Development of Beam Target Cooling System Using Two-Phase Flow Natural Circulation

（KEK）N. Kamei, H. Akiyama, S. Makimura, T. Kanayama, J. Suzuki
（Waseda Univ.）S. Morooka, M. Furuya

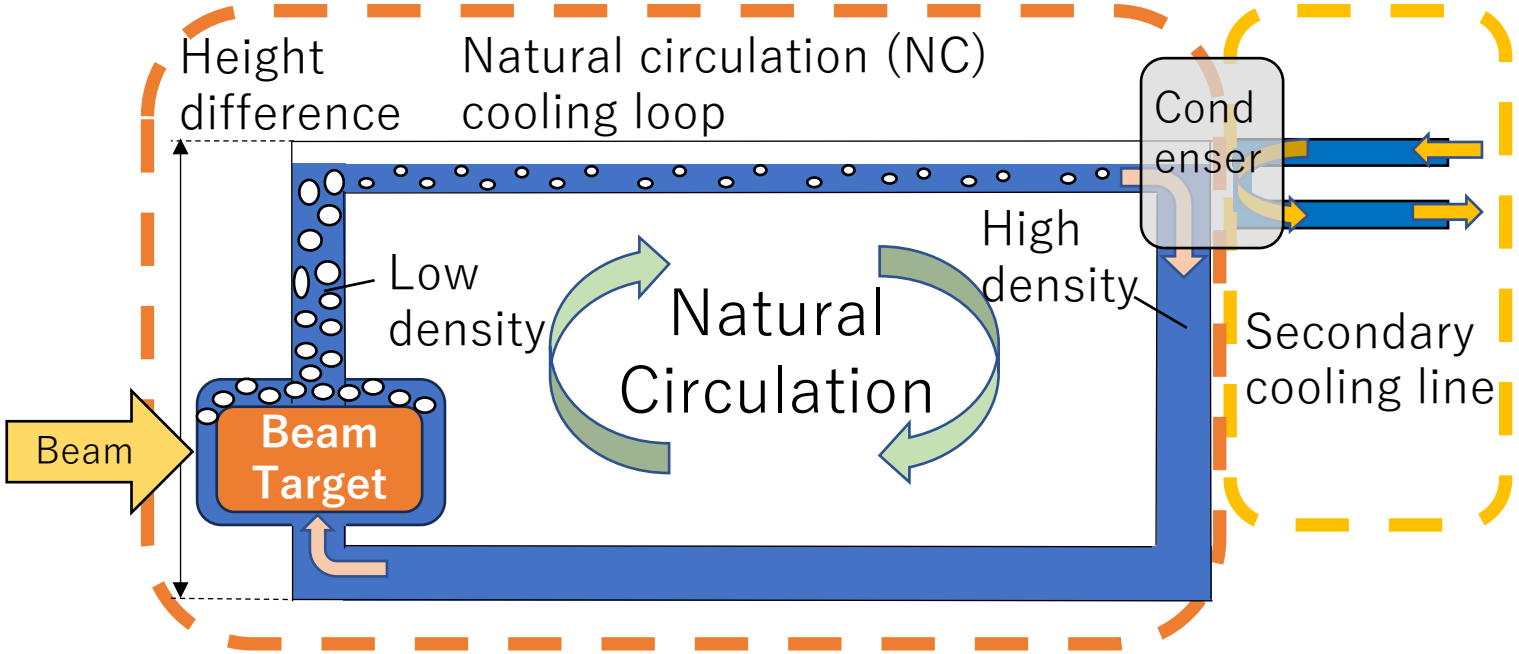
2023.11.07@HPTW2023

Introduction

【Background】

- In recent years, beam intensity has been increasing.
- For cooling a target with high beam intensity, water cooling is required.

● Conceptual Design of the Beam Target Cooling System with Natural Circulation



【Advantage】

- ➢ No pumps and electricity for NC line
- ➢ Reduces failure probability and maintenance frequency
- ➢ High reliability of circulation system
- ➢ Contaminated water can be trapped in the NC line
- ➢ Operates without power for short periods of time, even during power outages

✓ To change the phase of water in the pipe and transport heat through NC w/o power source.

