Effect of Nanofluid Concentration on the Nucleate Pool Boiling Heat Transfer
Enhancement on a Copper Plain Surface

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Abstract

This work presents the nucleate pool boiling heat transfer experiments of TiO$_2$-water nanofluids. The horizontal circular plates made from copper with roughness values of 2.5 $\mu$m and nanofluids with various concentrations of 0.00005 to 0.01 vol\% are employed. The results indicate that at nanofluids concentrations of not more than 0.0001 vol\%, there was an increase in heat transfer. When the concentration of nanofluids was more than 0.0001 vol\%, the heat transfer decreased when compared with that for base fluid.

Keywords: Nucleate boiling, Nanofluids, Nanoparticles, Heat transfer, Heat flux.
1. Introduction

The nanofluid technology has issued as a new enhanced heat transfer technique in recent years. Choi [1] called fluids with nanoparticle size suspensions, “nanofluids”, which gained popularity later. Then, Murshed et al. [2] studied the thermal conductivity of TiO$_2$-water nanofluids with a particle concentration of 5.0 vol.%, and the results indicated that the thermal conductivity of nanofluids is 33% higher than that of base fluid. Recently, Duangthongsuk and Wongwises [3] determined the thermal conductivity of TiO$_2$-water nanofluids experimentally. Their results showed that the thermal conductivity of nanofluids with 2.0 vol.% is higher than that of base fluids by around 7%.

As mentioned above, it is clearly seen that nanofluids show high heat transfer potential in comparison to conventional heat transfer fluids. Thus, many researchers have aimed to use nanofluids as the working fluid in heat exchangers. The pool boiling heat transfer characteristic is an important parameter in the development of heat exchangers. The examples of recent publications involving pool boiling heat transfer of nanofluids are summarized as follows.

For pool boiling of nanofluids on cylindrical heating surface, there are researchers carrying out the studies as follows.

Das et al. [4, 5] studied the horizontal cylinders heating surfaces with diameters of 4, 6.5, and 20 mm with different surface roughness values. The results indicated that the boiling heat transfer coefficient of water deteriorated with the addition of nanoparticles. Trisaksri and Wongwises [6] studied nucleate pool boiling heat transfer of TiO$_2$ nanoparticles mixed with R-141b at volume concentrations of 0.01, 0.03, and 0.05 vol.%, respectively. The results indicated that the boiling heat transfer coefficient decreased with increasing volume concentrations.

The purpose of this work is to study the effect of concentration of nanofluids on the nucleate pool boiling characteristics of nanofluids. The boiling curves of TiO$_2$-water nanofluids are presented in this paper.

2. Preparation of Nanofluids

In the present study, nanofluids provided by a commercial source (DEGUSSA, VP Disp. W740) were used. This mixture was composed of TiO$_2$ nanoparticles with average diameter of 21 nm dispersed in water. The original particle concentration was 40 wt%. In order to produce other required particle volume fractions, dilution with water followed by a stirring action was done. The desired volume concentrations used in this study are 0.00005% to 0.01%. At these very low concentrations, the stable dispersions of nanoparticles could be kept for 3–4 days. The photograph of TiO$_2$ nanoparticles obtained from the transmission electron microscope (TEM) is shown in Figure 1(a). The particle size distribution is also shown in Figure 1(b).

![Figure 1(a). TEM image of dispersed TiO$_2$ nanoparticles in water.](image-url)
3. Results and Discussion

This present work was conducted by using the experimental apparatus and data reduction described in Suriyawong and Wongwises [7].

In Figure 2, the heat flux obtained from electric power measurement is plotted against the heat flux obtained from heat conduction measurement. Based on 35 data points, it is found that the calculated result shows good agreement with the measured result with a mean deviation $(1/n \sum (q_{\text{cond}} - q_{\text{elec}}) / q_{\text{cond}} \times 100))$ of 5.8%. The relative deviation of prediction is ±15% for 94.3% of the measured results.

Nucleate pool boiling heat transfer on the horizontal circular plates were made from copper with surface roughnesses of 2.5 µm. The measurements were performed within the range of 0.00005 to 0.01 vol.%. The details of the experimental results are given as follows.

3.1 Comparison with pool boiling curve of water

Figure 3 shows the pool boiling curve of water. The results obtained from the experiment tend to go in the same direction as the experimental data of Das et al. [4, 5], Bang and Chang [8], Liu and Liao [9] and Rohsenow’s correlation (Eq. 1)

$$C_p \frac{(T_s - T_{sat})}{h_{fg} \Pr^{m}} = C_f \left( \frac{q}{\mu h_{fg} \sqrt{g \rho (\rho_f - \rho_l)}} \right)^{0.33}$$

where $m$ and $C_f$ which are constants in Rohsenow’s correlation have values of 1 and 0.031, respectively.

3.2 Effect of nanofluid concentration

This section presents the effect of nanofluids concentration on the pool boiling curve and heat transfer coefficient. The nanofluids at concentrations of 0.00005, 0.0001, 0.0005, 0.005, and 0.01 vol.% are tested on a copper surface with a surface roughness of 2.5 µm. At nanofluids concentrations of not more than 0.0001 vol.%, there was an increase in heat transfer with respected to the base fluid. At the concentration of 0.0001 vol.%, the heat transfer coefficient increased by around 15%. When the concentration of nanofluids was more than 0.0001 vol.%, In contrast, the heat transfer decreased when compared with that for base fluid.
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Figure 2. Comparison of the heat flux.

Heat Flux form Heat Conduction Measurement (kW/m²)

0 200 400 600 800 1000

Heat Flux form Electric Power Measurement (kW/m²)

0 +15% -15%

Ts−Tsat, K

10 100

Heat flux, kW/m²

10 100 1000

Working fluid: Water

1 atm

Rohsenow’s Correlation

Das (2003)

Bang and Chang (2005)

Liu (2008)

Present results

Figure 3. Comparison of experimental data with Rohsenow’s correlation.

Distilled water

0.00005 vol.%

0.0001 vol.%

0.0005 vol.%

0.0050 vol.%

0.0100 vol.%

Heating surface: Copper

Roughness: Ra = 2.5 μm.

Working fluid: TiO₂ - water

(a)

Figure 4. Nucleate pool boiling heat transfer of TiO₂–water nanofluids for copper heating surface with roughness 2.5 μm at 1 atm.

(b)
4. Conclusions

The nucleate pool boiling of TiO$_2$-water nanofluids at concentrations of 0.00005, 0.0001, 0.0005, 0.005, and 0.01 vol.% at atmospheric pressure are experimentally studied. The copper surfaces with roughnesses of 2.5 µm are used as a test section.

It was found that with a nanofluids concentration of 0.0001 vol.%. The heat transfer is increased at an average of 15% compared with the case of base fluid.

With nanofluids concentrations of more than 0.0001 vol.%, the heat transfer coefficient was found to be less than that of the base fluid at all surface roughness.

5. Acknowledgement

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6. References


