Study on Pb-Bi-Water Direct Contact Two-Phase Flow and Heat Transfer

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by

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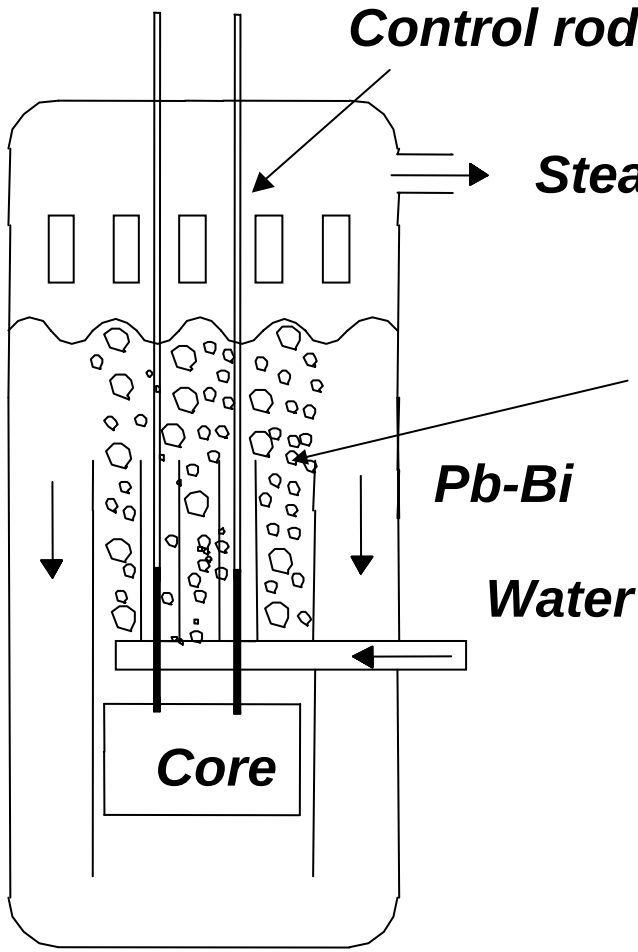
Development of Innovative Reactor System



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Direct Contact Boiling

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

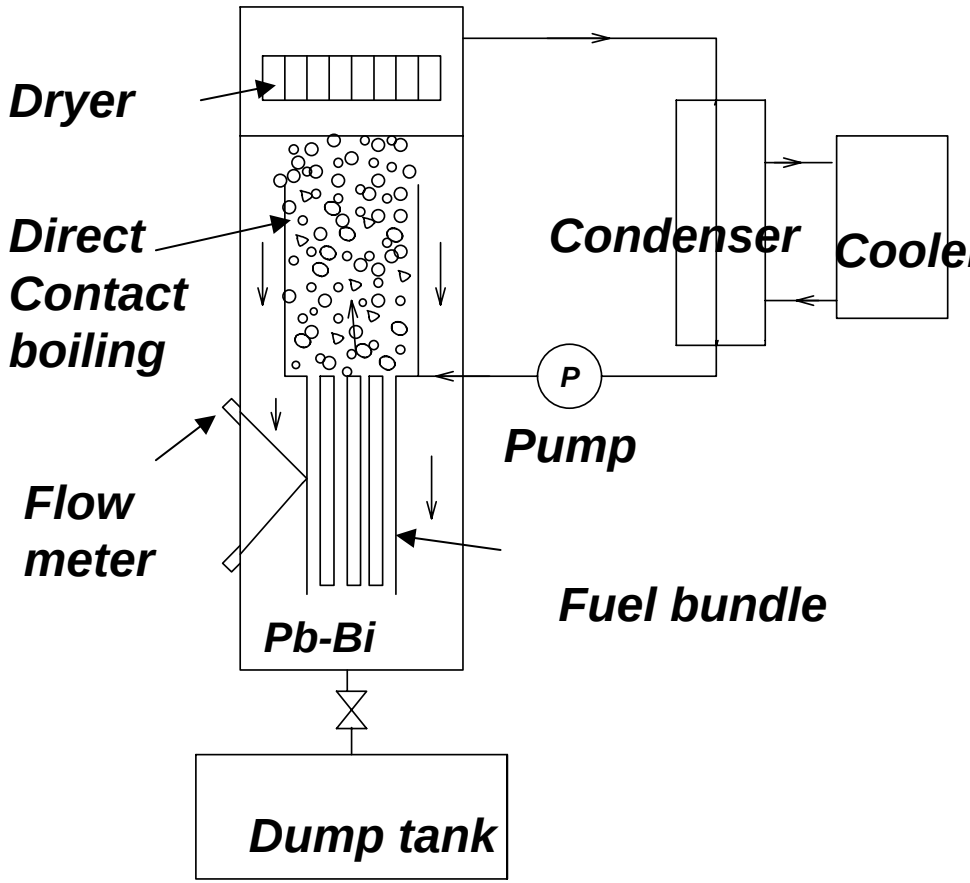
Previous studies

Takahashi, et al. （Tokyo Tech.）, Russian researcher, Kinoshita, et al. (CRIEPI), Corradini（Wisconsin-Madison Univ.), Branover, et al. （Ben Gurion Univ.）	Pb-Bi-Water Boiling, Hg-Volatile Liquid、Pb-Bi system, Bubble observation with X-ray
Sakai, et al. (JNC-CRIEPI)	Analysis of SG Pipe Failure
Saito （Tokyo Tech.）	Wood's metal-Nitrogen Two-Phase Flow