Diagram of how natural circulation driving forces arise

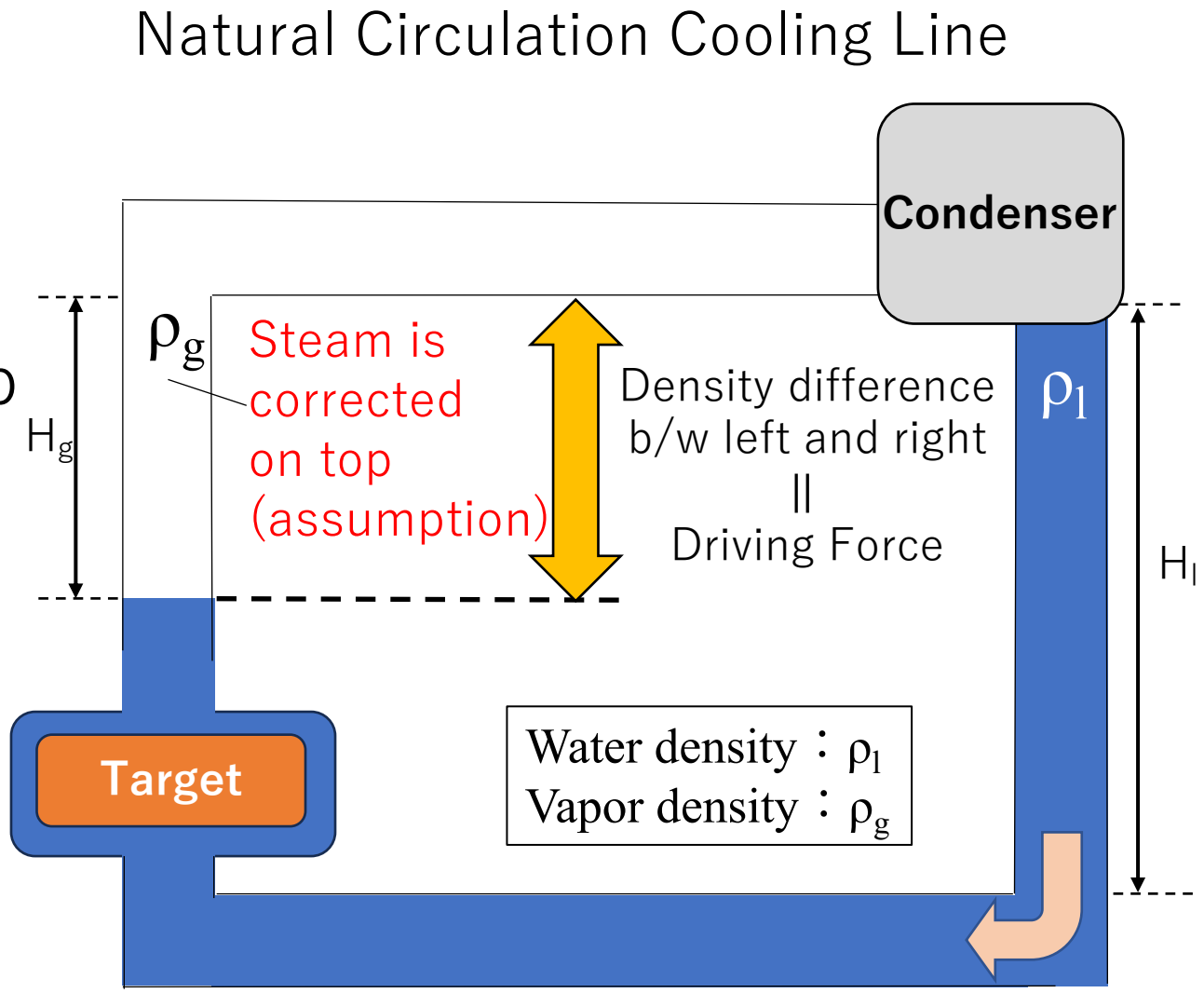
- The NC driving force F [Pa] is

$$F = (\rho_l - \rho_g) g H_g$$

