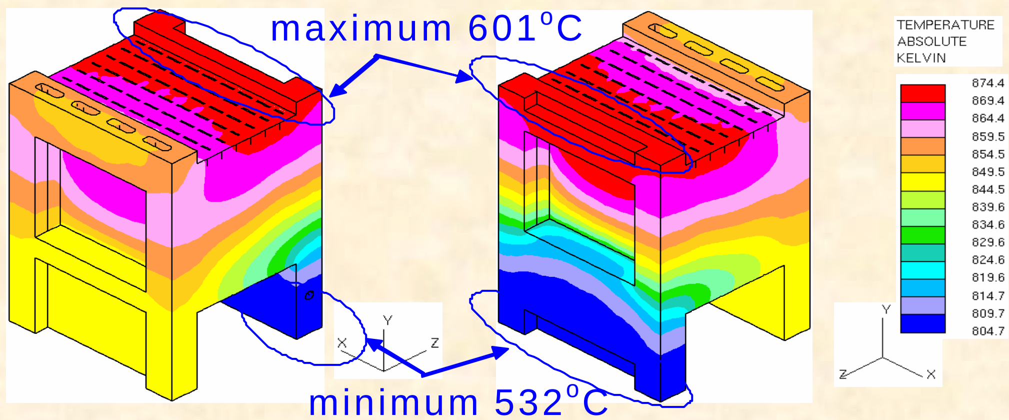
SO_3 gas flow velocity distribution



Temperature distribution in SO_3 flow path



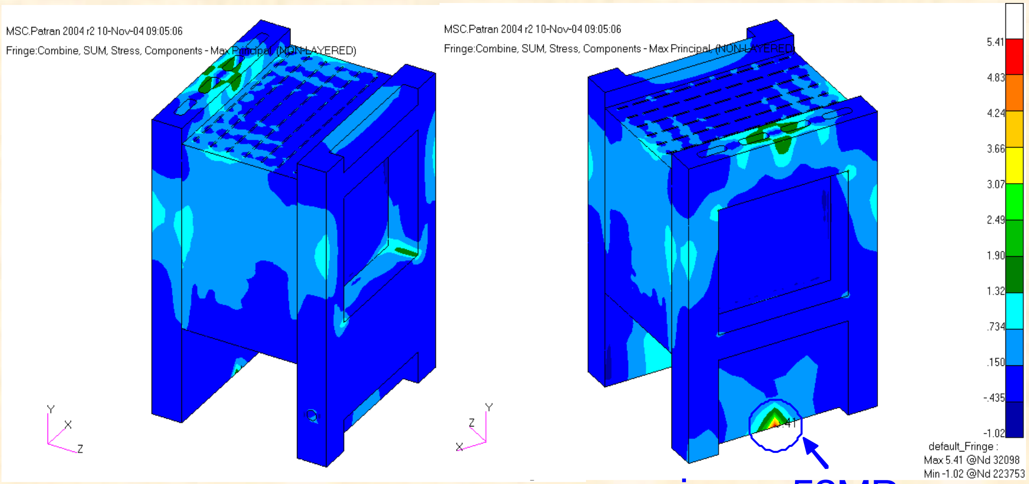
Temperature distribution in He flow path



Temperature distribution in solid unit

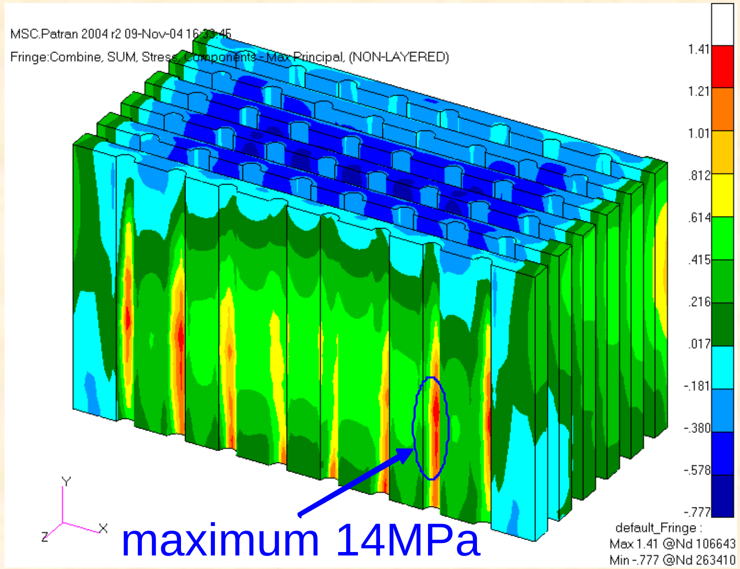
Ref) A. Kanagawa et al., 13th Int. Conf. Nuclear Engineering (ICONE13), Beijing, China, May 16-20, 2005, ICONE13-50451