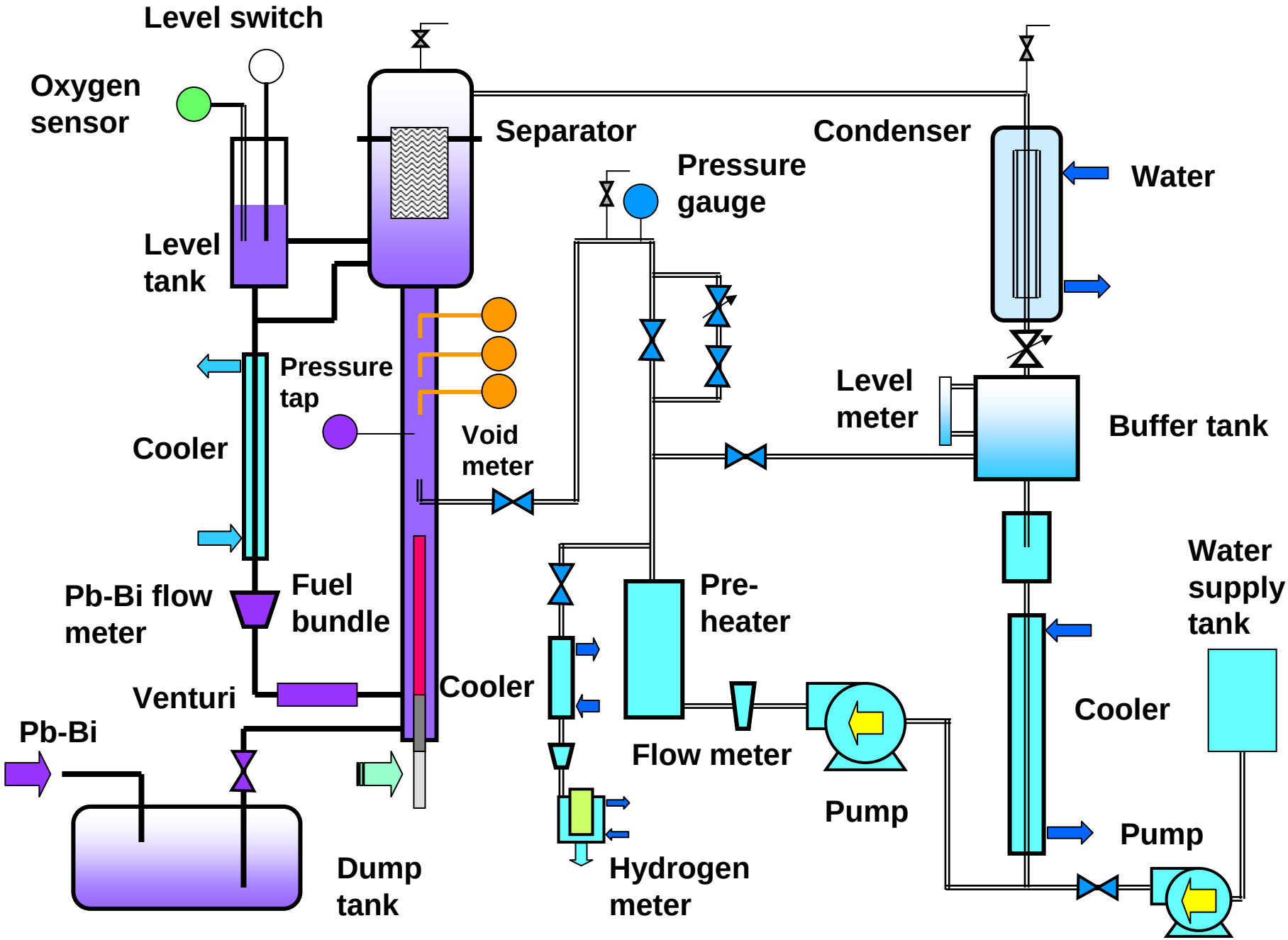
Objectives

- To clarify the lift pump performance for Pb-Bi circulation.
- To clarify the direct contact boiling heat transfer.