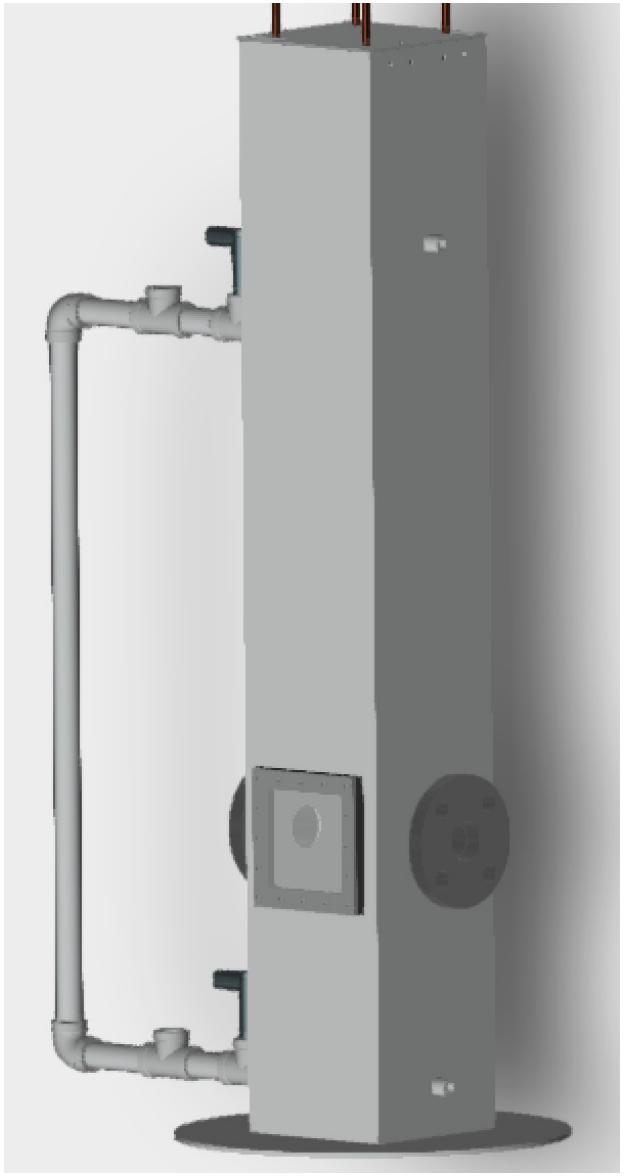
- ΔP_{all} [Pa] :Pressure loss as the fluid flows through the NC loop
- If the NC flow rate is W [kg/s], then

