Study on Pb-Bi Natural Circulation Phenomena

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by

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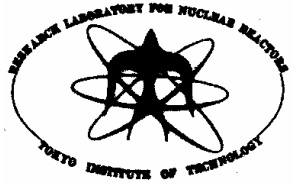

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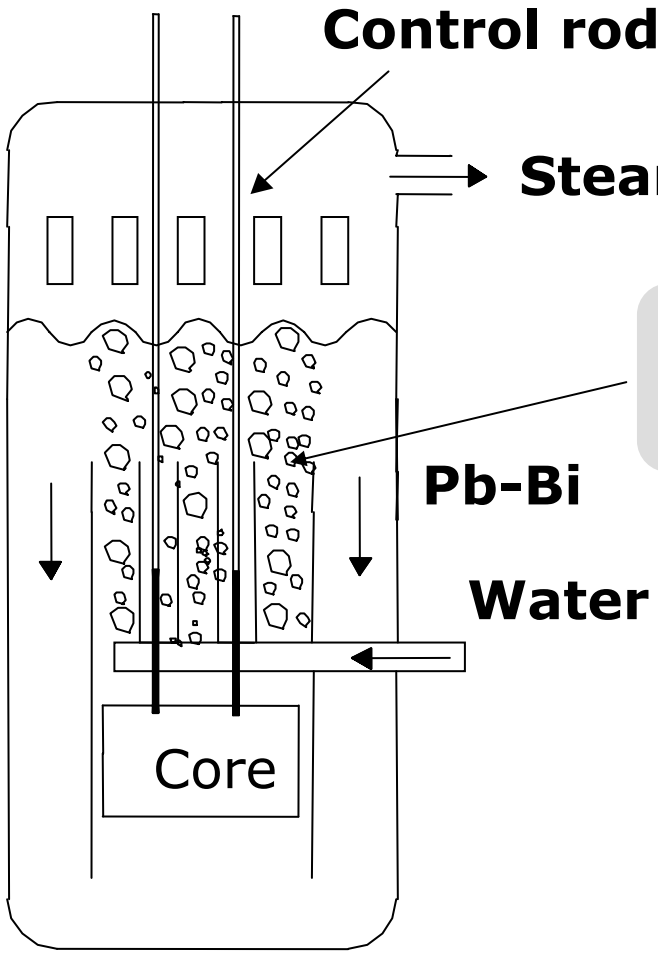
Direct Contact Type PFR: PBWFR



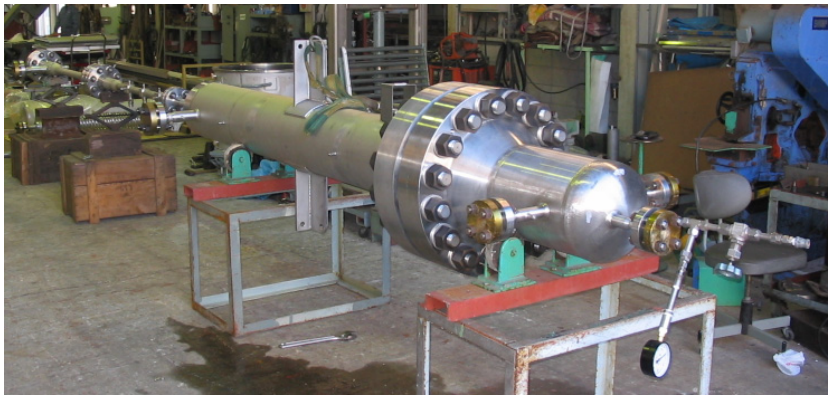
Natural Circulation
Direct Contact Boiling

Objective is to clarify the characteristics of Pb-Bi natural circulation

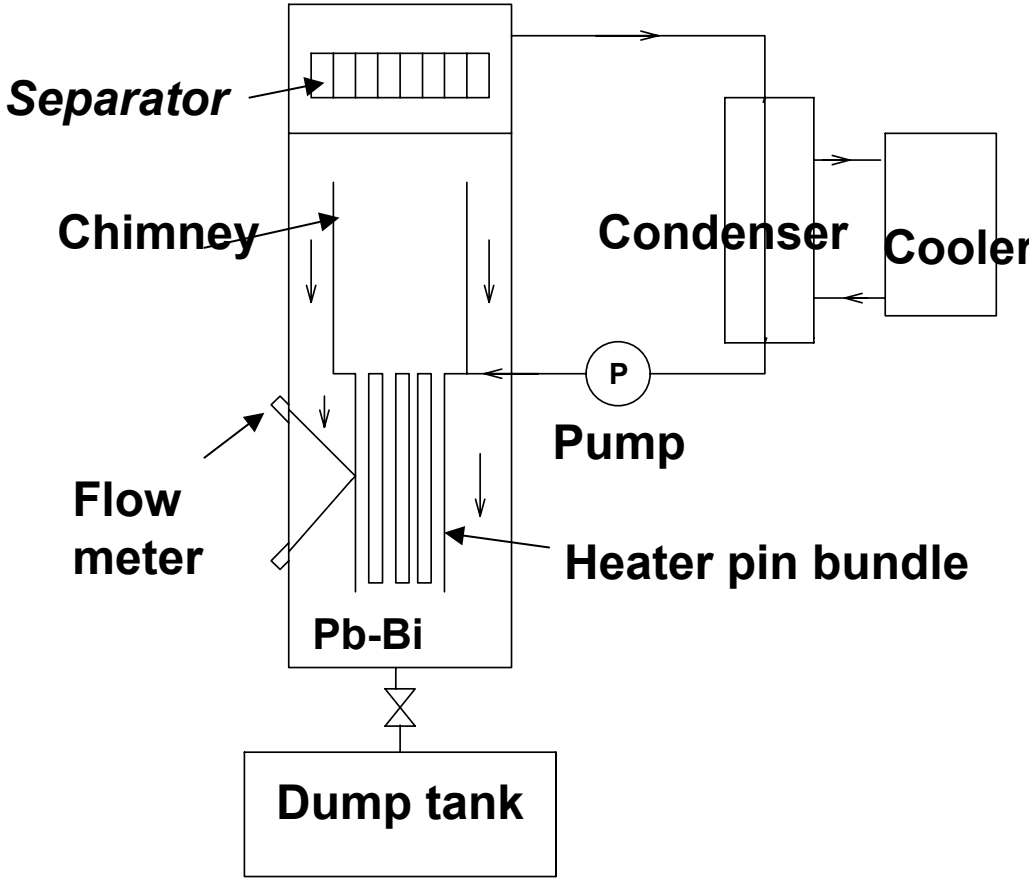
Pb-Bi Cooled Direct Contact Boiling Water FR (PBWFR)