Experiment of Pb-Bi-Water Direct Contact Boiling Two-phase Flow

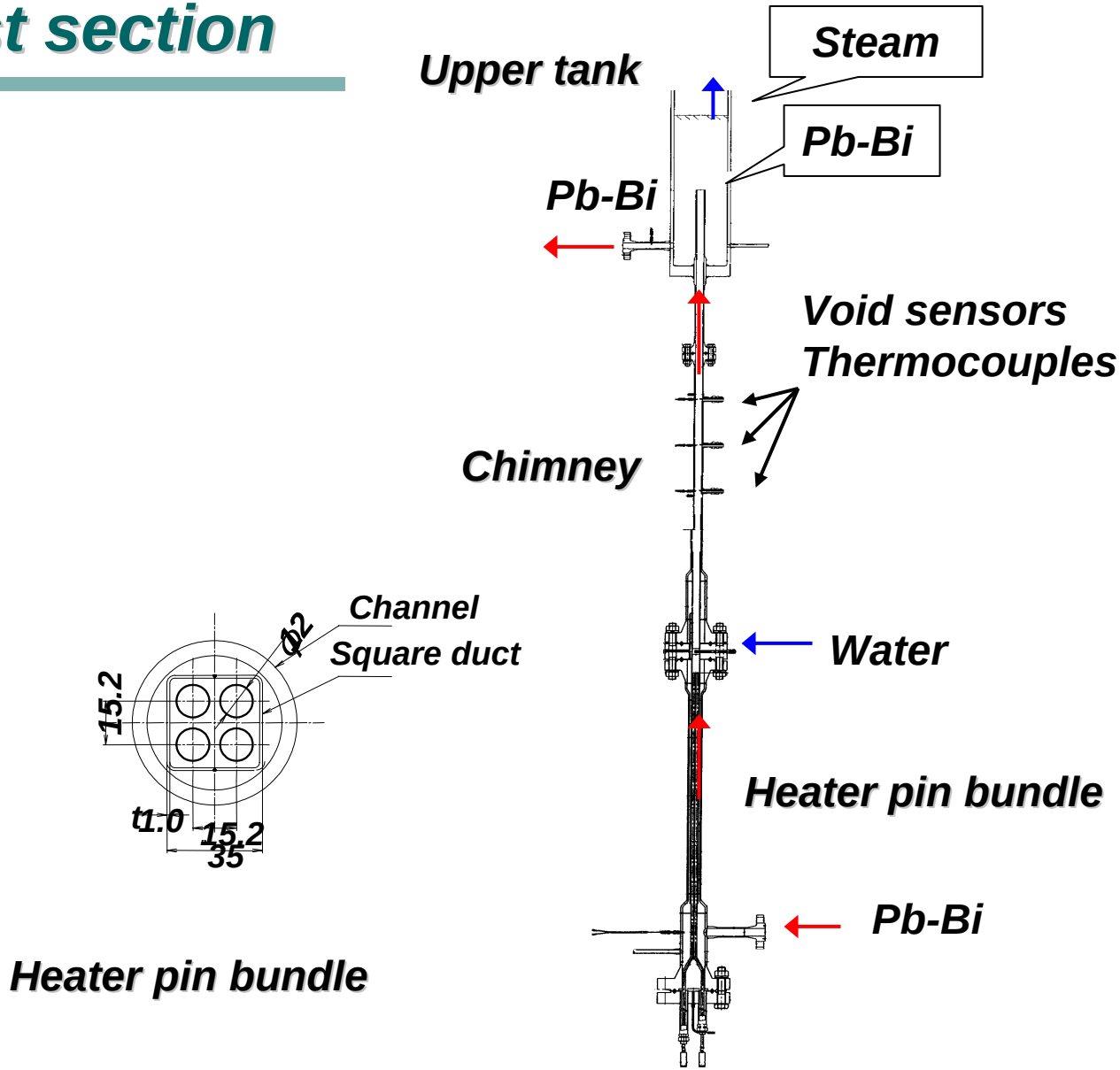


Pb-Bi-Water Direct Contact Boiling Two-phase Flow Test Apparatus



Direct Contact Boiling Test Loop

Test section



Operational procedure

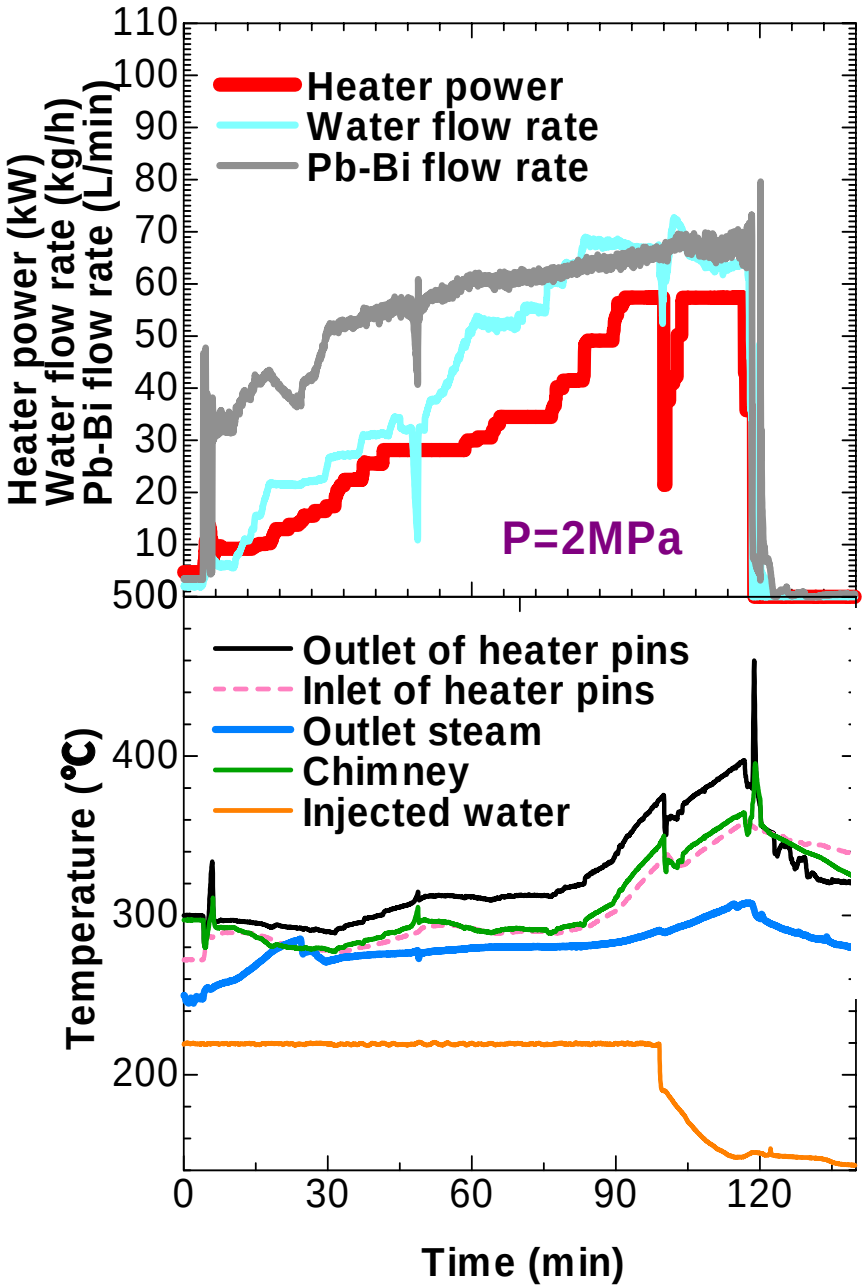
1. Evacuation of Pb-Bi and water loops
2. Charge of Pb-Bi into the Pb-Bi loop and heat up to 300℃
3. Water supply into water loop and heat up to 220℃
4. Natural circulation in Pb-Bi loop with heater pin power
