# Film Boiling Heat Transfer Properties of Liquid Hydrogen in Natural Convection

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## Abstract

Film boiling heat transfer properties of $LH_2$ for various pressures and subcoolings were measured by applying electric current to give an exponential heat input to a test PtCo wire with the diameter of 1.2 mm submerged in $LH_2$. The test wire was set to be horizontal to the ground. The heat transfer coefficient $h$ in film boiling region was higher for higher pressure and higher subcooling. The experimental results were compared with the equation of pool film boiling heat transfer. It was confirmed that the pool film boiling heat transfer coefficients in $LH_2$ were expressed well by the equation.

## Introduction

Liquid hydrogen ($LH_2$) has the excellent properties as a coolant for HTS conductors.

Knowledge of heat transfer in film boiling is important for using superconducting devices cooled by $LH_2$ safely.

In this report, we show the film boiling heat transfer properties of $LH_2$ in natural convection as a preliminary step to forced flow film boiling experiment. We obtained the experimental data of pool film boiling heat transfer from a horizontal PtCo wire for various pressures, liquid-subcoolings, and surface superheats. The experimental data of the heat transfer coefficient in range of film boiling was compared with the equation of pool film boiling heat transfer presented by Sakurai *et al*.

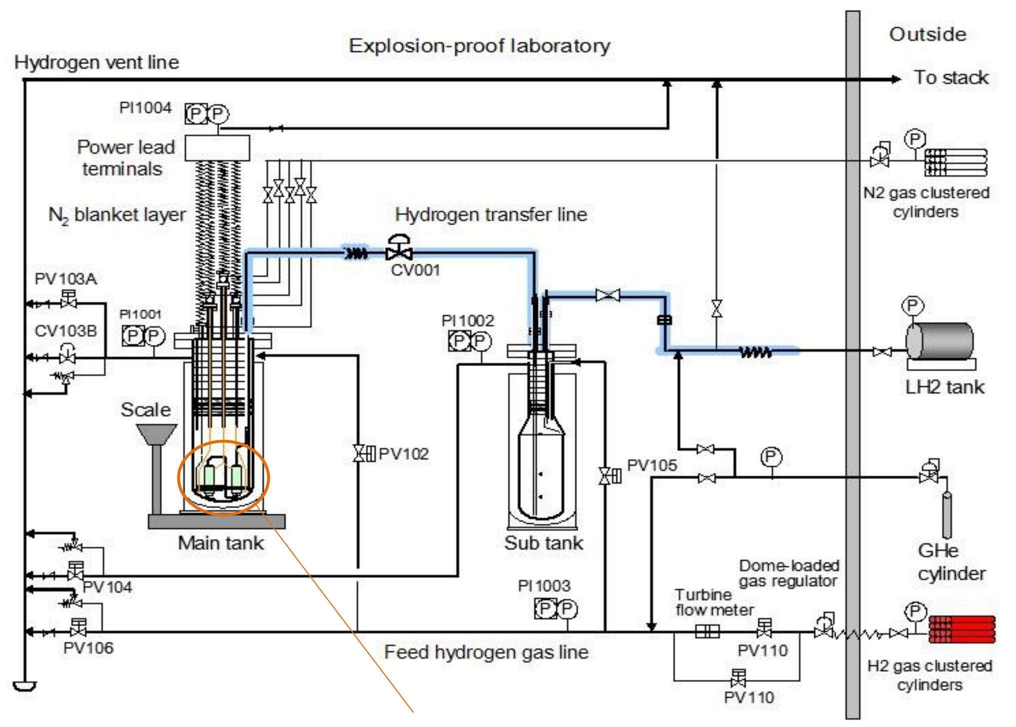
## Experimental Apparatus

◆ The test heater was heated by applying electric current to give an exponential heat input.