Experimental Apparatus for Pb-Bi and Water-Steam Flows

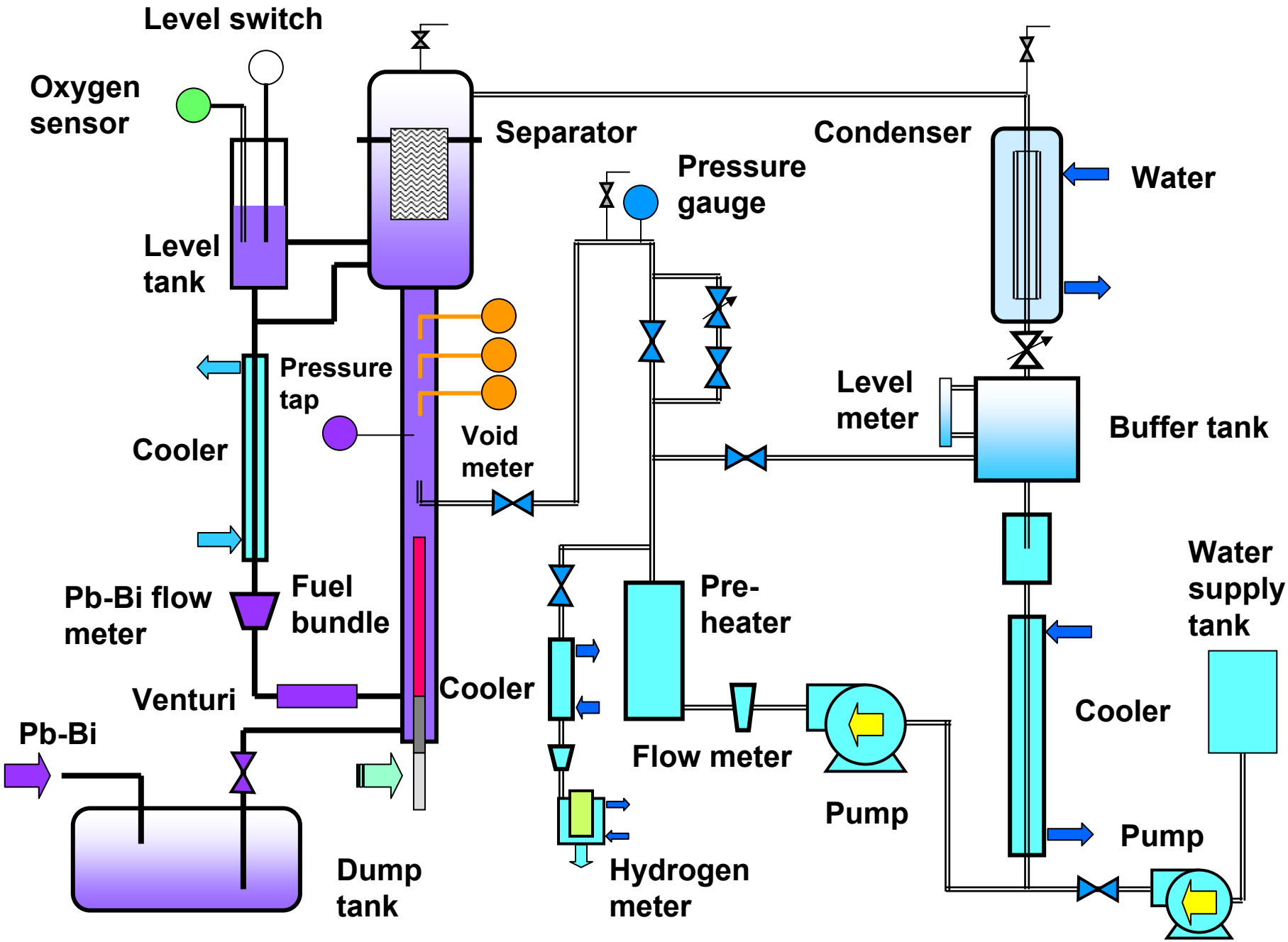
System characteristics of Pb-Bi single-phase natural circulation flow