5. Injection of water into Pb-Bi loop
6. Increase in the water injection flow rate and heater pin power
7. Control of condenser cooling
8. Achievement of desired flow rate, temperature and pressure

Controlled parameters in operation

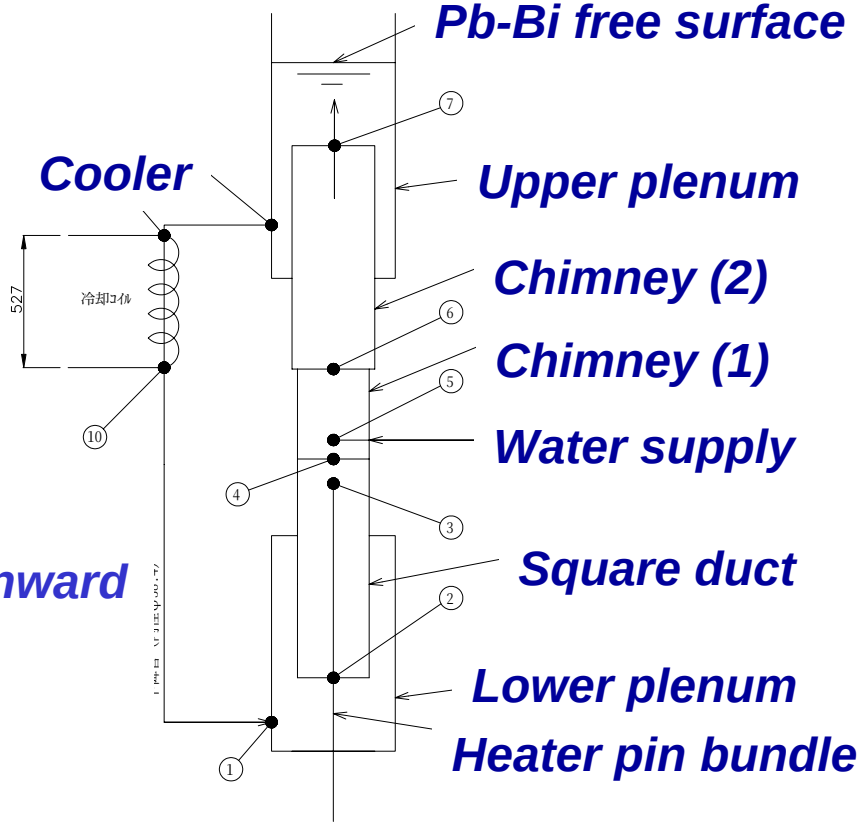
		Experimental condition	Rated conditions
Heater pin bundle	Power (kW)	5-106	133
	Pb-Bi temp. at outlet	308-469	460
Injected water	Flow rate (kg/h)	5.8-245	256
	Temperature (℃)	198-228	220
Steam pressure (MPa) (Condenser cooling)		2, 7	7

