Forced flow boiling heat transfer properties of liquid hydrogen for manganin plate pasted on one side of a rectangular duct

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Introduction

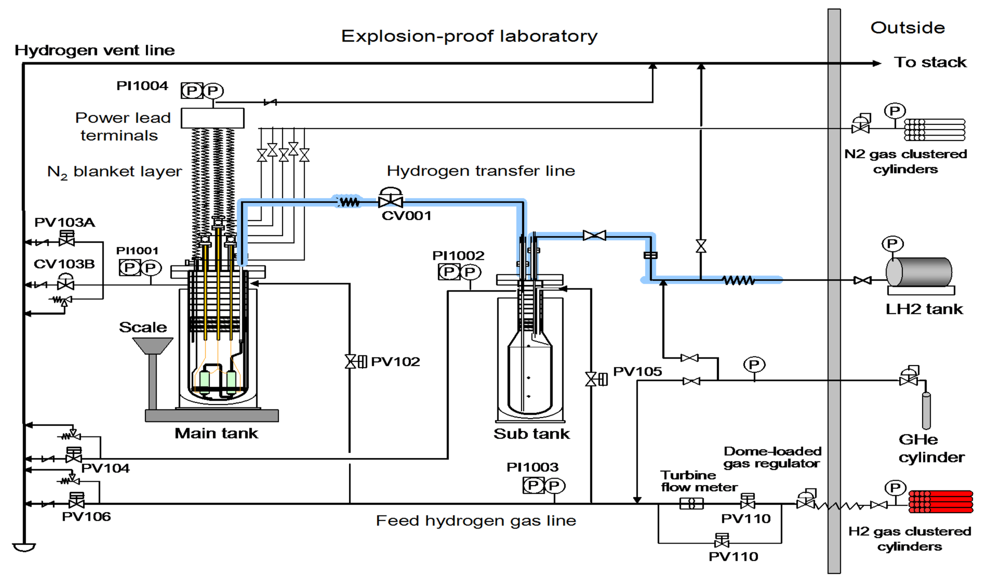
Liquid hydrogen (LH2) is expected to be a coolant for high critical temperature superconducting devices on account of its good properties as a coolant. In order to design the LH2 cooling system of superconducting devices, it is important to grasp the cooling characteristics of forced flow LH2. We have studied forced flow heat transfer properties of LH2 for inner side of heated tubes under wide range of experimental conditions and heater's dimensions. But there would be many shapes of LH2 flow channel and actual superconducting devices.

Assuming a plate heater and a rectangular flow channel, we designed and made a test plate heater of manganin pasted on one side of a rectangular duct made of FRP (Fiber Reinforced Plastic) block. Forced flow heat transfer properties of the plate heater was measured, and the experimental results are shown below.

Experimental system and sample

A schematic diagram of the experimental system is shown on the right. The system consists of a main cryogenic tank, a sub cryogenic tank, hydrogen transfer tube with a flow control valve (CV001) and feed hydrogen gas line.

The main tank is pressurized to a desired pressure by hydrogen gas, while the pressure of the sub tank is always kept equal to atmospheric pressure. The difference of their pressure and the open ratio of CV001 produce forced flow of LH2 from the main tank to the sub tank through the hydrogen transfer tube. There is a scale under the main tank, the LH2 mass flow velocity is measured by the weight change of the main tank.

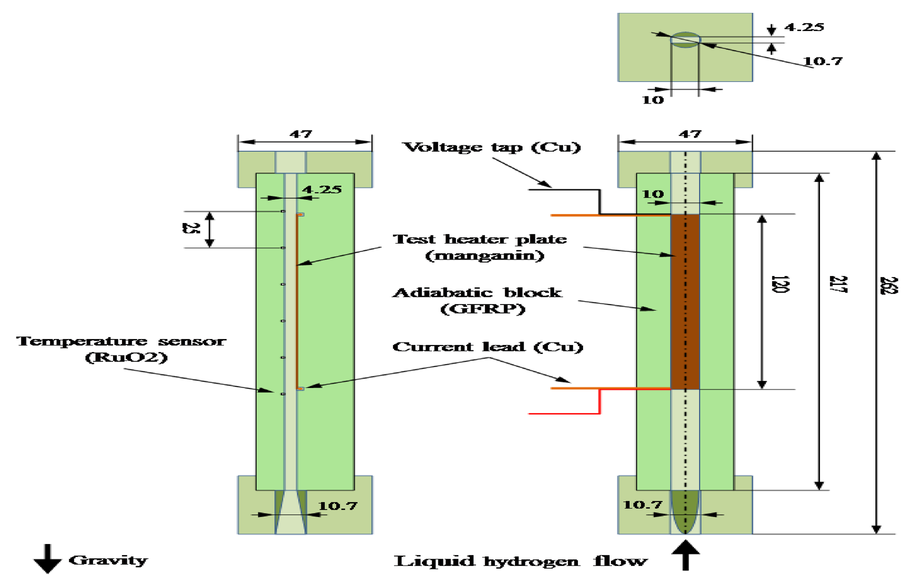


The test heater is a manganin plate pasted on one side of a rectangular duct made of FRP with 4.2 mm × 10 mm in cross section.

