CHF Enhancement in Flow Boiling at low mass flux using Al_2O_3 Nano-fluid

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1. Introduction

The CHF enhancement allows higher limit of operation condition so that heat transfer equipments can be operated safely with more margins and can have more economics. Nano-fluid is one of the most potential methods which can enhance the CHF. The flow boiling CHF enhancement experiments using Al_2O_3Nano-fluids with three different concentrations (0.001 vol%, 0.01 vol%, and 0.1 vol%) were conducted under atmospheric pressure, at low mass flux of 100~300 kg/m^2s, at inlet temperature of 50~75℃. The CHFs of Al_2O_3 Nano-fluids were enhanced in flow boiling for all experiment conditions up to about 70%. Maximum CHF enhancement (70.24%) was shown at 0.01 vol% concentration, 50℃ inlet temperature and 100kg/m^2s of mass flux. The Zeta potentials of Al_2O_3 Nano-fluid were measured before and after the CHF experiments.

2. CHF experiments with Al_2O_3Nano-fluids

2.1. Experimental apparatus and procedure

The low pressure and low flow water CHF test apparatus of KAIST is schematically shown in Figure 1.

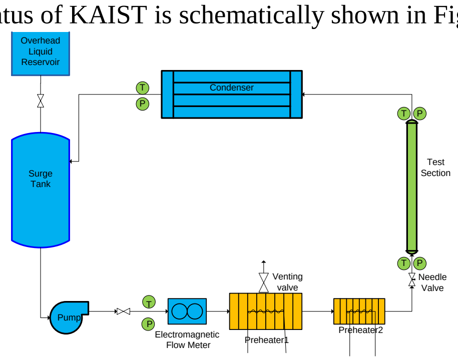

Figure 1. Schematic diagram of experimental loop

Working fluid flows vertically upward in the test section tube. The dimensions of the test section tube and flow parameters are listed in Table 1 and the schematic diagram of the test section is shown in the Figure 2.

The experimental procedure is as follows. The experimental loop is filled with DI water or Al_2O_3 Nano-fluid. The working fluid is circulated by centrifugal pump and heated by pre-heaters to remove non-condensable gas. Degassing is performed for an hour under atmospheric pressure.

After degassing process, sample of working fluid is extracted for measuring zeta potential and pH to confirm the dispersion stability of Al_2O_3 Nano-fluid.

CHF experiments are conducted at two inlet temperatures (50℃ and 75℃) and three mass flux levels (100, 200 and 300 kg/m^2s) as shown in table 1. After CHF experiments, sample of working fluid is extracted for measuring zeta potential and pH to confirm the dispersion stability of Al_2O_3 Nano-fluid. After CHF experiments, test section tube is replaced by new one.

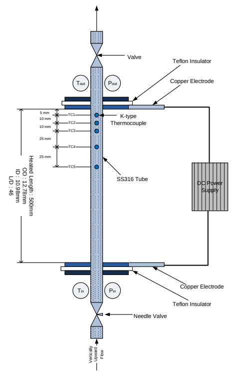

Figure 2. Schematic diagram of test section

Table 1. Test matrix

Test Matrix		
Uniformly heated cylindrical tube		
Outer diameter		12.78 mm
Innerdiameter		10.98 mm
L/D ratio		45.53
Heated length		500 mm
Vertically upward flow		
Pressure		101.3 kPa
Mass flux		100~300 kg/m^2s
Inlet temperature		50~75 ℃
Working fluid		
Total fluid		53l
DI water		
NanoFluid	Al_2O_3	0.001~0.1 vol%

2.2. Results and Discussion

The CHFs of Al_2O_3 Nano-fluids were enhanced in flow boiling for all experiment conditions up to about 70%. Maximum CHF enhancement (70.24%) was shown at 0.01 vol% concentration, 50℃ inlet temperature and 100kg/m^2s of mass flux.

The CHFs of Al_2O_3 Nano-fluids were increased with increasing mass flux at inlet temperatures of 50℃ and

75℃ and this trend is also shown in the DI water (Figure 3). However the CHF enhancement ratios of Al_2O_3 Nano-fluids were decreased with increasing mass flux at inlet temperatures of 50℃ and 75℃. The effect of flow characteristics reduced the effect of wettability enhancement by deposition of nano-particles as increasing mass flux. This can lead the enhancement reduction as increasing mass flux. Jeong et al. also concluded that CHF enhancement was more pronounced at very low mass flux (100 kg/m^2 s), which is due to an increasing wettability of the heater surface [1].

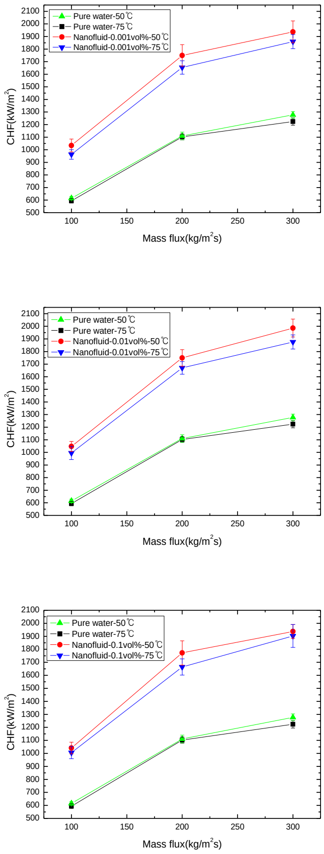

Figure 3. CHFs with different mass flux levels

The CHFs of Al_2O_3 Nano-fluids were almost not changed within the margin of error with increasing Al_2O_3 nano-particle concentration from 0.001vol% to 0.1 vol% at inlet temperatures of 50℃ and 75℃ (Figure 4). The deposition effect may be saturated already at concentration of 0.001vol% and this hypothesis can be confirm by very low nano particle concentration ($\leq 10^{-4}$ vol%) CHF experiments. Kim et al also showed that CHF of Al_2O_3 Nano-fluids in pool boiling is increased at very low concentration ($\leq 10^{-4}$ vol%) and is almost not changed above 10^{-3} vol% [2].

The zeta potentials and pHs of Al_2O_3 Nano-fluids were almost not changed before and after CHF experiments within the margin of error (Table 2). These results guarantee that Al_2O_3 Nano-fluid in the experimental loop was stable during the CHF experiments.

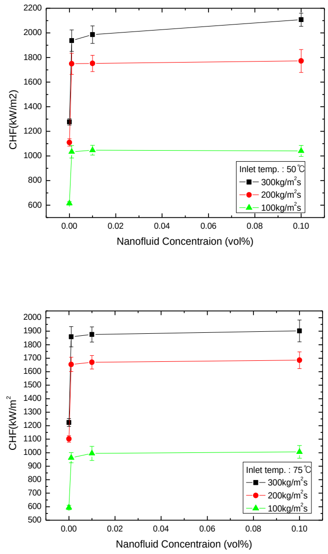

Figure 4. CHFs of Nano-fluids with different concentration

Table 2. Zeta potentials and pHs before and after CHF experiments at 100kg/m^2s

	Zeta 0.001 vol%	Zeta 0.01 vol%	Zeta 0.1 vol%
Before	37±2	48±2	45±4
After	35±1	53±2	49±1

3. Conclusions

The CHFs of Al_2O_3 Nano-fluids were enhanced in flow boiling for all experiment conditions up to about 70%. Deposition of Al_2O_3 nano-particles on the inner surface of test section tube can lead to CHF enhancement.

Acknowledgements

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