Result of operation

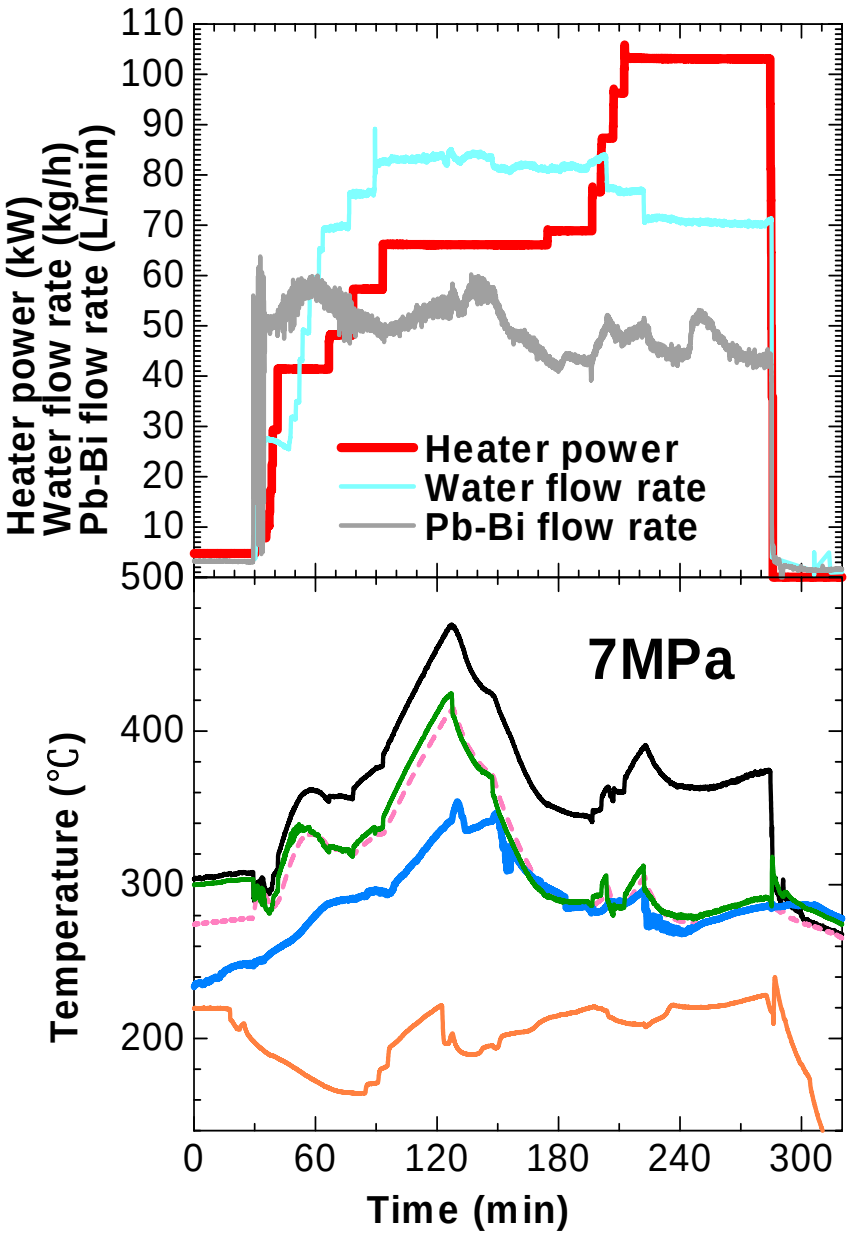
	Result	Rated conditions
Pb-Bi temp. at inlet of heater pin bundle (℃)	278-414	310
Pb-Bi flow rate (L/min)	56-61	36.5
Temperature in chimney (℃)	303-316	-