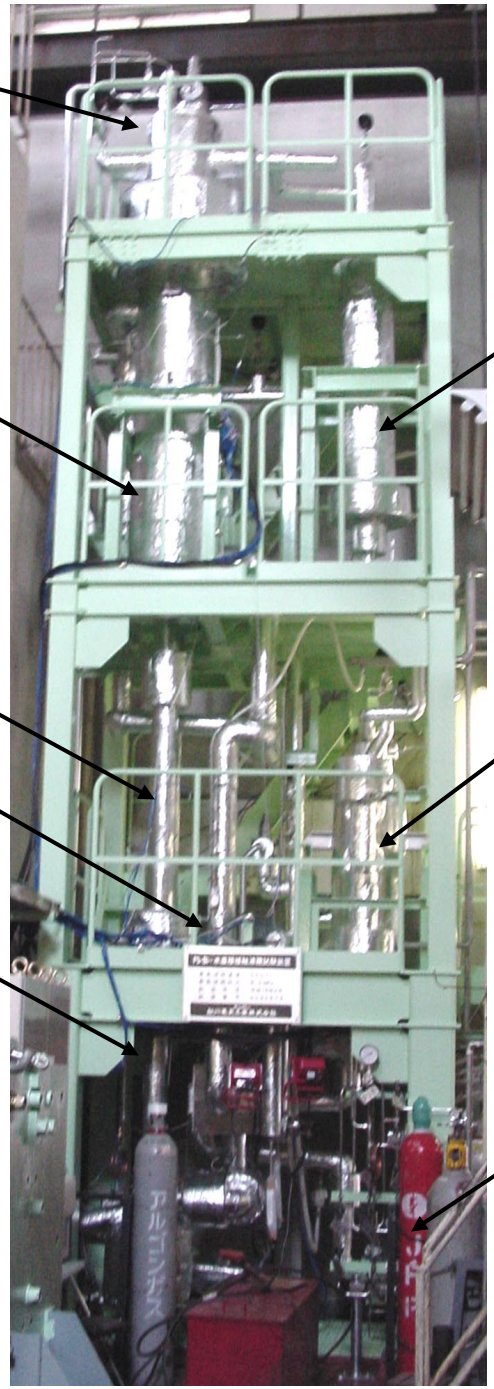
Heater pin bundle, Chimney and Separator