$$F = \Delta P_{all}(W)$$

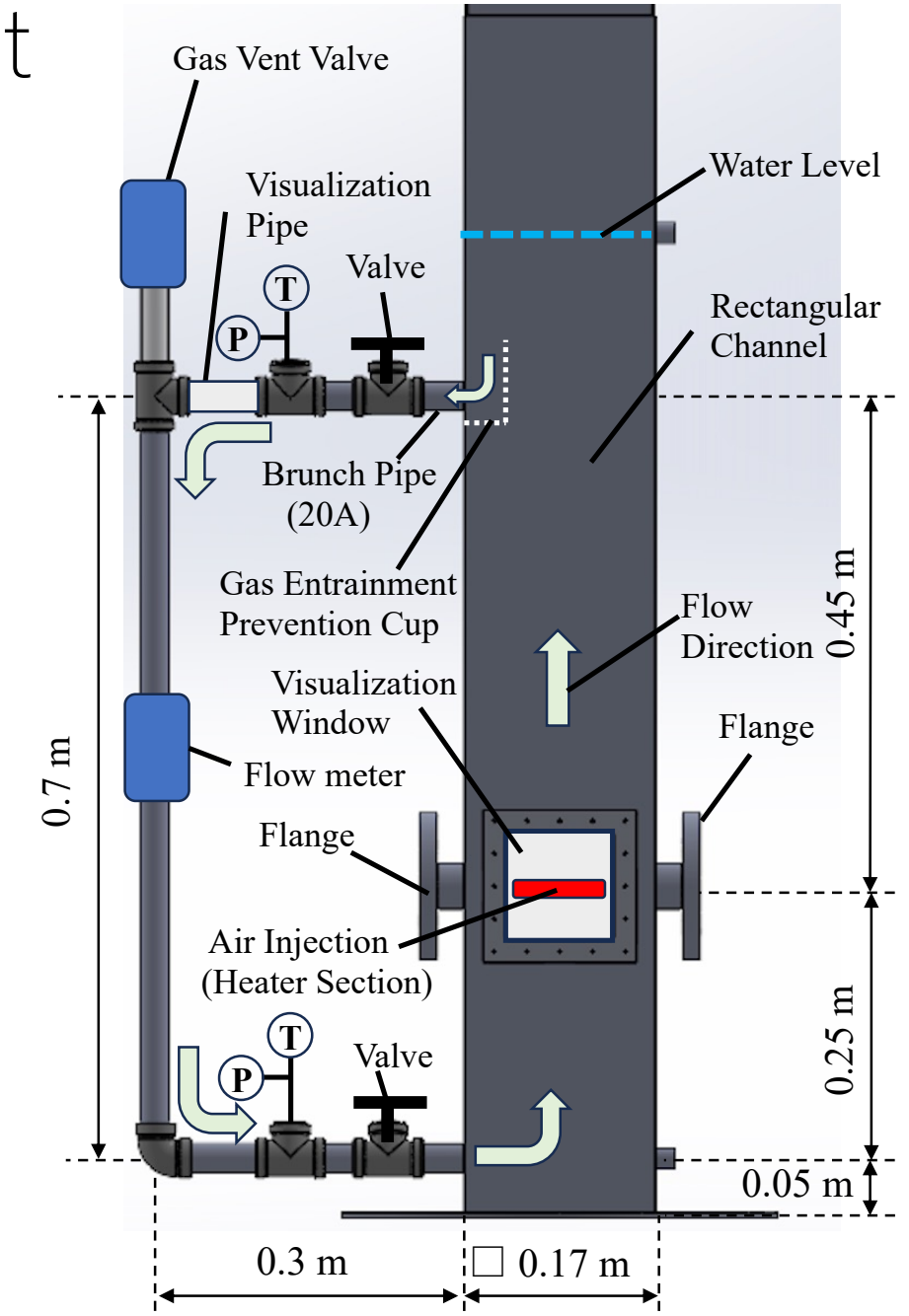
In the actual phenomenon, gas-liquid is not separated and a gas-liquid two-phase flow flows in the left pipe.