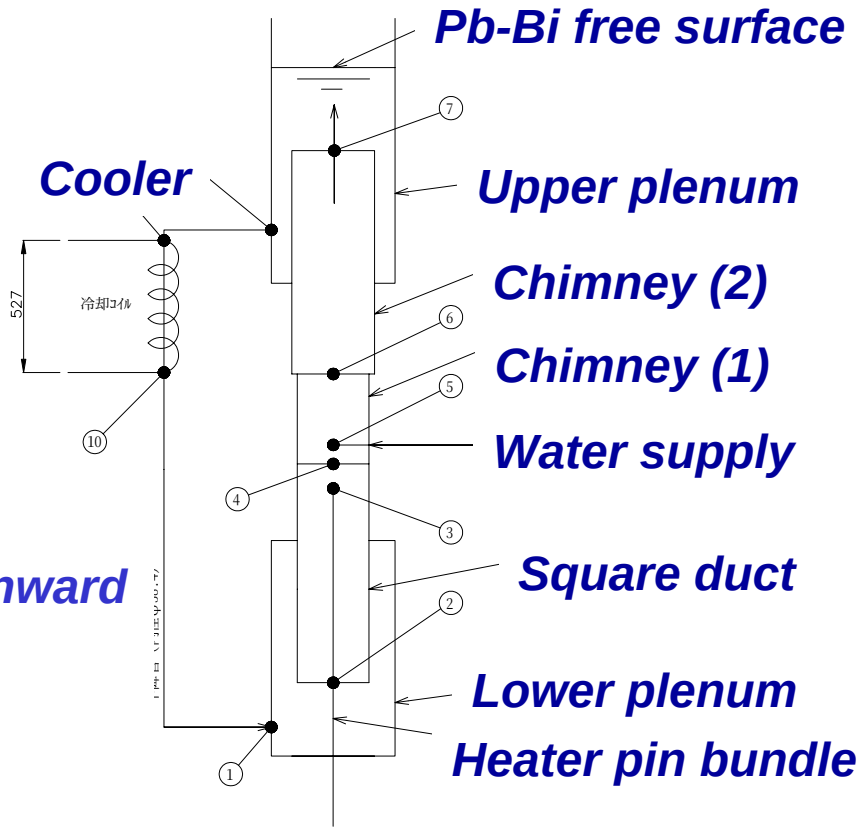


Downward pipe



Flow model


Heater power (kW)
Water flow rate (kg/h)
Pb-Bi flow rate (L/min)
Heater power
Water flow rate
Pb-Bi flow rate
7MPa
Temperature (℃)
Time (min)
Outlet of heater pins
Inlet of heater pins
Outlet steam
Chimney
Injected water


Pb-Bi free surface
Cooler
Upper plenum
Chimney (2)
Chimney (1)
Water supply
Square duct
Lower plenum
Heater pin bundle
Downward pipe
527
冷却コイル

Flow model

Evaluation of Lift Pump Performance

Driving force of Pb-Bi circulation by steam lift pump

$$\Delta P = \rho_{dc} h_1 g - \left[\rho_{dc} h_2 + \rho_3 h_3 + \rho_4 h_4 + \rho_c (1-\alpha) h_5\right] g$$

Frictional pressure loss in chimney

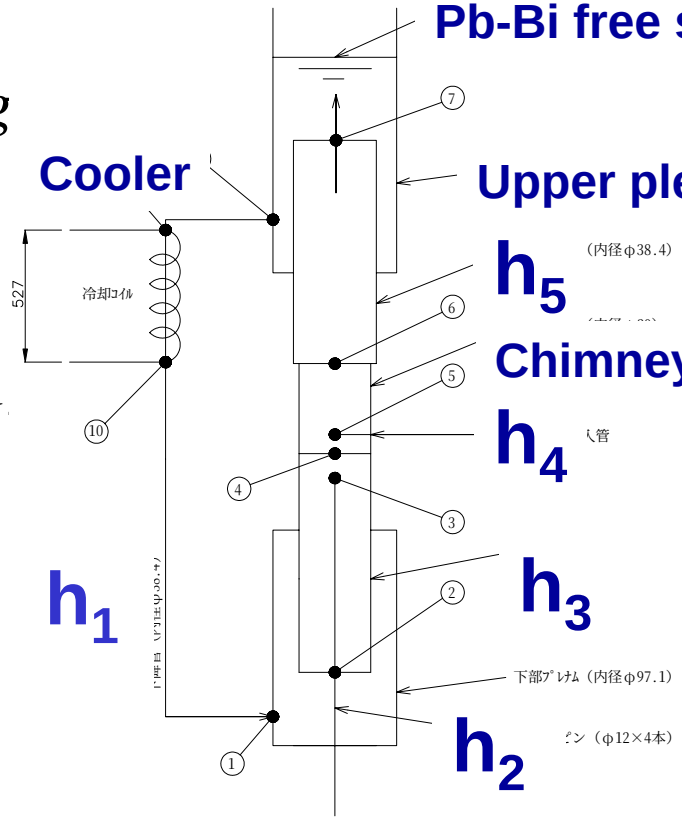
$$\Delta P_{TP} = \phi_{L0}^2 \Delta P_{L0} \qquad \Delta P_{L0} = \left(\varsigma + \lambda \frac{L}{D}\right) \frac{\rho}{2} V$$

Two-phase multiplication factor

$$\phi_{L0}^2 = \left\{1 + x\left(\rho_p / \rho_w - 1\right)\right\} \times \left\{1 + x\left(\mu_p / \mu_w - 1\right)\right\}^{-0.25}$$