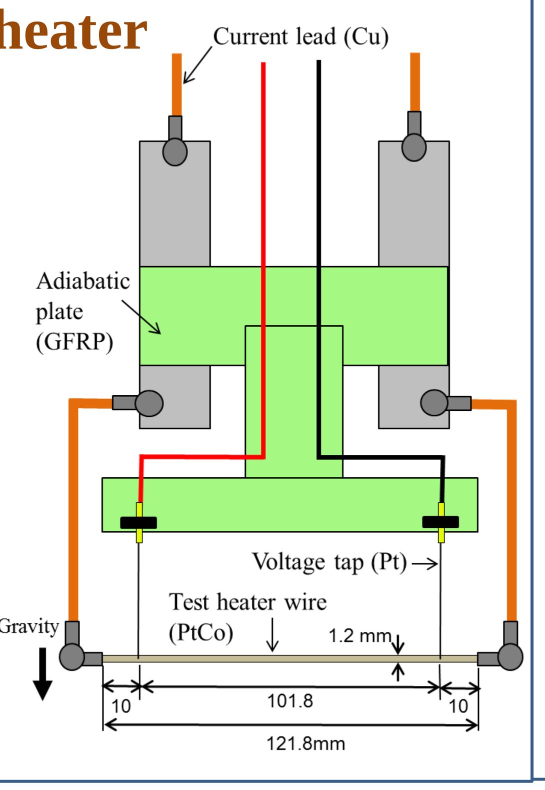
◆ The heat input was increased exponentially until the temperature of the test wire rose by about 400 K and then reduced exponentially to zero.

◆ The average temperature of the heater was obtained by a resistance thermometry by four-terminal method.

◆ The surface temperature of the heater was calculated from the measured average temperature and heat flux by solving the one-dimensional thermal conduction equation in the radial direction of the heater.




Test heater




### Experimental Conditions

Test heater : PtCo wire
$d$ = 1.2 mm, $L$ = 101.8mm
Pressure : 0.1, 0.4, 0.7, 1.1 MPa
$LH_2$ temperature : 21~32 K

## Results and Discussion

### Typical Boiling Heat Transfer Process

◆ With increase of heat input, the heat flux at non-boiling region gradually increases along the curve predicted by the natural convection equation presented by Mcadams.

◆ When the heater surface temperature reaches the saturation temperature, nucleate boiling starts.

◆ When the heat flux reaches CHF, heater temperature rapidly increases with a decrease of heat flux to film boiling regime.

◆ Heat input is further increased until heater temperature reaches around 400 K. Then the heat input is decreased exponentially and film boiling heat transfer coefficients are measured down to the minimum heat flux point (about $\Delta T_L$ = 20 K)