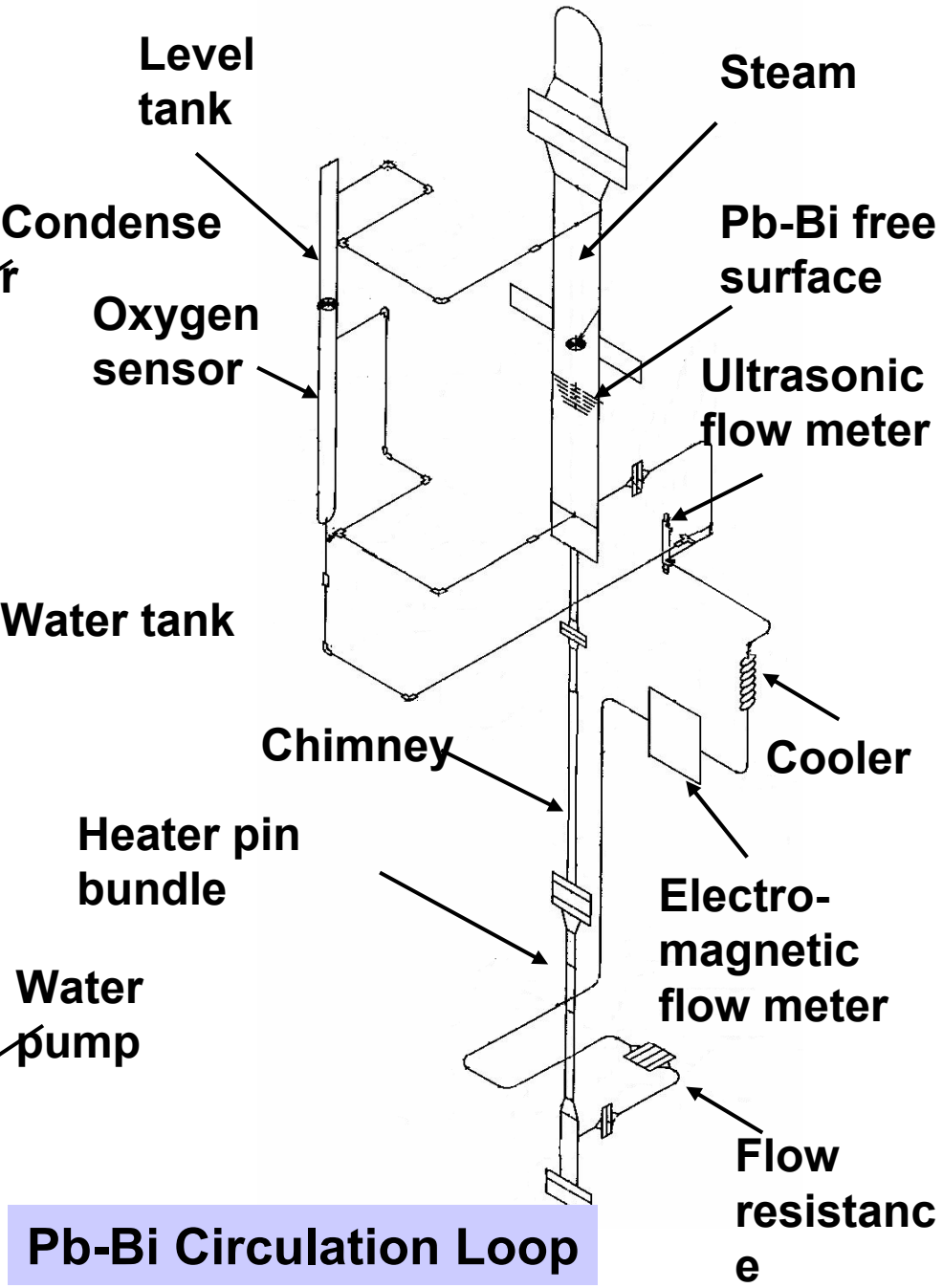
Pb-Bi and Water-Steam Flow loops



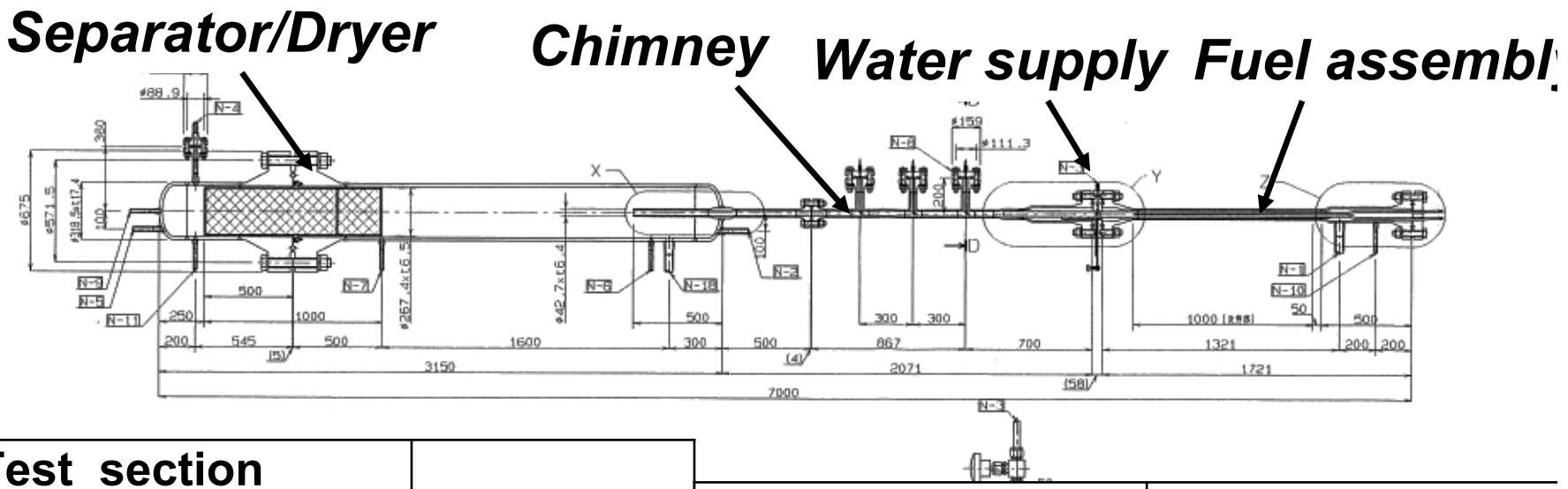
Direct Contact Boiling Test Loop



Experimental apparatus

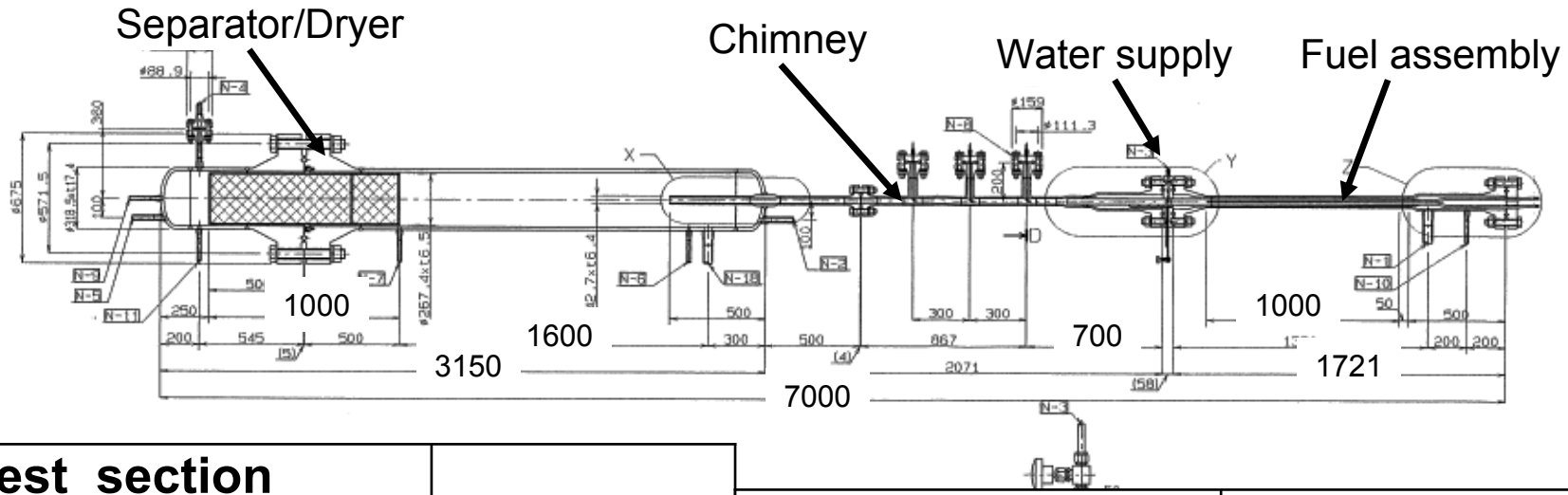


Pb-Bi Circulation Loop



Test section	
Length	**7m**
Heater power	**133kW**
Pb-Bi	
Inventory	**1000 kg**
Outlet temp.	**460℃**
Inlet temp.	**310℃**
Water loop	
Inventory	**50 kg**
Supply temp.	**220℃**
Steam temp.	**296℃**
Pressure	**7MPa**
Cooling power	**133kW**

Subassembly	
Length	**1.72m**
Fuel pin	**4 / 1.65m**
Fuel pin	
Outer dia./ Pitch	**12mm/15.9mm**
Heater length	**1000mm**
Power	**33.3kW x 4**
Cladding material	**STPA24**