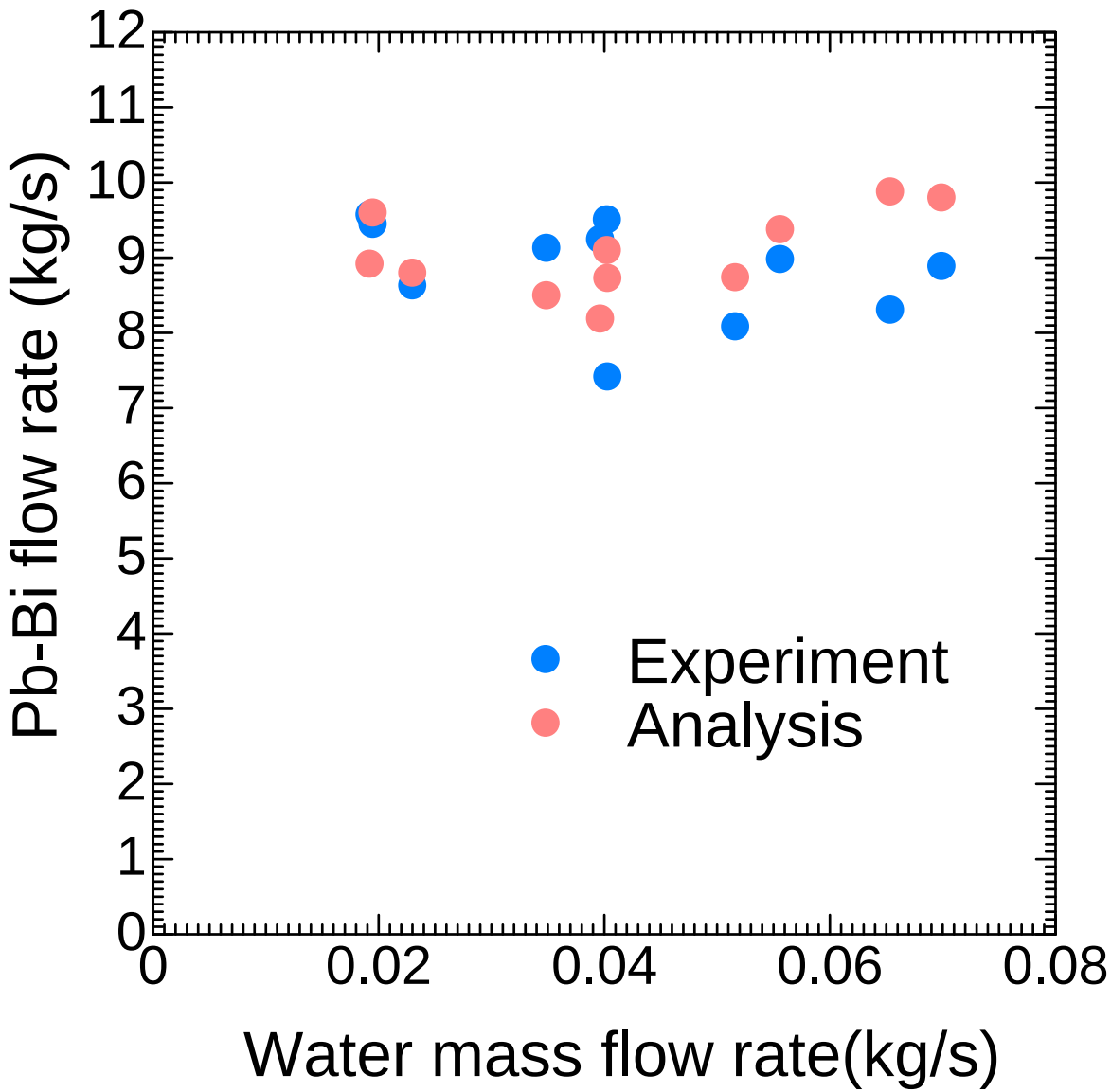
Acceleration loss at water injection point

$$\Delta P_a = G^2 x \left(\frac{1}{\rho_w} + \frac{1}{\rho_p}\right)$$



Flow model

Comparison of Experiment and Analysis



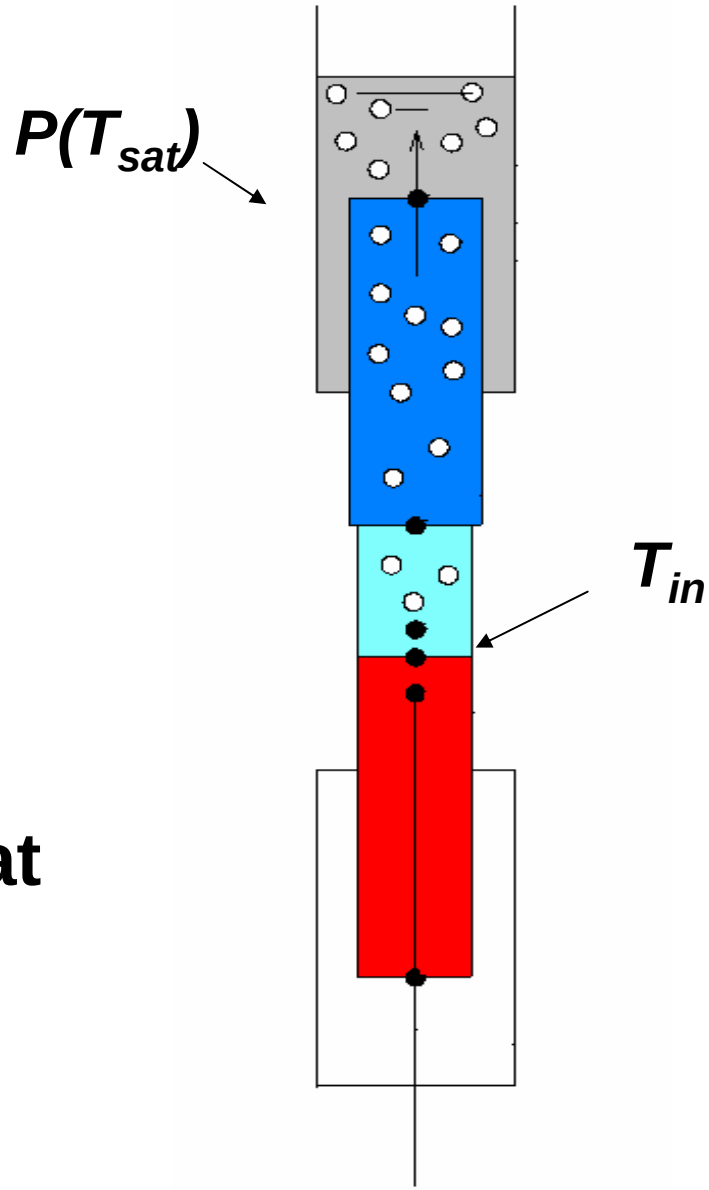
Estimate of Direct Contact Boiling Heat Transfer