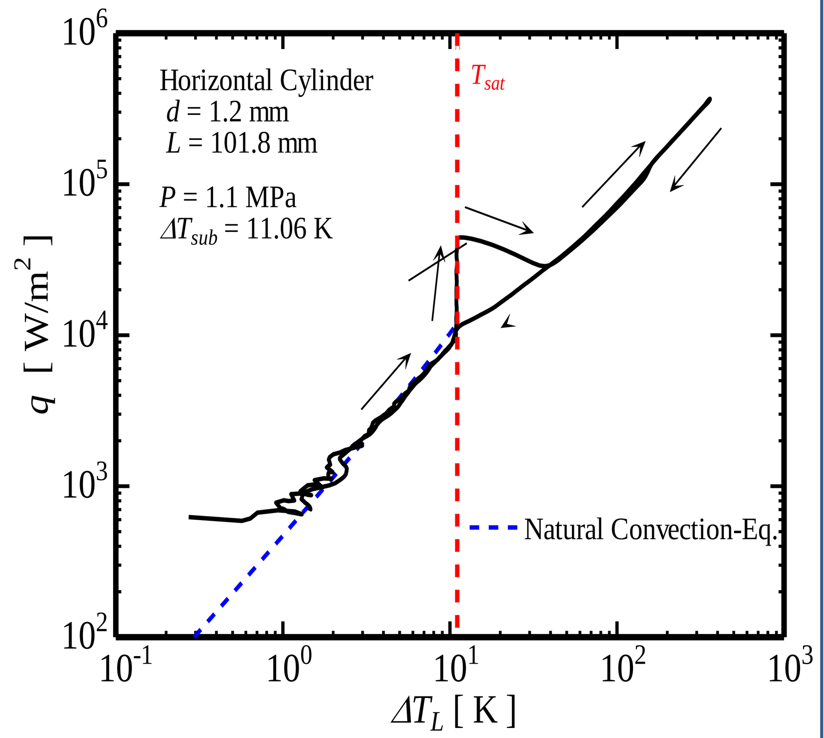



Fig. 2 Typical result of boiling curve in natural convection for the PtCo wire

### Effect of Pressure on Film Boiling Heat Transfer Coefficient

◆ Fig. 3 shows film boiling heat transfer coefficients under saturated condition with pressure as a parameter.

◆ The value of $h$ for each pressure decreases with the decrease of wall superheat and takes a minimum at around K. Then it increases significantly with the decrease of wall temperature.

◆ The heat transfer coefficient $h$ in film boiling region is higher for higher pressure.

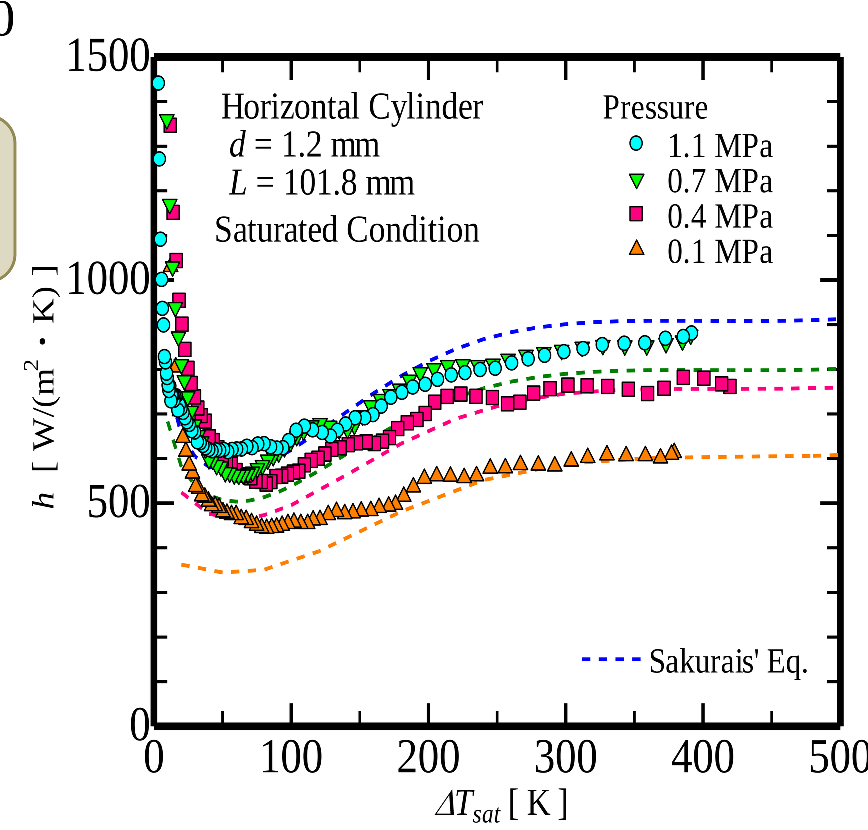



Fig. 3 Saturated film boiling heat transfer coefficients against with pressure as a parameter. The horizontal axis is the excess heater surface temperature beyond saturation temperature.

### Effect of Subcooling on Film Boiling Heat Transfer Coefficient

◆ Trend of dependence on $\Delta T_{sat}$ is similar to that for the saturated condition mentioned above.

◆ The values of $h$ are higher for higher subcooling.

◆ The effect of subcooling is comparatively smaller than that of pressure because it is difficult to realize the sufficiently high subcooing for $LH_2$

### Comparison with Conventional Correlation

◆ Sakurai et al. presented the correlation of pool film boiling heat transfer from a horizontal cylinder by slightly modifying their solution of two-phase boundary layer film boiling model based on experimental data for various liquids. The predicted curves by their equation are shown in Fig. 3 and 4 as broken lines.