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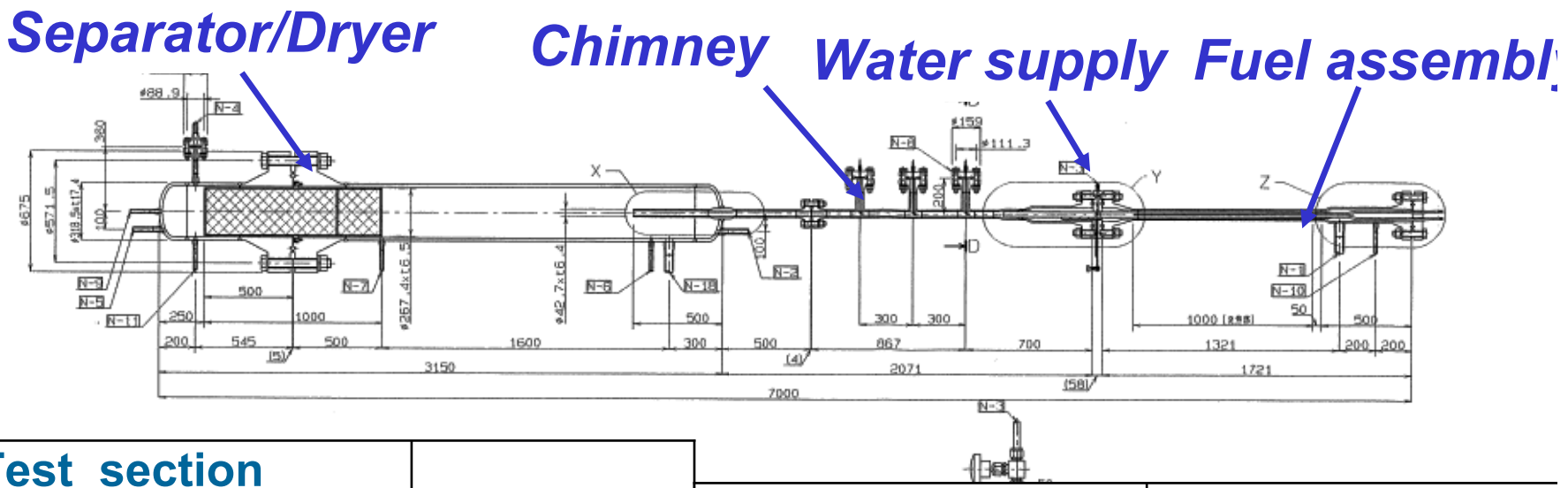

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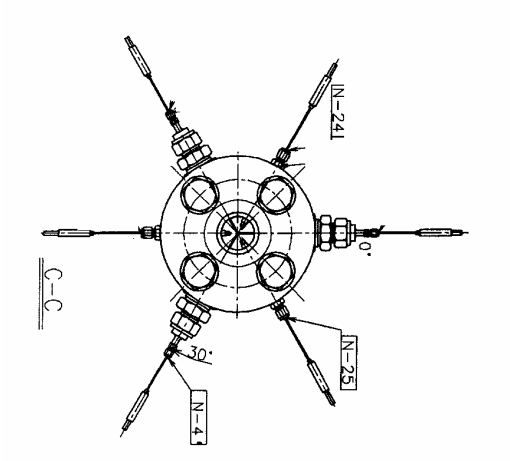
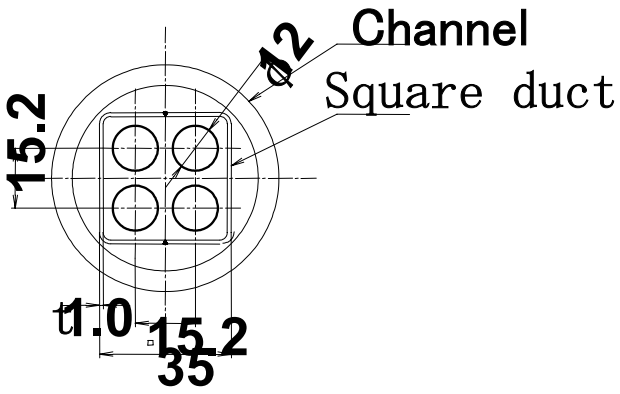
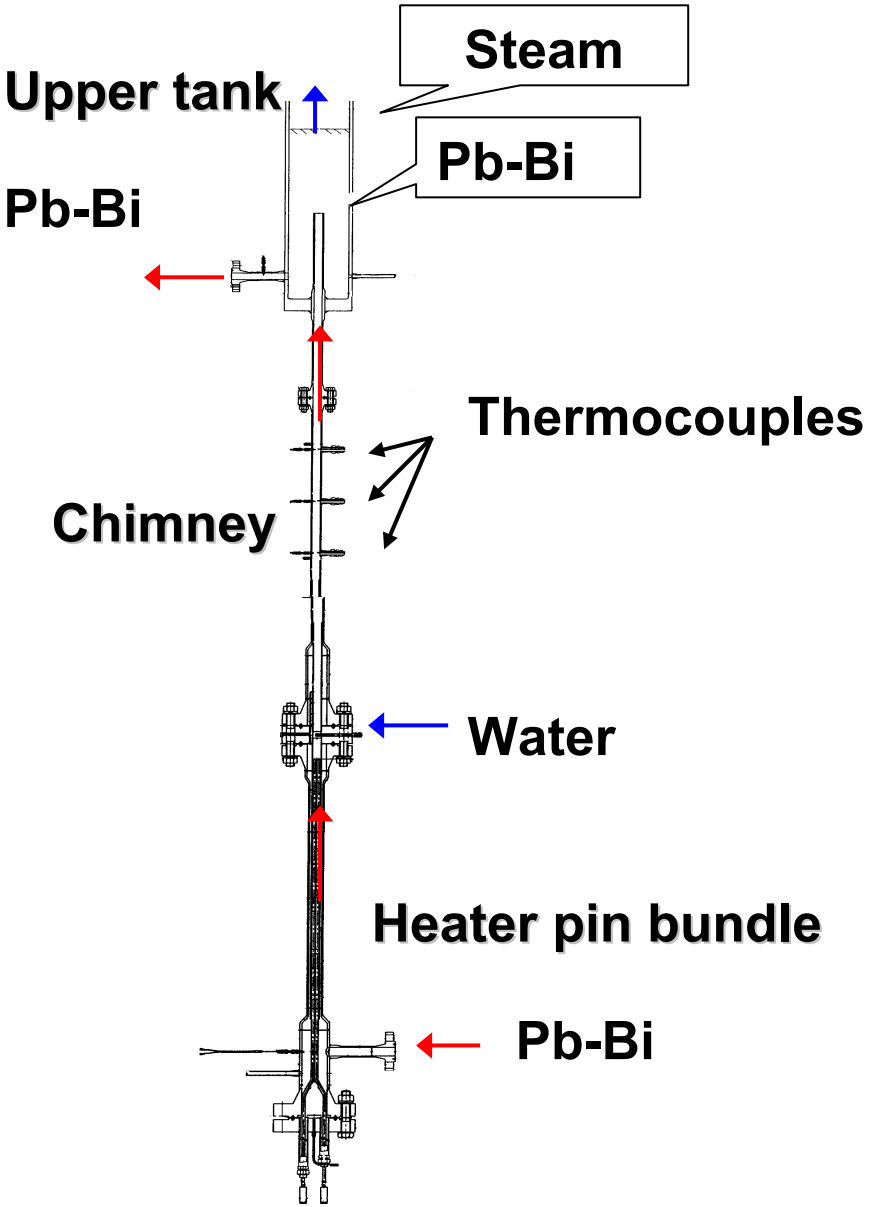