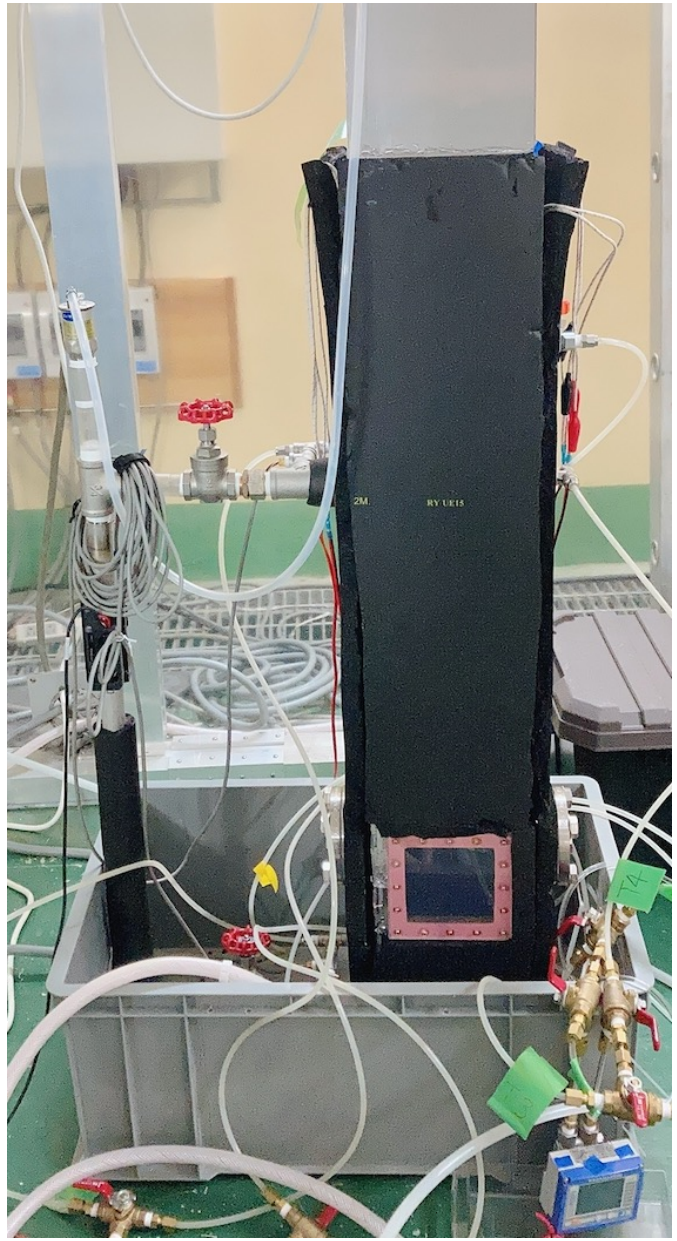
Test equipment



3D CAD model



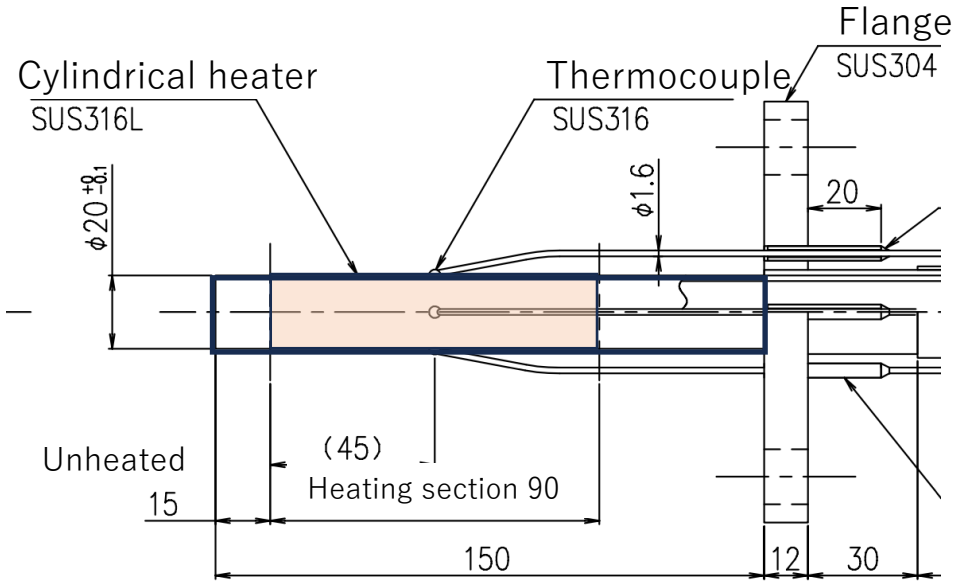
The natural circulation test equipment



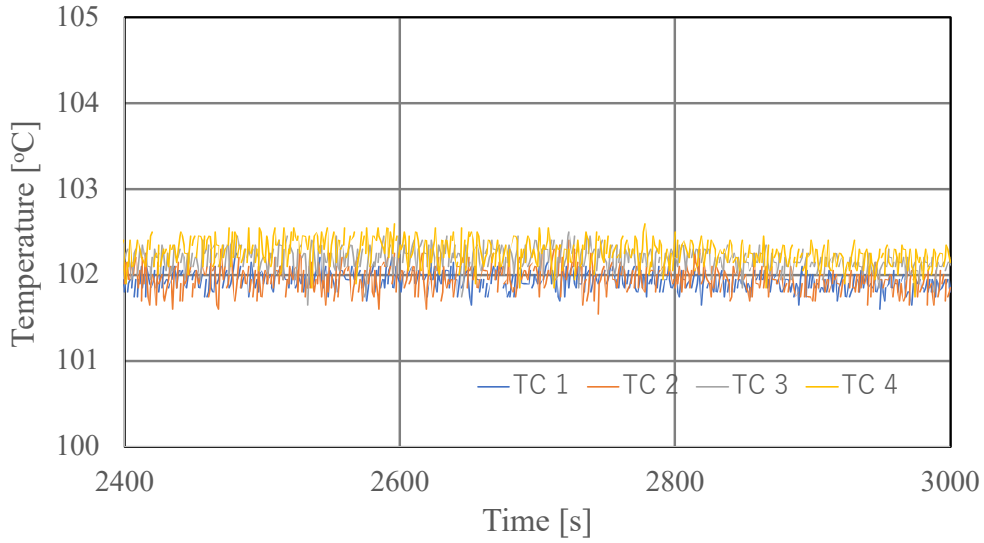
Produced by KEK's Mechanical Engineering Center

Heating test with beam target simulation heater

