An Experimental Study of the Effect of Twisted Tape on CHF Enhancement in a Circular Tube with R-134a

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1. Introduction

Critical Heat Flux(CHF) is the heat flux the phase of fluid near the heated surface changed from liquid to vapor by changing flow or heating condition. Thus CHF has been important role to design and operate the heat transfer instruments having high heat flux. Any increase in CHF to ascent thermal limit can increase the safety margins and allow economic operation. It is one of the widely studied methods to use swirl flow with twisted tape in a circular tube. The centrifugal force is generated in the tube with twisted insert. The swirl flow induced by the centrifugal force has significant ability to enhance heat transfer rate [1]. The swirl effect is generally quantified as the ratio of centrifugal acceleration to the gravity as follow:

$$\theta = \frac{a_t}{g} = \frac{\pi^2 u^2}{2gy^2 D} \quad (1)$$

where a_t is centrifugal acceleration, y is twisted tape ratio defined as length for 180° twist of inside diameter [1]. The recent studies of CHF with twisted tape are conducted below pressure 4MPa with non-uniform heating condition. Most of existing correlations are covered under 4MPa pressure [2]. It is important to develop reliable correlation under high pressure for high heat flux components. Furthermore, most nuclear power plants are operated under high pressure more than 4MPa. CHF test were performed using R-134a for working fluid since R-134a can be used as reliable CHF modeling fluid [3]. In this study the effects of twisted tape to improve CHF and relation between CHF increase and flow conditions are discussed.

2. Experiments apparatus

2.1.Experimental loop

The CHF experiments were performed in KAIST R-134a CHF test facility [4]. The test section is stainless steel (SUS304) circular tube with vertically upward flow and electrically heated with a DC current.

2.2. Test section and matrix

The heated length of the test section is 1000 mm and inside diameter is 10.4 mm. The geometry of twisted tape is length 1200 mm, width 9 mm, and thickness 3 mm. The twisted tape has 3 kinds of twisted tape ratio(y): 5.77, 7.21, and 9.62. The CHF experiment was performed at relatively high pressure and mass flux. The test conditions were covered in the present investigation: test section outlet pressure 12, 15, 18, and 20 bar, mass flux every 1000 from 1000 to 6000 kg/m^{2}s, and inlet subcooling 30, 40, and 50 kJ/kg. The water equivalent test condition converted from R-134a using Katto's fluid-to-fluid modeling is covered outlet pressure 70-120 bar and mass flux 1300-8500 kg/m^{2}s [5].

3. Experimental results and discussion

3.1. Smooth tube

The CHF test in smooth tube without twisted tape was first performed before with twisted tape for showing the effect of twisted tape on CHF enhancement. Figure 1 shows the results from different pressure and mass flux. The CHF increases with decreasing the pressure and increasing mass flux.

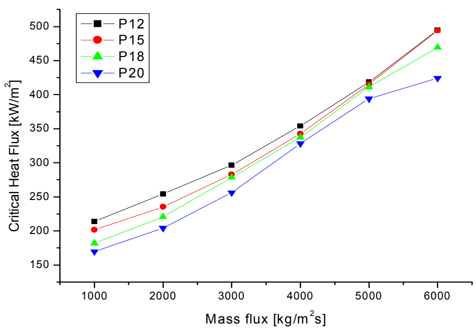

Figure 1. Variation of critical heat flux with mass flux in the smooth tube.

Figure 2 shows the compared results between CHF data measured from the test with R-134a in the smooth tube and converted from the Bowring correlation [6]. Though Bowring correlation is applicable for only water, this correlation is known for good prediction method covering a wide range of flow condition and tube geometry. Thus, the results of Bowring correlation are converted to R-134a equivalent values using fluid-to-fluid modeling. In Figure 2, the mean error and RMS error of the prediction of 68 data points are 4.31% and 7.22%, respectively.

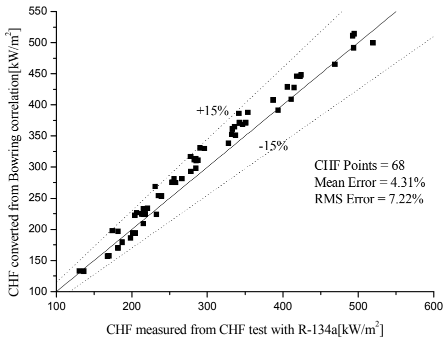

Figure 2. Comparison of CHF test results with Bowring correlation.