Structure Analysis of SO_3 Decomposer



Contour in 1st stage

Stress distributions
(thermal stress + static stress)



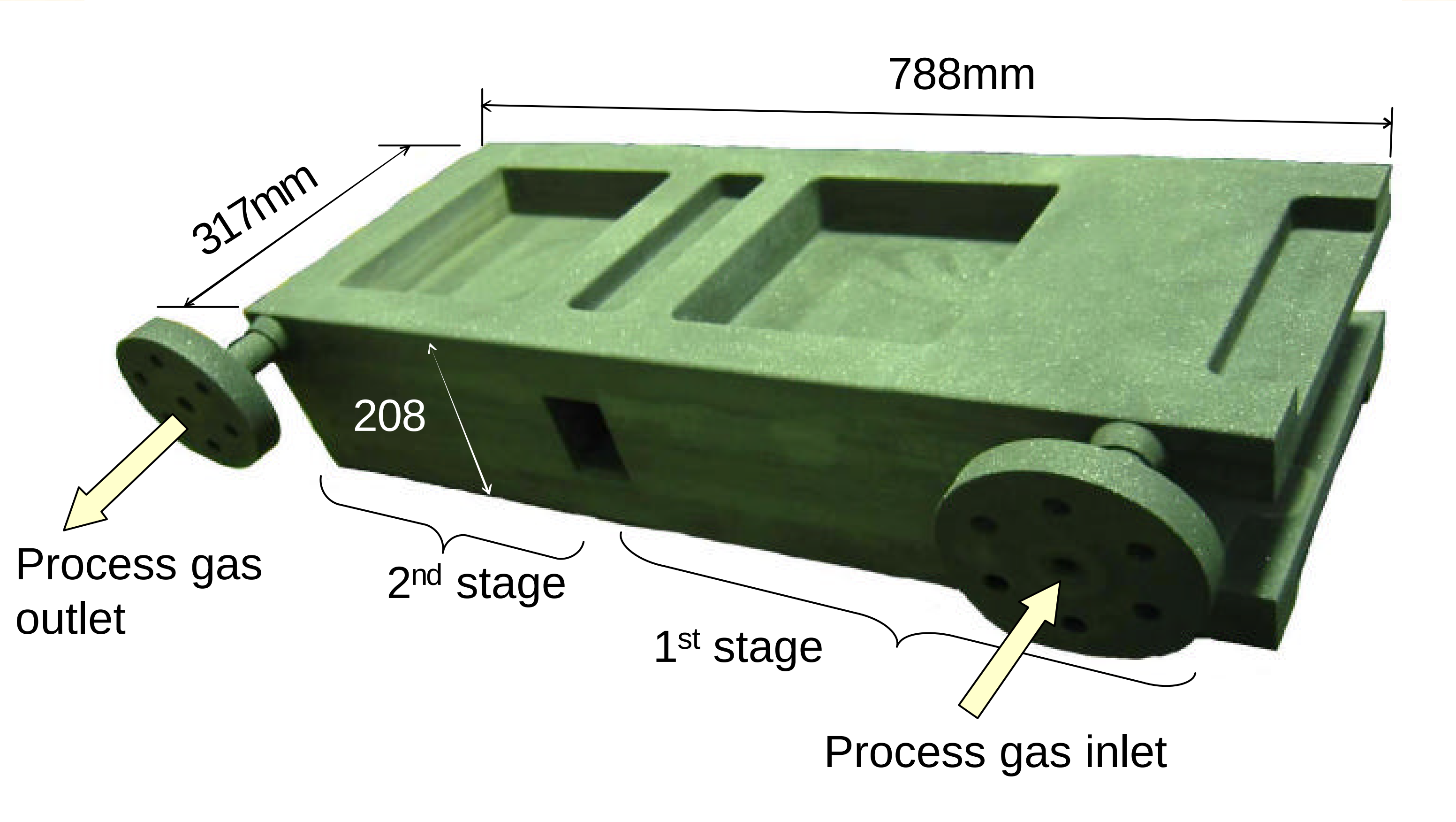
Contour in process gas channel

- Analytical results
  - Leg Part Max 53 MPa
  - Process-gas side Max 17 MPa (surface)
- Analytical results in all places were below the tensile stress of SiC.

Ref) A. Kanagawa et al., 13th Int. Conf. Nuclear Engineering (ICONE13), Beijing, China, May 16-20, 2005, ICONE13-50451

Mock-up Model of Plate-Type SO_3 Decomposer

A SO_3 decomposer model consisting of 2 heat exchanger stages to confirm fabilicability and its mechanical strength.
⇨ It was very difficult to connect two stages without cracks.
⇨ It is necessary to improve a sintering connection technique between stages.