- Heater Power
  : ～ **4.4 kW**
- Avg. Heat Flux
  : ～ 780 kW/m2



- Pool boiling test:
  Heater surface temperature is maintained at approx. 102 °C for 10 minutes in the case of **4.4 kW** heating.



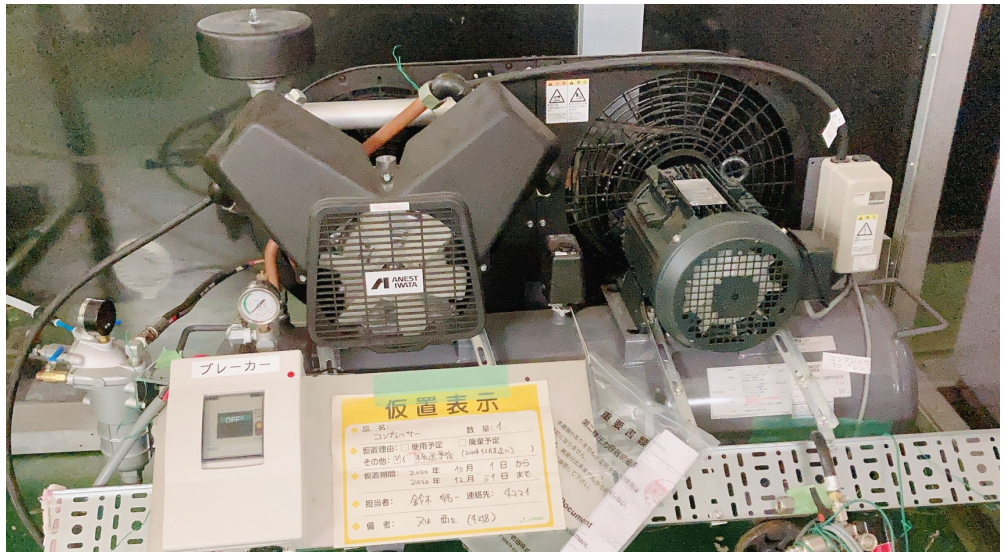
Heater Power : ≒1.1 kW
Avg. Heat Flux : ≒200 kW/m^2