Volumetric heat transfer coefficient

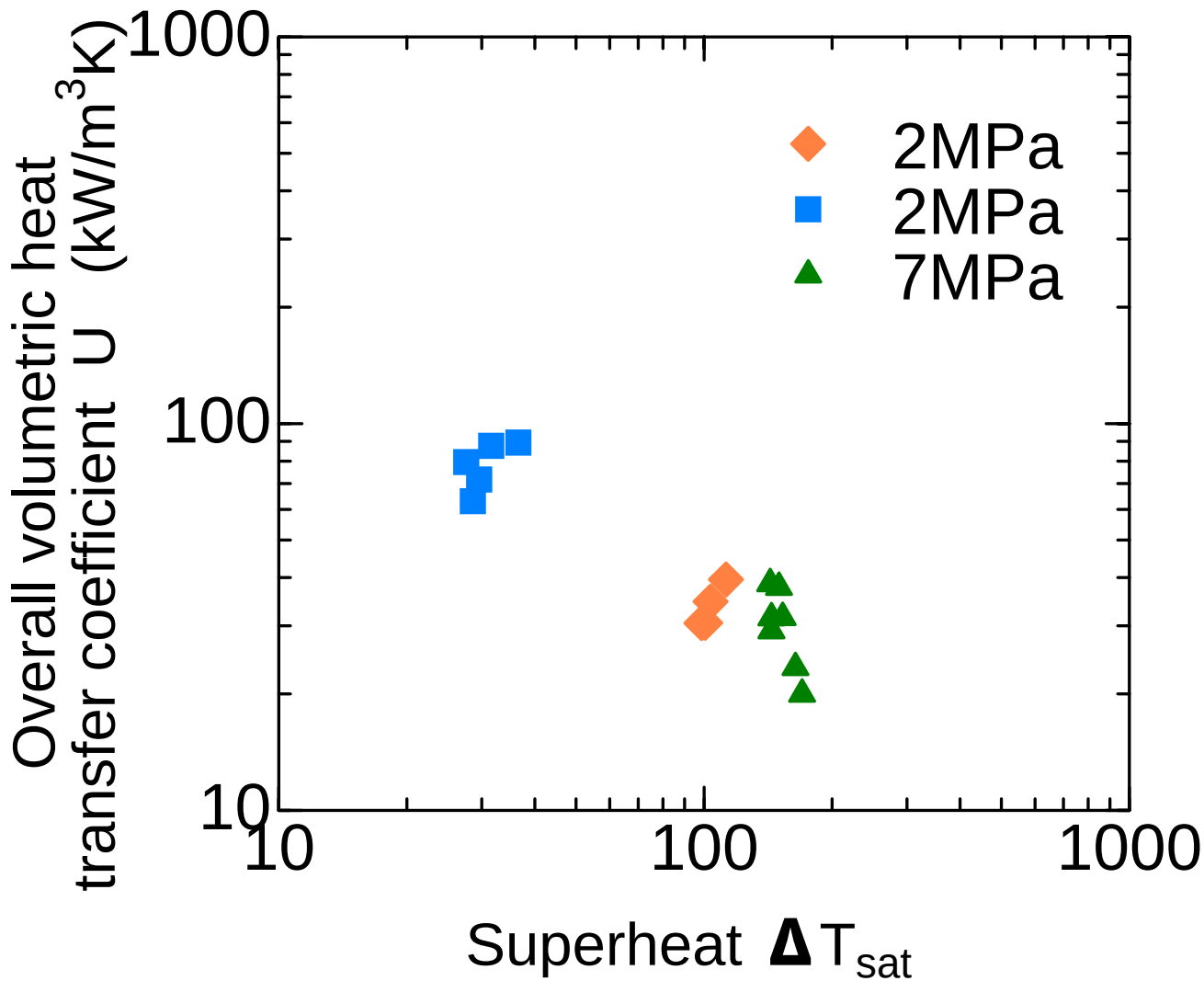
$$U = \frac{Q}{V\Delta T_{sat}}$$

Q : **Heat transfer rate**

$\Delta T_{sat} = T_{in} - T_{sat}$ **Superheat**



Volumetric Boiling Heat Transfer Coefficient



Conclusion

1. **Pb-Bi was circulated successfully by boiling bubbles of injected water into Pb-Bi above the heater pin bundle.**
2. **The experimental result of Pb-Bi flow rate agreed well with the analytical result.**
3. **Volumetric heat transfer coefficient ranged 20-100 kW/m^{3}K which was higher than the result of the other study. It decreased with superheat.**