A Preliminary Experimental Study on Flow Boiling CHF Characteristics of Ballooned Channel

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1. Introduction

Cladding is one of the most important parts in nuclear power plant because it is second barrier of radiation leakage from nuclear fuel. Originally, cladding keeps its integrity in 1200 ° C and 150bar, which is normal operation state of nuclear power plant. However, integrity of cladding is weakened by radiation from fuel and weakened cladding can be deformed by more severe conditions caused by accident. In case of LOCA, high temperature, oxidation and thermal shock induced by safety injection can deform cladding.

Main problem of deformed cladding is blockage of coolant flow path. After LOCA accident, core should be cooled to prevent core melt accident. Change of flow path by blockage affects flow of safety coolant, heat transfer coefficient and critical heat flux of rod bundles. Until now, there are insufficient heat transfer data for deformed flow path compared to normal flow path. In order to enhance safety of nuclear power plant after accident, it should be clarified that how deformed cladding affects heat transfer. The purpose of this research is to measure heat transfer characteristics experimentally and to develop correlation based on experimental data. Experiments are in progress.

2. Experimental Apparatus

2.1 Experimental Loop and Procedure

The experiment was conducted on KAIST flow boiling experimental loop. The KAIST flow boiling test loop is shown in Fig. 1. The test loop is composed of a pump, an electromagnetic flow meter, an electric pre-heater, test section, a condenser, and a surge tank. Water is working fluid of the test loop.

The direct Joule heating was used for heating test section. Electric power was provided by the 75kw DC rectifier which has specification of 25V*3000A.

The water was circulated in the test loop by a pump and it flows vertically upward in the test section tube. The signals of mass flux, inlet temperature, pressure and surface temperature of test section were acquired by data acquisition system, Agilent 34972A.

The experimental procedure is as follows. The massflux of working fluid and inlet temperature is setup before heating experiment. The test section is heated up gradually by slowly increasing the voltage of the test section. The heating power is increased stepwise after thermal equilibrium of the working fluid in the loop.

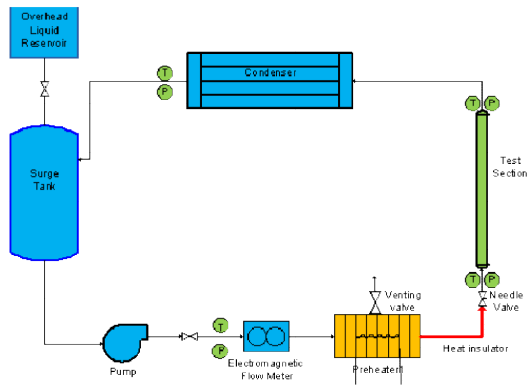

Fig 1. Schematic diagram of KAIST flow test loop

The CHF was detected by a sudden increase of the surface temperature of the test section. Heat flux in the test section is calculated as

$$q' = \frac{VI}{\pi D_i L}$$

where V and I are the measured voltage and current, Di is the inlet diameter of test tube and L is length of test section.

Thermo couples were clipped by bakelite jig on the test section to measure surface temperature. 5 thermo couples were used for reference data experiment and 7 thermo couples were used for deformed test section.

All tests were conducted under atmospheric pressure.

2.2 Design of Deformed Test Section

The test section was designed to simply tracing the shape of deformed(especially ballooning) fuel rod. The Schematic diagram of deformed test section is shown in Fig. 2.

Each part(L1~L5) is welded together and T1~T7 means the place thermo couple. The conducted experimental case in this study is as shown below. The thickness of the tube is 1mm for whole part of the tube.

The test condition were 50K of inlet subcooling and 100, 200 kg/m^2s of mass flux.

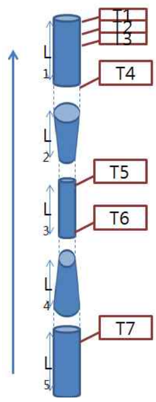

Fig 2. Deformed Test Section

ID_1	10	L_1	100
ID_2	10-8	L_2	50
ID_3	8	L_3	200
ID_4	8-10	L_4	50
ID_5	10	L_5	100

Table 1. Dimension of Deformed Test Section[mm]
(ID:Inlet Diameter)

3. Results and Discussion

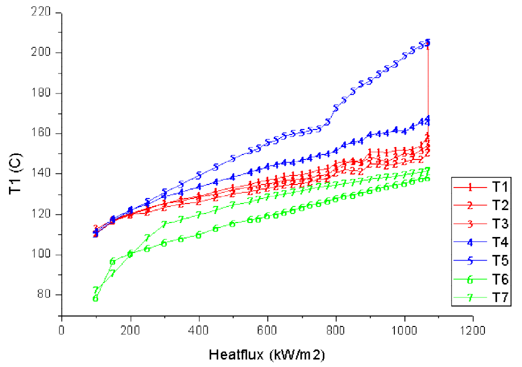

Fig 3. Temperature Profile of $100kg/m^2s$ case

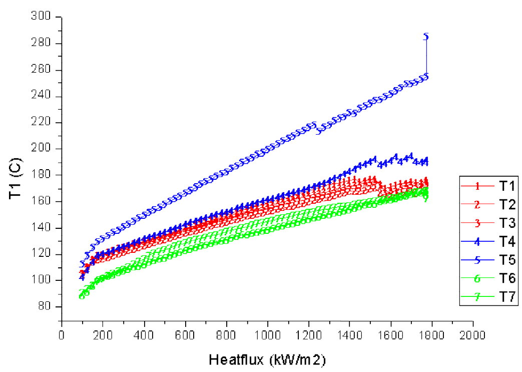

Fig 4. Temperature Profile of $200kg/m^2s$ case

The results of each 2 cases are shown in Fig 3 and 4. CHF was occurred at the outlet of the whole tube(T1) for $100kg/m^2s$ case. For $200kg/m^2s$ case, CHF was occurred at the outlet of the deformed part(T5). The mass flux condition is calculated by the inlet diameter of the tube. It has different value at the deformed part.

Inlet Part (ID:10mm)	Deformed Part (ID:8mm)
$100kg/m^2s$	$156kg/m^2s$
$200kg/m^2s$	$312kg/m^2s$

Table 2. Transition of Mass Flux

Also, the heat flux is different when same electric power is hanged on. The different value of heat flux when CHF was occurred is shown below

	Inlet Part (ID:10mm)	Deformed Part (ID:8mm)
$100kg/m^2s$	**$868kW/m^2$**	$1326kW/m^2$
$200kg/m^2s$	$1436kW/m^2$	**$2193kW/m^2$**

Table 3. Heat Flux of Each Part at CHF

The bold character means that CHF was occurred. The value of CHF data was compared with existing CHF correlation, Groeneveld(G), Katto(K), and Bowring(B). The experimental condition for predicting CHF value from existing correlation was based on smooth tube and 50K inlet subcooling with each given mass flux condition.

	G	K	B	Exp. Data
$100kg/m^2s$, 10mm	645	1040	1037	868
$312kkg/m^2s$,8mm	1163	2473	1807	2193

Table 4. Data Comparison with existing correlation[kW/m^2]

4. Conclusion

The result of preliminary experimental test of ballooned channel was reported. The trends of CHF value for deformed channel is not usual as normal smooth tube. The spot of CHF was moved by changing different experimental cases. The transition of flow pattern at neck of deformation is considered as main factor of changing CHF trends. More cases are under operation and analysis based on flow dynamics are developing.

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