✓ We plan to conduct the Critical Heat Flux test for the heater

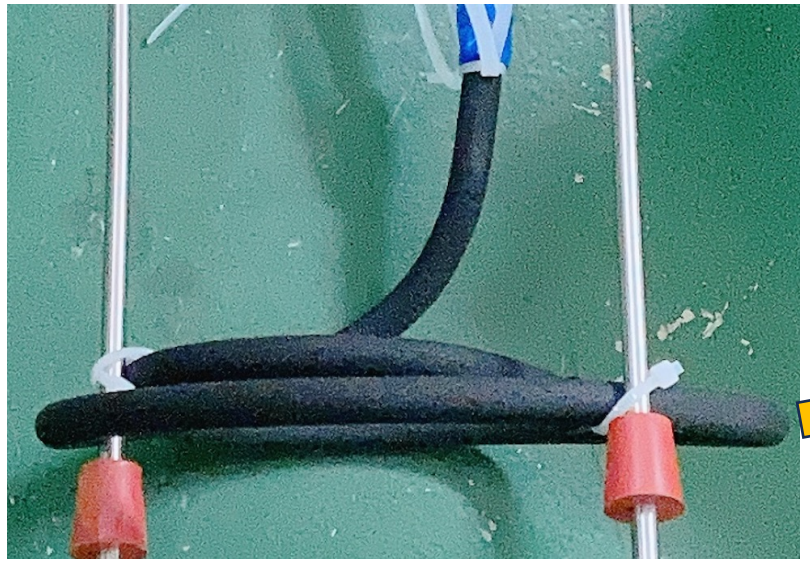
Air-water natural circulation test

- Purpose: to obtain the data of **NC flow rate** in each air injection rate
  Key parameter for CHF
- Air flow range：0 - 250 L/min
  (Covers steam generation equivalent to 5 kW of target heating power)
- Compressor supplies the required amount of air.
- Air flows uniformly into the test section from a spiral air curtain.

Supply air



Compressor (ANEST IWATA)