Water supply-Pressure measurement



Heater pin bundle



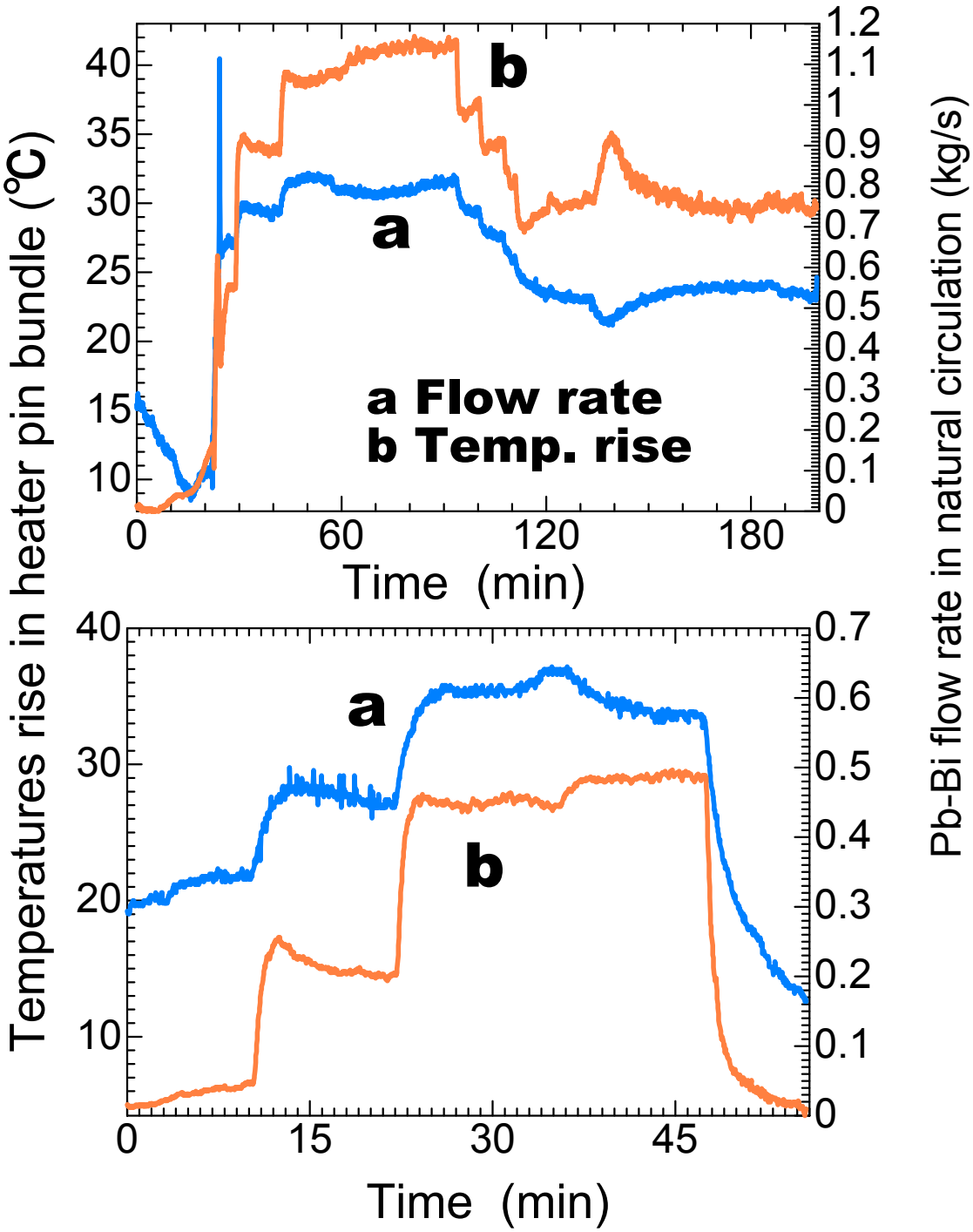
Controlled parameter in operation

Heater pin bundle	Experiment	Rated condition
Power (kW)	0.038-7.7	133
Outlet Pb-Bi temp. (℃)	251-308	460
Inlet Pb-Bi temp. (℃)	243-278	310

Result in operation

	Result	Rated condition
Pb-Bi flow rate (L/min)	1.5-4.8	36.5
Temperature in chimney (℃)	250-303	-