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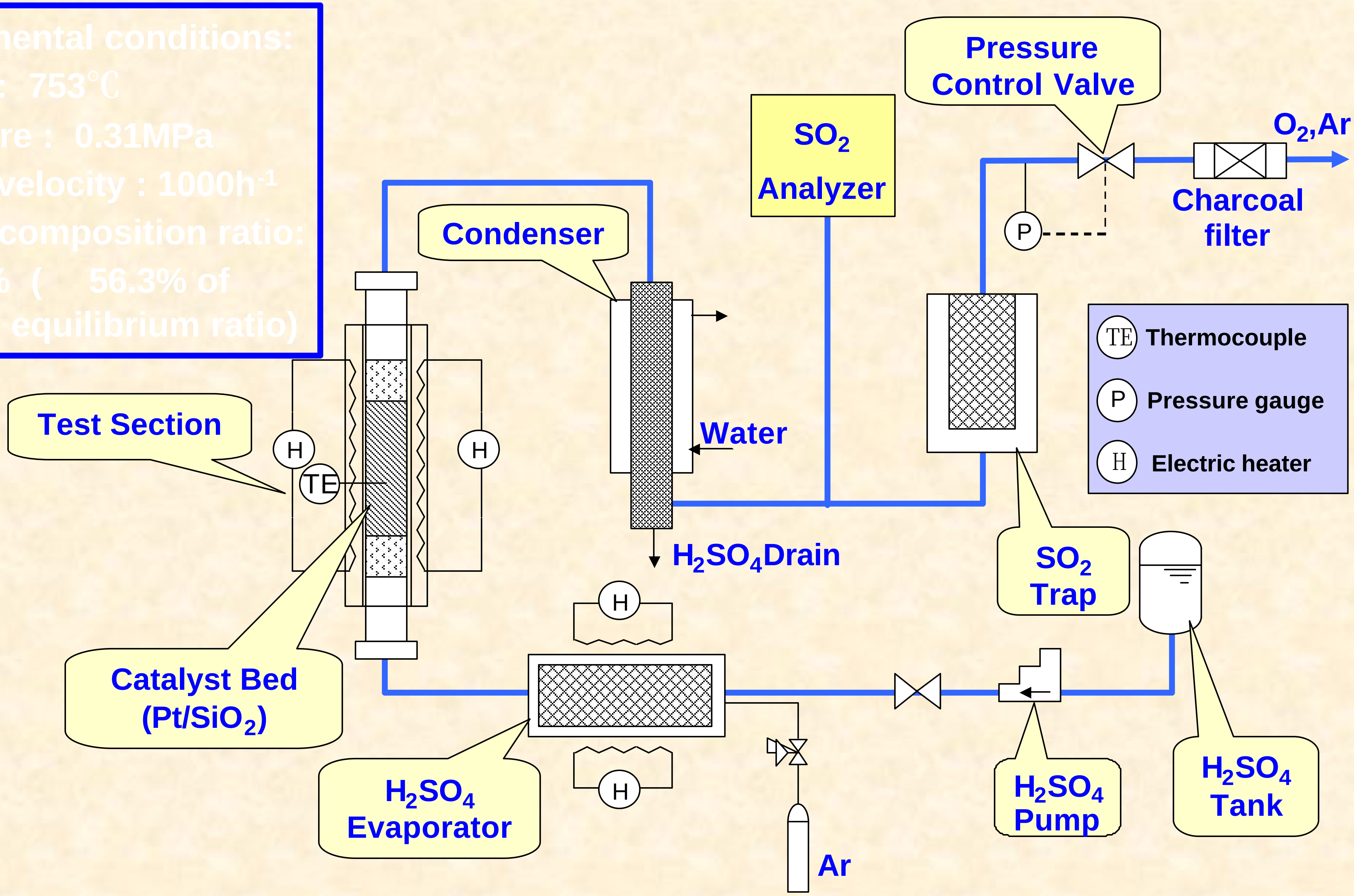
Flow Sheet of Catalyst Test Apparatus for SO_3 Decomposition

Experimental conditions:
- Temp. : 753℃
- Pressure : 0.31MPa
- Space velocity : 1000h^{-1}
- SO_3 decomposition ratio: 52.7 % (56.3% of equilibrium ratio)



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Summary

- **Conclusion**
  - Concepts of the H_2SO_4 and SO_3 decomposers made of SiC ceramics for the pilot test plant have proposed featuring corrosion resistant performance under high-temperature H_2SO_4 and SO_3 operations.
  - The feasibility of the proposed concepts has confirmed by thermal-hydraulic and mechanical strength analyses and test fabricated mock-up models.
- **Future work**
  - To accumulate design data for the pilot test plant, we will confirm the thermal-hydraulic performance of the H_2SO_4 decomposer and the SO_3 decomposition performance in the packed catalyst layer by using the sulfuric acid flow test loop and the catalyst test apparatus.