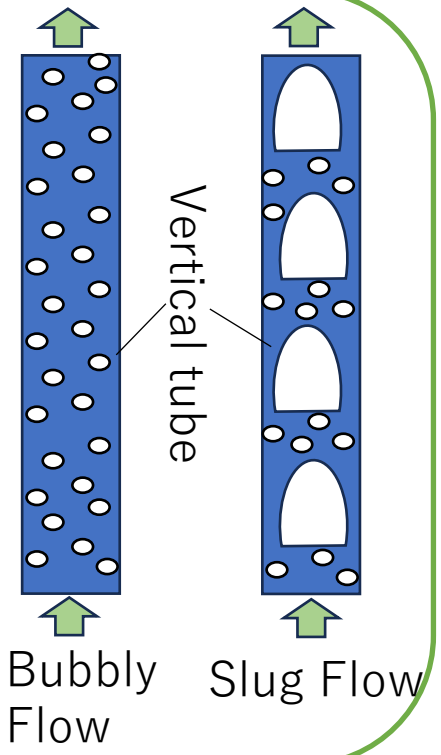


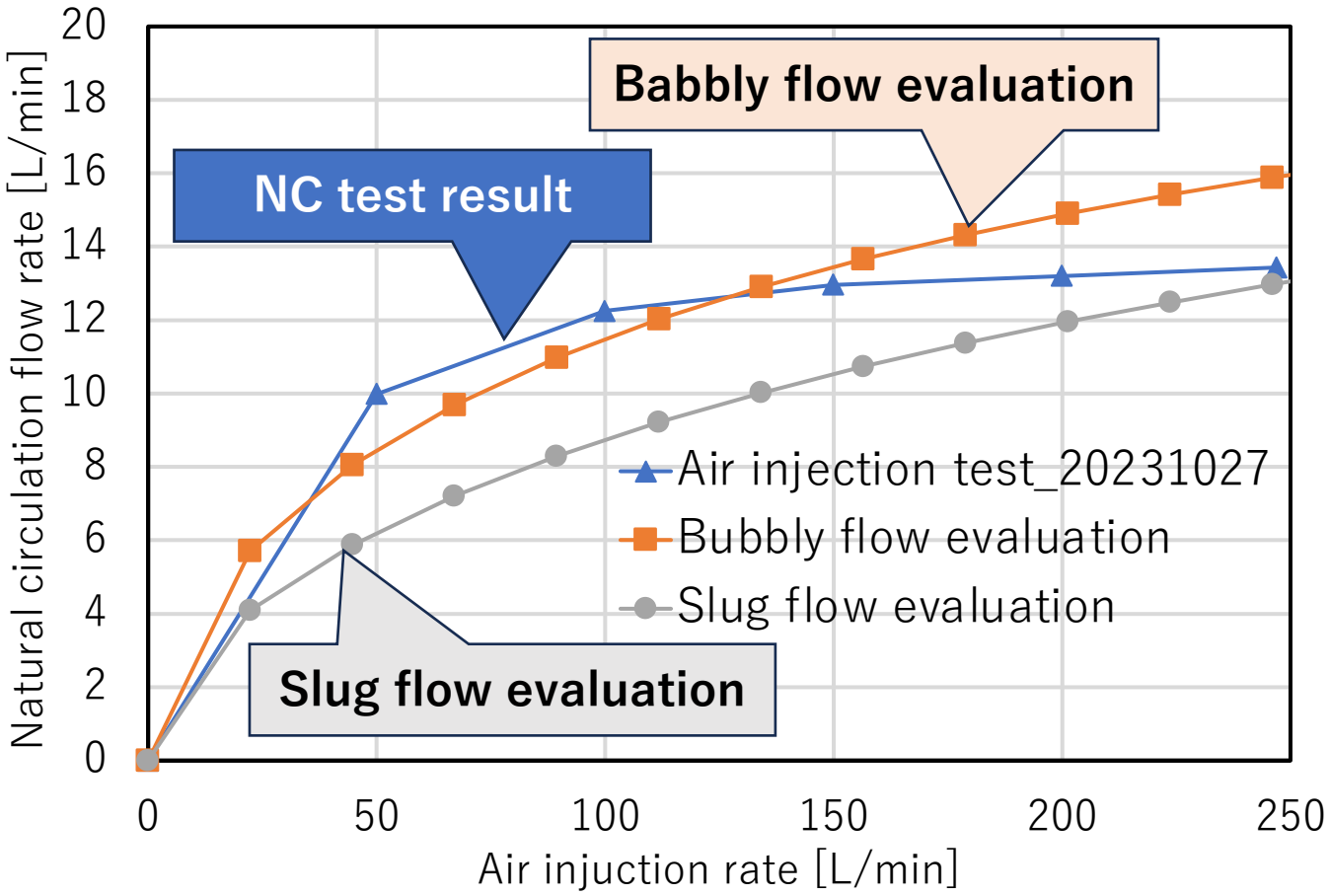
Spiral Air Curtain

Comparison between test result and analysis

【Flow Pattern】

- Babbly flow:
  Flow with small spherical bubbles making up most of the gas phase
- Slug flow:
  Flow in which bubbles merge with each other and a cannonball-shaped gas slug exists





- 0-100 L/min:
  Results slightly bigger than bubbly flow assumption evaluation
- 100-250 L/min:
  Approaching slug flow evaluation results with gradual increase

Within this range, the NC flow rate can be estimated to some extent between the BF and SF models.

Summary

- Conceptual design for a NC cooling system of beam target was developed.
- Manufactured natural circulation test equipment
- Pool boiling test with heater:
  - ➢Heater power of approx. 4.4 kW to maintain cooling (≒780 kW/m2)
- Air-water natural circulation test:
  - ➢Natural circulation were formed.
  - ➢Suggested that natural circulation flow can be predicted to some extent using a bubbly flow model and a slug flow model evaluation.

Acknowledgments

- This work was supported by JSPS KAKENHI Grant Number JP21K03608.
- The test equipment was manufactured by KEK Mechanical Engineering Center.

Thank you for your kind attention!