◆ The experimental data agree with the values calculated from the Sakurai's equation within -10 to +8 percent error as shown in these figures.

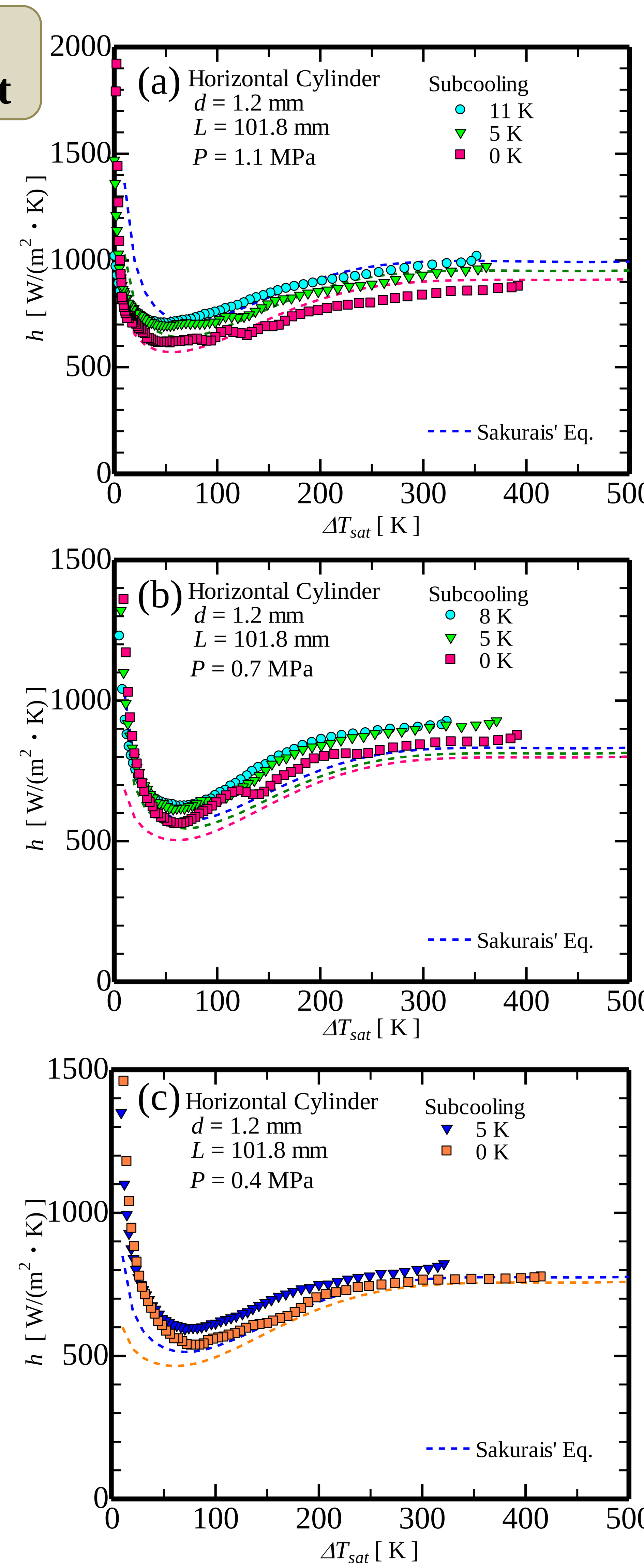



Fig. 4 Film boiling heat transfer coefficients against surface superheat with subcooling as a parameter.
(a) $P$ = 1.1MPa, (b) $P$ = 0.7MPa, (c) $P$ = 0.4MPa

## Conclusion

◆ Film boiling heat transfer coefficients for $LH_2$ in natural convection on horizontal wire were obtained for various system pressures and bulk temperatures.

◆ The heat transfer coefficient $h$ in pool film boiling region was higher for higher pressure and higher subcooling.

◆ It was confirmed that the pool film boiling heat transfer coefficients in $LH_2$ were expressed well by the equation presented by Sakurai et al..