Pb-Bi Single-phase Natural Circulation



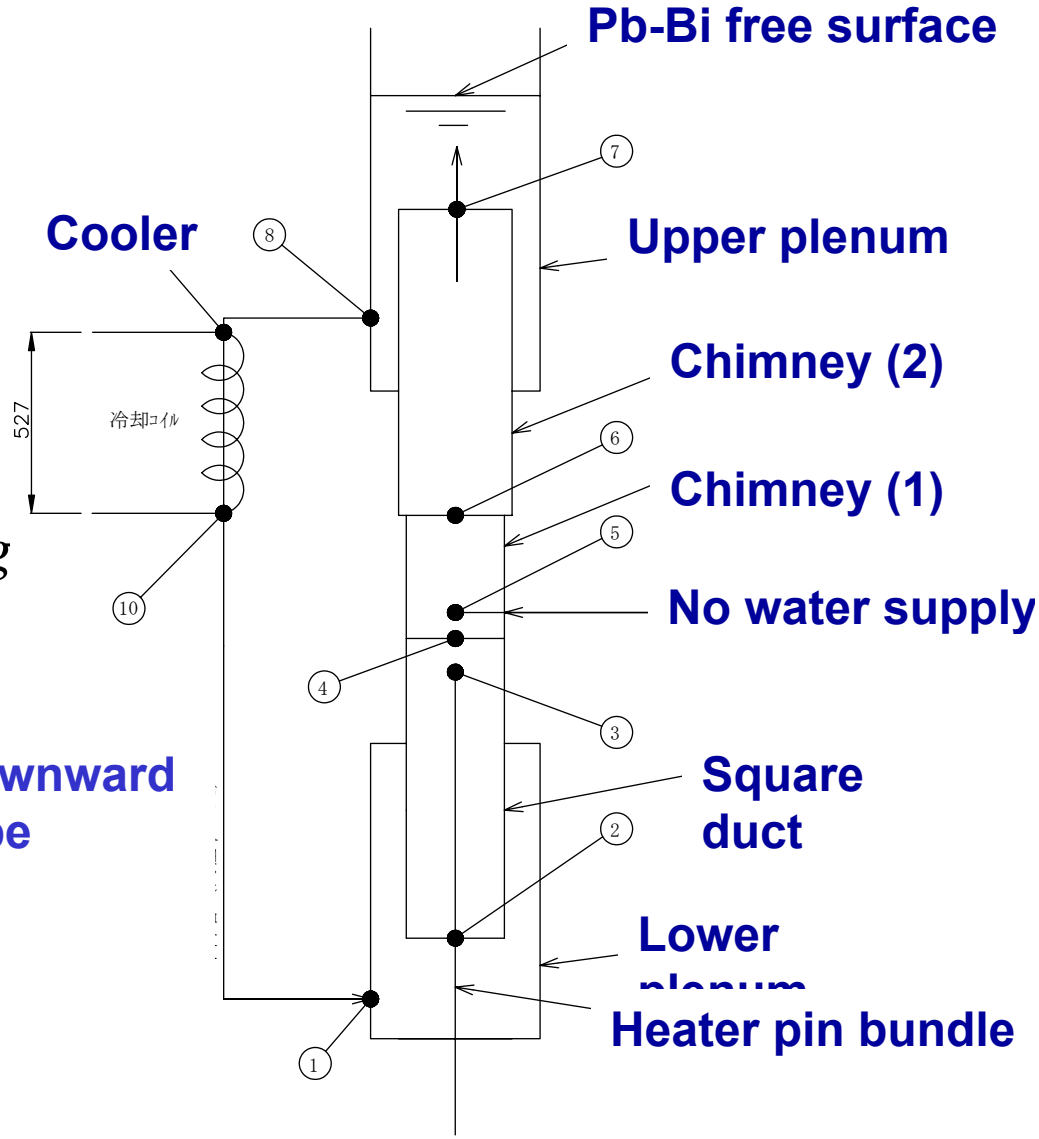
Evaluation of flow rate in natural circulation

Driving force of natural circulation

$$\Delta P = \rho_{dc} h_1 g - (\rho_{dc} h_2 + \rho_3 h_3 + \rho_4 h_4 + \rho_c h_5) g$$

Frictional pressure loss in chimney

$$\Delta P_{L0} = \left(\varsigma + \lambda \frac{L}{D} \right) \frac{\rho}{2} \cdot V^2$$



Flow model

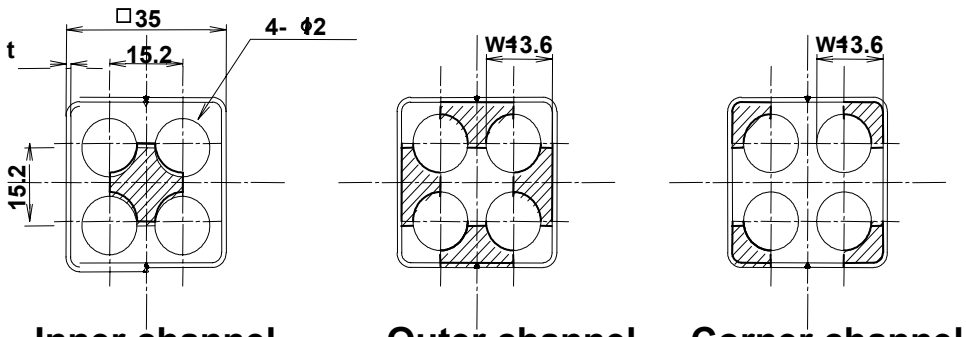
Frictional loss in bare bundle

$$\Delta P_b = \frac{\rho}{2} f \frac{L}{De} V_b^2$$

Laminar and turbulent $f_L = \frac{C_L}{Re} \quad f_T = \frac{C_T}{Re^{0.18}}$

$$C_L, C_T = a + b_1\left(\frac{P}{D} - 1\right) + b_2\left(\frac{P}{D} - 1\right)^2$$

$$C_{fb} = De_b \left[\sum_{i=1}^{3} S_i \left(\frac{De_i}{De_b} \right)^{\frac{m}{2-m}} \left(\frac{C'_{fi}}{De_i} \right)^{\frac{1}{m-2}} \right]^{m-2}$$



