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Effects of Exit Quality on the Flow Boiling CHF Enhancement of Nanofluids

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1. Introduction

Recently, nanofluid has been highlighted in thermal-hydraulic engineering fields. Considering importance of flow boiling heat transfer in practical applications, flow boiling CHF of nanofluid have been studied extensively, and CHF enhancement using nanofluids was observed in flow boiling condition [1-3]. However, previous works were done for relatively low exit quality conditions. In this study, flow boiling CHF of magnetite-water nanofluids is assessed for wide range of exit quality conditions, especially for intermediate and higher exit quality.

2. Experiments and Results

2.1 Experiments: Apparatus, Procedure & Test Matrix

Shown in Fig. 1, the experimental loop for flow boiling tests consists of pump, flowmeter, variable orifice, test section, condenser, surge tank, and pre-heater. As the test section, 1/2 inch stainless steel round tube is used – inner diameter is 10.92 mm and heating length is 25 or 50 cm. To ensure the fully-developed flow conditions, entrance length of 55 cm (or fifth times the tube inner diameter) is assured. The test section tube is installed in vertical direction, and is uniformly heated up by means of direct current Joule heating with 100 kW capacity DC rectifier.

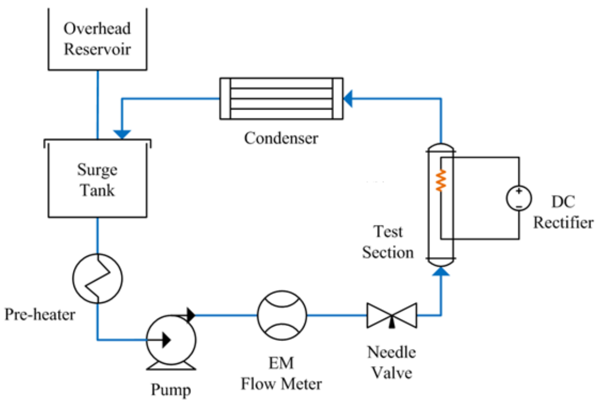

Fig. 1. Schematic of experimental loop for CHF test

Experimental loop is filled with the prepared working fluids, and both mass flux and inlet sub-cooling level are adjusted to the experimental conditions. During experiments, heating power and corresponding heat flux are gradually increased in accordance with the prepared heat flux plan. The occurrence of CHF could be detected by observing a sudden rise of temperature at the test section tube wall.

Experimental conditions for working fluid flow are summarized here. Magnetite-water nanofluids of 1 and 10 ppm volumes are used as working fluid, and the working fluid flows through the test section tube in a vertically upward direction. Various mass flux and inlet sub-cooling are considered to investigate the flow boiling CHF of nanofluids for wide range of exit quality conditions: mass flux ranges from 100 to 500 kg/m^2s and inlet sub-cooling ranges from 10 to 50 K or from 40.55 to 208.05 kJ/kg. And all the experimental data given in this study were produced without the magnetic field condition.

2.2 Flow Regime and Thermal Crisis Type

Based on the Hewitt and Roberts map for the vertical upflow in a round tube, all of experimental data in this study corresponds to the annular flow. [4] However, it is hard to assure that the actual two-phase flow regime is annular flow for every experimental case: For cases of relatively short heating length with the low exit quality conditions, there would be the pre-mature two-phase annular flow and the resulting thermal crisis type would be DNB-like rather than LFD.

In previous works, exit quality ranges from 0.01 to 0.39, and in this study, experiments were conducted with more various exit quality conditions; especially, intermediate and higher exit quality conditions were considered. – calculated exit quality ranges from 0.07 to 0.72 with various heating length, mass flux, and inlet sub-cooling. Thermal crisis mechanism for two-phase flow with low exit quality is known as DNB-like, and for annular flow with relatively higher exit quality, thermal crisis mechanism of LFD is observed. In this study, since flow boiling CHF data were secured with various exit quality conditions, especially with higher exit quality, LFD characteristics of nanofluids could be investigate experimentally.

2.3 Exit Quality and CHF Enhancement

Flow boiling CHF of magnetite-water nanofluids are measured and illustrated in Fig. 2 and Fig. 3. For the cases with heating length of 25 cm and inlet sub-cooling of 50 K, there exists CHF enhancement. Relevant exit quality ranges from 0.07 to 0.35, and this is similar to previous works. Measured CHF enhancement and its tendency related to the nanofluid concentration are consistent with previous works, too. On the other hand, for the cases with heating length of 50 cm and inlet sub-cooling of 10~20 K, there is not CHF enhancement. Relevant exit quality ranges from 0.59 to 0.74, and this is relatively higher compared to the previous works.