The manganin plate is 10 mm wide, 120 mm long and 0.1 mm thick.

The flow channel gradually change from the transfer tube to a rectangle. In order to stabilize LH2 flow, the support running distance of 69mm is prepared before the heater.

In addition six Ruthenium-Oxide (RuO2) temperature sensors of 0.3 mm × 0.5 mm × 1.0 mm are attached in small holes on FRP opposite side of the heater in the rectangular duct. These RuO2 temperature sensors are prepared in order to clarify the growth of thermal boundary layer on the heater with the information of liquid temperature distribution opposite to the heater.



Experimental method

At first the main tank was pressurized to a desired pressure, which produced LH2 flow from the main tank to the sub tank. When the LH2 flow rate became constant, heating current was inputted to the heater. The exponentially increasing heat input Q_L was given as following.: $Q_L = Q_0 \exp\left(\frac{t}{\tau}\right)$

In these experiments, the heat generation Q_L expressed above and τ = 5 s was applied to the heater. It was experimentally verified that heat transfer phenomenon could be considered as a continuous series of steady state.

The temperature of the heater an RuO2 temperature sensors were measured by the thermal resistivity which had been calibrated before all experiments.

The heat transfer from the heater was measured under various condition. Experimental condition are shown in the table on the right.

Heat generation rate

$$Q_L = Q_0 \times \exp(t/\tau) \quad (\tau = 5\ \mathrm{s})$$

Experimental conditions

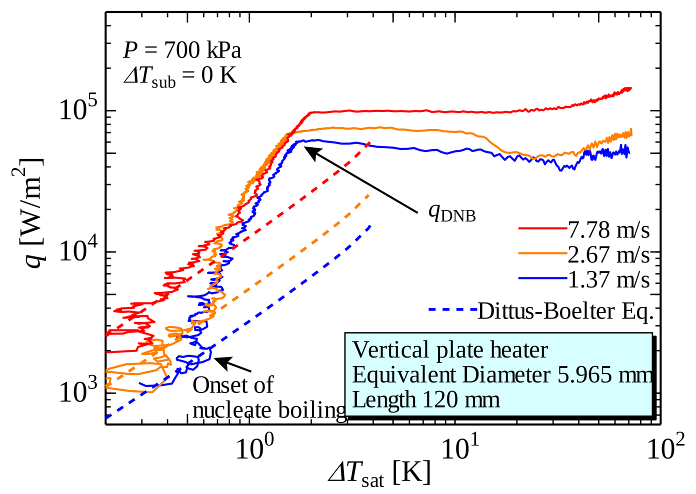
Pressure	0.4 , 0.7, 1.1 MPa
Subcooling	0 ~ 11 K
Flow velocity	0.3 ~ 15 m/s
Liquid temperature	21 ~ 32 K

Results and Discussion

・The heat transfer properties under saturated and subcooled condition

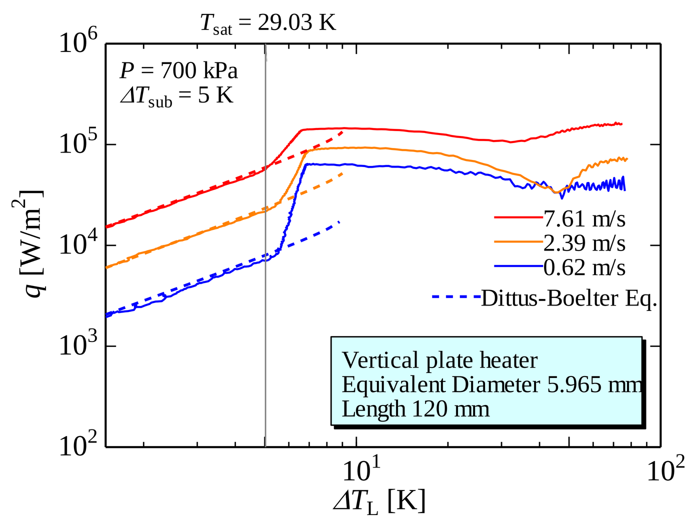
ΔT_{sat} : the heater surface superheat

- As the heat input increases, heat flux, q, gradually increases along the curve predicted by Dittus-Boelter equation.
- In nucleate boiling region, heat flux rapidly increases up to DNB heat flux, q_{DNB}. Then boiling phenomenon jumps to film boiling region.



ΔT_L : the difference between the heater surface temperature and the inlet liquid temperature of the flow channel

- In non-boiling region, with increase of ΔT_L by heat input, heat flux increases along the curve predicted by Dittus-Boelter equation.
- In non-boiling and nucleate region, the heat flux is higher for higher flow velocity.