Heater Pin Bundle

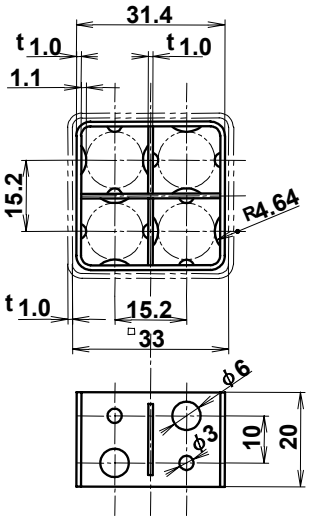
Form loss coefficient

$$\log_{10}(C_V) = 3.018 - 0.8712 \cdot \log_{10}(\mathrm{Re}_b) + 8.688 \times 10^{-2} \cdot (\log_{10}(\mathrm{Re}_b))^2$$

Pressure loss in Loop

$$\Delta P = \left(\varsigma + \lambda \frac{L}{D} \right) \frac{\rho}{2} \cdot V^2$$

Honeycomb grid spacers (3 stages)

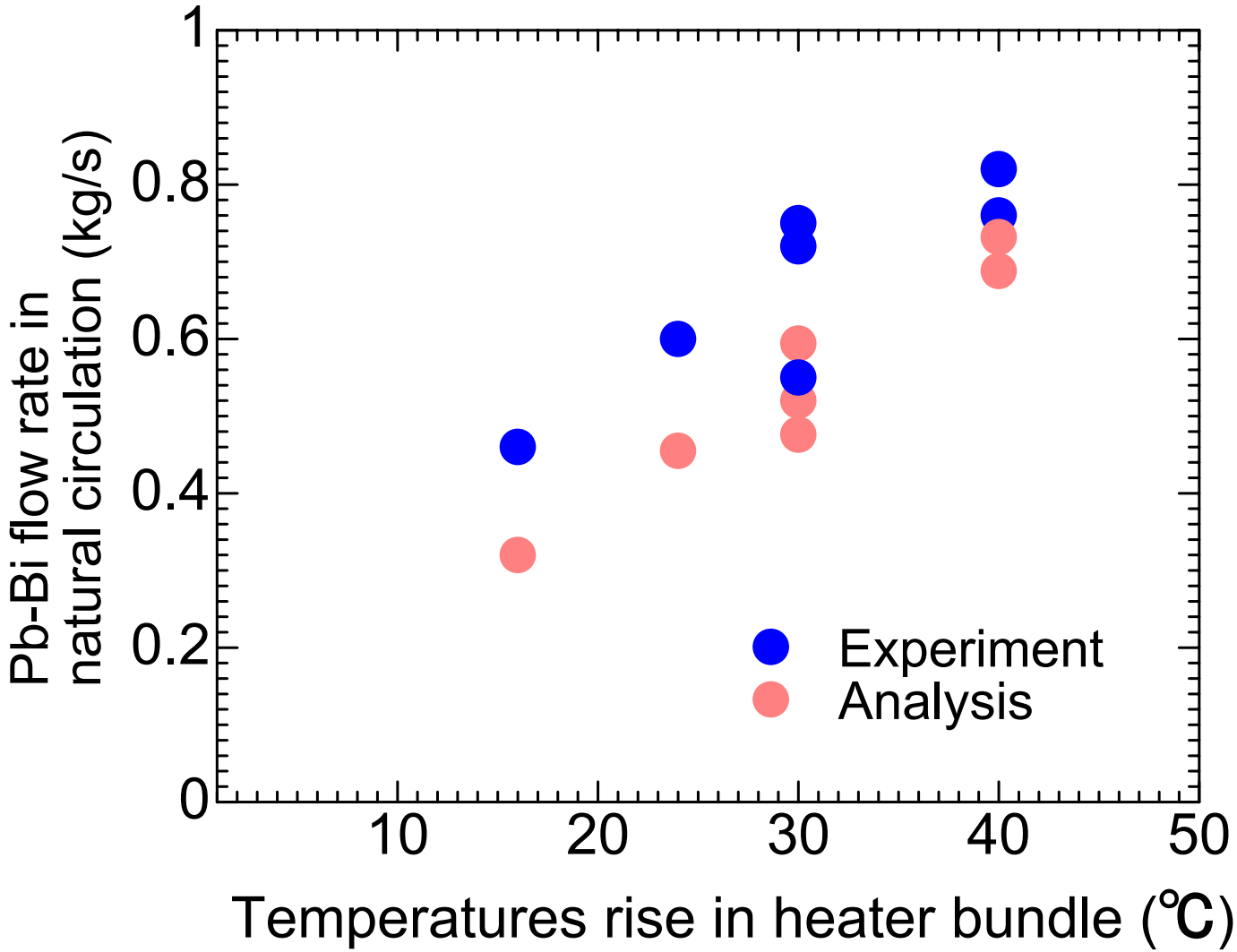


$$\Delta P_G = \frac{\rho}{2} \cdot C_V \cdot \varepsilon^2 \cdot V_b^2$$

Area ratio

$$\varepsilon = \frac{A_{SP}}{A}$$

Experimental and analytical results of flow rate in natural circulation



Conclusion

1. **Natural circulation flow was successfully achieved by heating Pb-Bi in the heater pin bundle.**

2. **Analytical result of Pb-Bi natural circulation flow rate was slightly lower than the experimental result.**