3.2. Twisted tape inserted tube

The experiments of CHF with twisted tape in a circular tube were performed to compare with the CHF data in the smooth tube. The parametric trends of CHF in twisted tape inserted tube are similar with that in the smooth tube. CHF increases following mass flux increase and pressure decrease. Figure 3 shows CHF in twisted tape inserted tube improves relative to that in the smooth tube. The fluid mixing between the tube core and the near wall region is enhanced by twisted tape. Thus, CHF increases with decreasing the twisted tape ratio due to the swirl induced tangential flow velocity component.

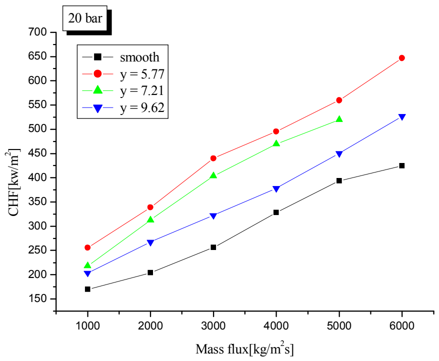

Figure 3. Variation of critical heat flux with mass flux in twisted tape inserted tube at 20 bar.

Figure 4 confirms the effect of the twisted tape on CHF enhancement. CHF improves 10-70% according to flow condition and twisted tape ratio. CHF enhancement ratio increases as following mass flux increase and has maximum value at 2000 or 3000 kg/m^{2}s. CHF enhancement ratio decreases with mass flux at higher than 2000 or 3000 kg/m^{2}s. CHF enhancements increase again at high mass flux about 6000 kg/m^{2}s.

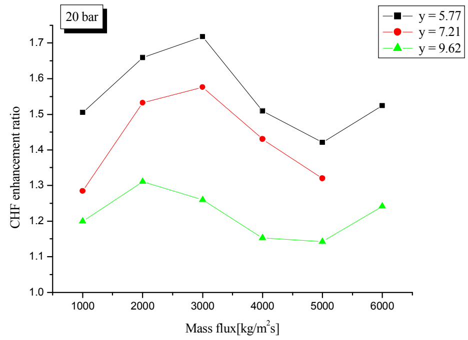

Figure 4. CHF enhancement ratio with mass flux in twisted tape inserted tube at 20 bar.

4. Conclusion

Experiments for CHF using R-134a in smooth tube and three twisted tape inserted tube were performed. Based on this investigation, the following conclusions are obtained.

(1) CHF prediction from Bowring correlation is good agreement with water-equivalent CHF data.
(2) The parametric trends of CHF in twisted tape inserted tube are similar with that in the smooth tube.
(3) The CHF enhancement with twisted tape depends on twisted tape ratio (y) and mass flux.
   - ✓ CHF enhancement increases with decreasing twisted tape ratio.
   - ✓ CHF enhancement ratio has higher values at 2000 or 3000 kg/m^{2}s than others.

REFERENCES

[1] F. Inasaka et al., Critical heat flux of subcooled flow boiling in tubes with internal twisted tape, ASME, 1991.
[2] F. Inasaka, H. Nariai, Evaluation of subcooled critical heat flux correlations for tubes with and without internal twisted tapes, Nuclear Engineering and Design 163 225-239, 1996.
[3] R. M. Tain, S. C. Cheng, Critical heat flux measurements in a round tube for CFCs and CFC alternatives, Int. J. Heat Mass Transfer 36 2039-2049, 1993.
[4] B. S. Shin, S. H. Chang, Experimental study on the effect of angles and positions of mixing vanes on CHF in a 2 x 2 rod bundle with working fluid R-134a, Nuclear Engineering and Design 235 1749-1759, 2005.
[5] Y. Katto, H. Ohno, An improved version of the generalized correlation of critical heat flux for the forced convective boiling in uniformly heated vertical tubes, Int. J. Heat Mass Transfer 27 1641-1648, 1984.
[6] R. W. Bowring, A simple but accurate round tube uniform heat flux, dryout correlation over the pressure range 0.7-17MN/m^2(100-2500psia), AEEW-R 789, 1972.