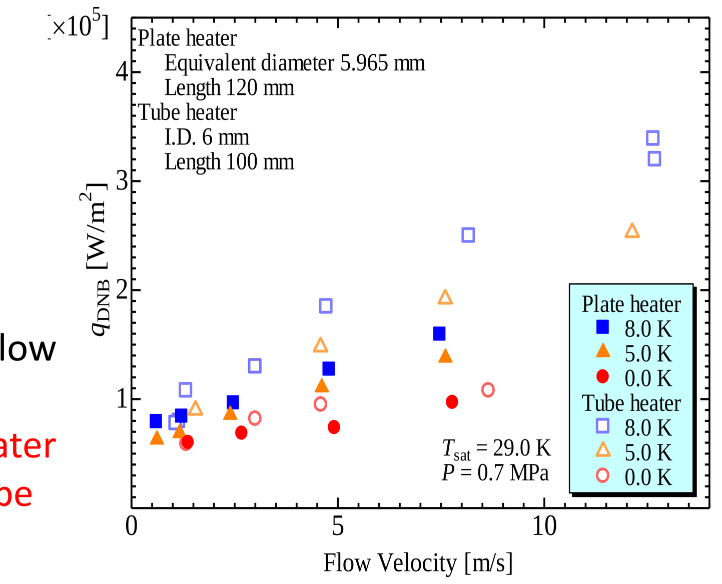


・Relation between DNB heat flux and flow velocity

Closed symbol :
this results of the plate heater

Open symbol :
past experimental data for the round tube heater of nearly equal equivalent diameter

- DNB heat flux is higher for higher flow velocity and subcooling.
- The DNB heat flux for the plate heater is lower than that for the round tube heater under most conditions.



In nucleate boiling around DNB heat flux …

Heated surface :
A lot of boiling bubbles would make LH2 easy to flow.

Unheated surface :
There would be few vapor bubbles. So the viscosity of LH2 would make flow velocity on unheated surface of the duct close to zero.

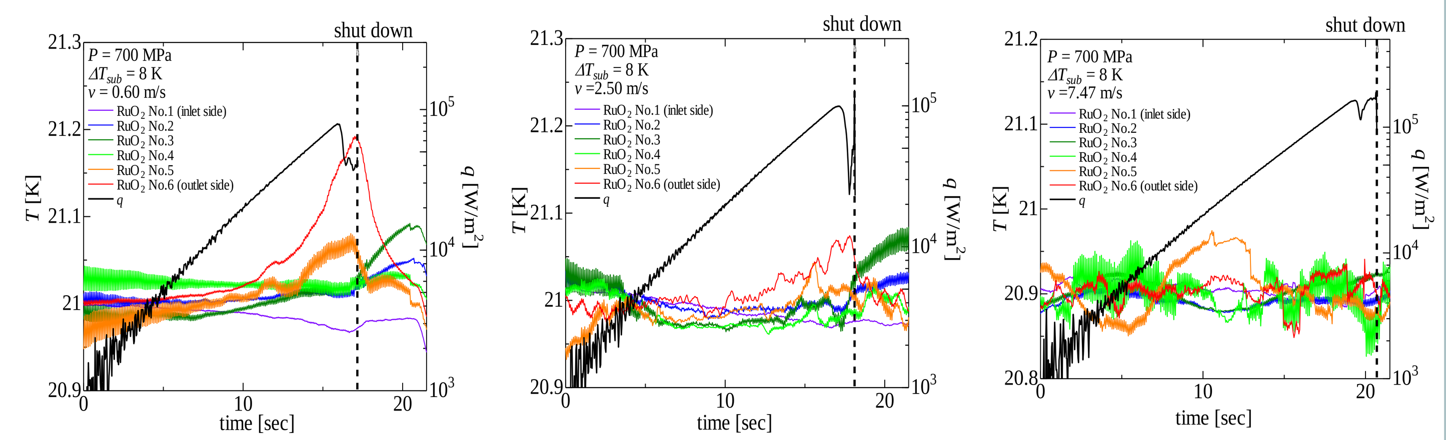
The flow velocity on both ends of the heater in width direction would be lower than other heated area. This may cause locally lower DNB heat flux.

・Liquid temperature distribution

Numbers of RuO2s from 1 to 6 are assigned in order from the inlet side to the outlet side.

- The temperature of two RuO2s nearer to the outlet of the flow channel rise up higher with comparatively slow flow velocity of 0.60 and 2.50 m/s during heat input.
- The temperature of all RuO2s hardly change with high flow velocity of 7.47 m/s.

This means that the thermal boundary layer on heated surface did not develop thick enough with high flow velocity.



Conclusions

Forced flow boiling beat transfer properties and DNB heat flux were measured for manganin plate pasted on one side of a rectangular duct. The experimental results lead to the following conclusion

- Non-boiling heat transfer coefficients are well described by Dittus-Boelter equation.
- DNB heat flux is higher for higher flow velocity and subcooling.
- Compared with experimental results on a round tube heater of nearly equal equivalent diameter, the DNB heat flux for this plate heater is lower than that for the round tube heater under most conditions.

This may be because the LH2 flow velocity around the corner of heated and unheated sections is lower. Additional experiments for another plate heater need to be carried out so that the assumption could be confirmed.

- Liquid temperature distribution opposite the heated surface was measured by RuO2 temperature sensors. The temperature nearer to the outlet of the flow channel rises up higher with comparatively lower flow velocity.