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Experimental Study of Pool Boiling Heat Transfer and Critical Heat Flux on a Horizontal Zircaloy Tube

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1. Introduction

The zirconium-based claddings are widely used as cladding materials of light water reactors (LWR). However, oxidation and hydrogen generation of zircaloy cladding are accelerated in a severe environment, such as LOCA or Fukushima Daiich accident.

Recently researches on an alternative material for claddings have been conducted. For example, Silicon carbide (SiC) is one of the potential claddings recommended for its safety and performance. However, many issued remains un-solved, especially on manufacturing methods, irradiation behavior, and thermal hydraulics performance. To confirm the performance of a new cladding, comparison of the current cladding material, zircaloy tube, and SiC material is needed in aspects of boiling phenomena.

2. Theoretical Background

Many studied have been carried out to explain the CHF phenomenon qualitatively and quantitatively over several decades. Sun and Lienhard noticed that the diameter of heaters affected the CHF [1]. In order to modify the previous CHF correlation, they introduced the dimensionless heater radius R' as defined by

$$R' = R\sqrt{\frac{g\left(\rho_l - \rho_v\right)}{\sigma}} \qquad (1)$$

The CHF correlation for small cylinders (0.2 < R' < 2.4) based on their analysis was suggested by

$$q^{"}_{crit} = 0.123 h_{fg}\rho_v^{1/2}\left[\frac{\sigma^3 g\left(\rho_l - \rho_v\right)}{R^2}\right]^{1/8} \qquad (2)$$

Lienhard and Dhir conducted extensive experiments to verify the equation on various liquids []. Moreover, Liaw and Dhir observed that the CHF decreased with increasing contact angle in a range of 27^o to 107^o as shown in Fig. 1 [1].

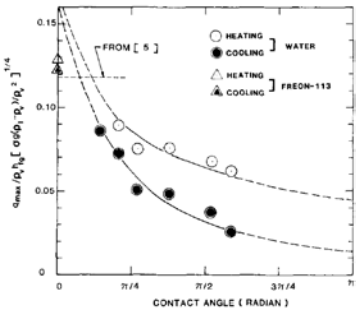


Fig. 1. Dependence of CHF on contact angle [1]

It was noticed that the higher CHF occurs on a wettable surface, which has a small contact angle. The Zuber and Lienhard-Dhir theories of CHF correspond to the low very contact angle.

3. Description of Experimental Apparatus and Test Procedure

A 3D drawing of the pool boiling apparatus used in this study is shown in Fig. 2. It has a cubic geometry, which is 0.3 m in length, 0.3 m in width, and 0.3 m in height. Since a pool boiling experiment is usually accompanied by visualization work, three windows made of quartz are installed on different sides. Copper electrodes inserted from the top of the equipment are used to supply electrical power during boiling tests.


Fig. 2. 3D drawing of pool boiling facility

There are two types of heaters used in this study. A zircaloy tube heater is directly connected to the copper electrodes. For a SiC tube heater, a stainless steel tube is inserted to the inside of the SiC tube, and connected to the electrodes. During the tests, both tubes directly linked up with the electrodes are electrically heated with increasing current. As a result, the zircaloy tube is heated directly while the SiC tube is powered indirectly. The heater dimensions are summarized in Table 1. In order to measure wall temperature K-type thermocouples wrapped by metal foil were attached to the inner wall of both heaters.

Table 1: Heater Dimensions

	Zircaloy	SiC
Length (m)	0.1250	0.0504
O.D. (m)	0.0095	0.0100
I.D. (m)	0.0084	0.0083
Surface area (m^2)	0.0037	0.0016
Heating type	Direct	Indirect

4. Experimental Results

In this study, experiments of the heat transfer on a zircaloy tube in the pool boiling were carried out, especially focused on an observation of CHF. Furthermore, boiling behaviors on the zircaloy tube were compared with those on a SiC tube in low heat fluxes.

To confirm the effect of surface wettability, contact angles were measured before the experiments. Pictures of contact angles on the bare zircaloy and SiC tubes are presented in Fig. 3.

(a) Zircaloy – CA: 77.9° (b) SiC – CA: 74.0°

Fig. 3. Contact angles of zircaloy and SiC tubes

The zircaloy heater was heated with increasing heat flux of 30 kW/m^2 gradually, and reached to the point of CHF, which is 599.98 kW/m2, as shown in Figs. 3 and 5. A comparison of the CHFs is presented in Table 2.

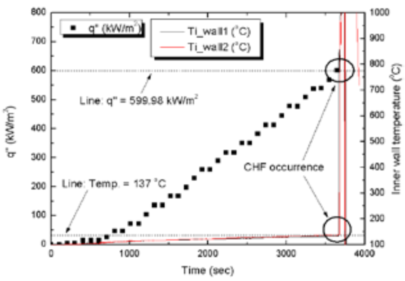


Fig. 4. Variation of heat flux and inner wall temperatures with time

Visual comparison of boiling behavior on zircaloy and SiC tubes at low heat flux is shown in Fig. 6. The SiC tube shows an improved boiling heat transfer.

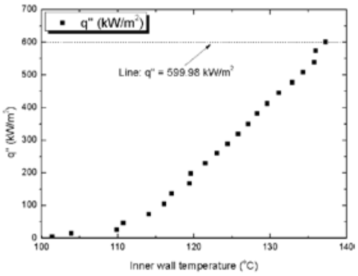
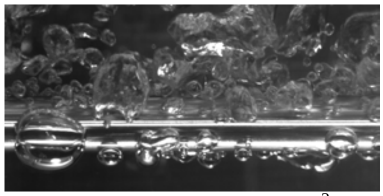


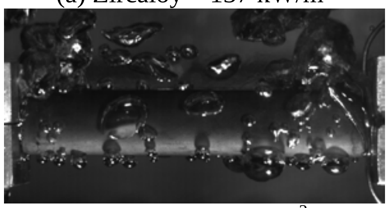
Fig. 5. Variation of heat flux with inner wall temperature

Table 2: CHF values

	CHF (kW/m^2)
Experiment	599.98
Lienhard and Dhir [1-2]	886.70
Liaw and Dhir [1-2]	592.14



(a) Zircaloy – 137 kW/m^2



(b) SiC – 120 kW/m^2

Fig. 6. Comparison of boiling behavior on zircaloy and SiC tubes at low heat flux

5. Conclusions

An experimental study of the pool boiling heat transfer and CHF on a horizontal zircaloy tube was carried out, comparing those on SiC tube in a low heat flux. The observed CHF are different from the predicted values since geometrical and surface wettability effects are not considered together in the correlations suggested. Thus, a modification for current correlations to reflect both effects is recommended.

Acknowledgements

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