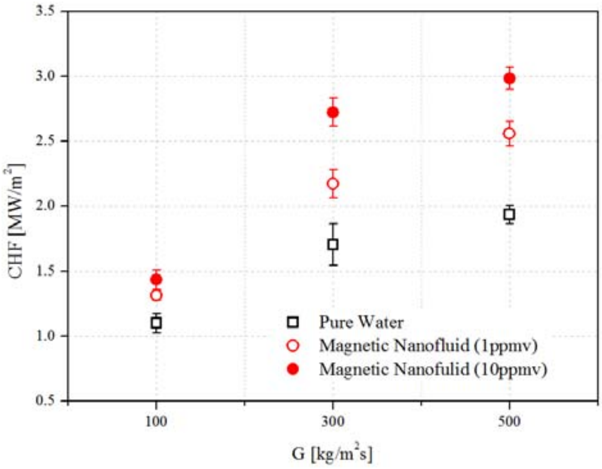

Fig. 2. Flow boiling CHF of magnetite-water nanofluid (L_h = 25 cm, ΔT_{sub} = 50 K, x_{exit} = 0.07~0.35)

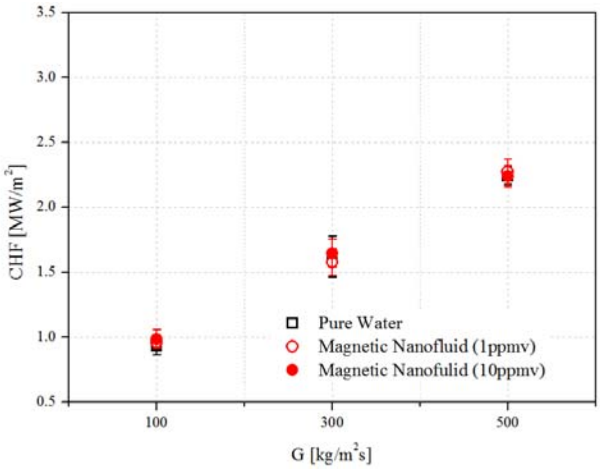

Fig. 3. Flow boiling CHF of magnetite-water nanofluid (L_h = 50 cm, ΔT_{sub} = 10~20 K, x_{exit} = 0.59~0.74)

Major difference between two groups of data, Fig. 2 and Fig. 3, is exit quality, and CHF enhancement is noticeable for the lower exit quality cases rather than for the higher exit quality cases. In annular flow, thermal crisis type tends to approach the LFD as exit quality increases, while tends to approach the DNB-like CHF as exit quality decreases. Therefore, it could be concluded that flow boiling CHF enhancement using nanofluids is remarkable for DNB-like CHF, rather than LFD. To investigate the relationship between flow boiling CHF enhancement and exit quality, experimental results are re-organized in Fig. 4. For lower exit quality region, there exists CHF enhancement. As exit quality increases, extent of CHF enhancement is reduced and ultimately approaches to zero, that is, there does not exist CHF enhancement for higher exit quality region.

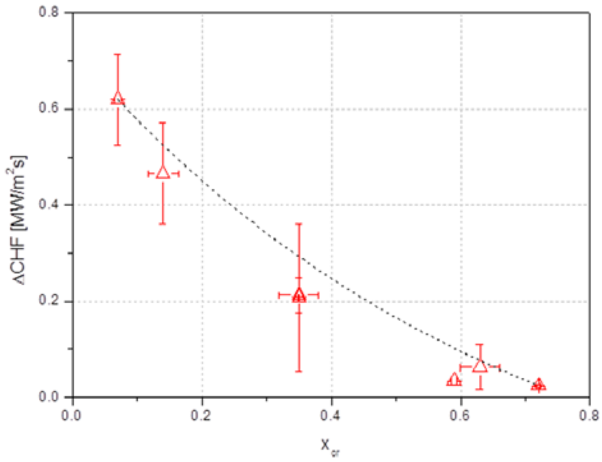

Fig. 4. Flow boiling CHF enhancement vs. exit quality

Reminding that thermal crisis type of two-phase flow with lower exit quality is DNB-like, it could be concluded that CHF enhancement using nanofluids is remarkable for DNB-like thermal crisis. And also, And also, LFD would occur in annular flow with higher exit quality, and therefore, delay of LFD is not expected even though nanofluids are used as working fluid.

3. Conclusions

CHF Enhancement using nanofluids is assessed experimentally for wide range of exit quality conditions, especially for intermediate and higher exit quality. Enhancement is observed for two-phase flow with lower exit quality cases, meanwhile not for higher exit quality cases. As exit quality increases from 0.07 to 0.74, amount of enhancement is reduced and approaches to zero. CHF enhancement using nanofluids could not be expected for annular flow with higher exit quality.

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