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Critical Heat Flux during Flow Boiling Experiment with Surfactant Solutions

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1. Introduction

Some additives enhance heat transfer, although, the magnitude and mechanism of enhancement are not consistent or clearly understood. A low concentration of surfactant can also reduce the solution's surface tension considerably, and its level of reduction depends on the amount and type of surfactant present in solution. The surfactant concentrations are usually low enough that the addition of surfactant to water causes no significant change in saturation temperature and most other physical properties, except viscosity and surface tension. Reduced surface tension influences the activation of nucleation sites, bubble growth and dynamics, affecting the boiling heat transfer coefficient. [1-3]

Surfactants effect on CHF (Critical Heat Flux) was determined during flow boiling at atmospheric pressure in closed loop filled with water solutions of tri-sodium phosphate (TSP, $Na_3PO_4.12H_2O$). TSP was added to the containment sump water to adjust pH level during accidents in nuclear power plants. CHF was measured for four water surfactant solutions at different mass fluxes (100 ~ 500 kg/m^{2}sec) and two inlet subcooling temperatures (50^{o}C and 75^{o}C). Wettability was determined by measuring the contact angle at different concentration cases that will substantiate any CHF increase.

2. Experimental Apparatus and Procedure

At atmospheric pressure, a closed water flow boiling loop with a test section was heated directly using an electrical DC power supply unit. The main test loop consisted of a condenser, surge tank, a centrifugal pump, turbine flow meter, two pre-heaters, needle valve and a test section.

The water solution flows in an upward direction in the test section tube. The test section was made of SS-316 circular tube of outer diameter 12.7 mm and length of 230 mm. Three Type-K thermocouples were attached onto the outer surface of the test section to detect wall temperature as shown in Figure 1.

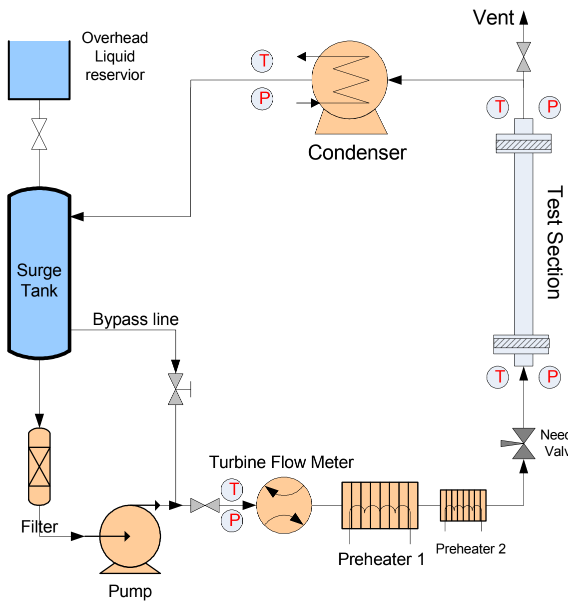

Figure 1: Schematic diagram of experimental test section

TSP solution was filled in the closed loop to perform CHF flow boiling experiment. The experiment was performed with four concentrations:

a) 0.05% solution
b) 0.2% solution
c) 0.5% solution
d) 0.8% solution

3. Results and Discussion

Enhanced (~48%) CHF was observed for 0.05% surfactant solution at mass flux of 100 kg/m^{2}sec and at inlet subcooling temperature of 50^{o}C as shown in Figure 2. CHF enhancement was lowered as the mass flux increased (200~300 kg/m^{2}sec), while some decrease in CHF (~10%) was observed with surfactants at higher mass flux (500 kg/m^{2}sec), as compared to plain water data.

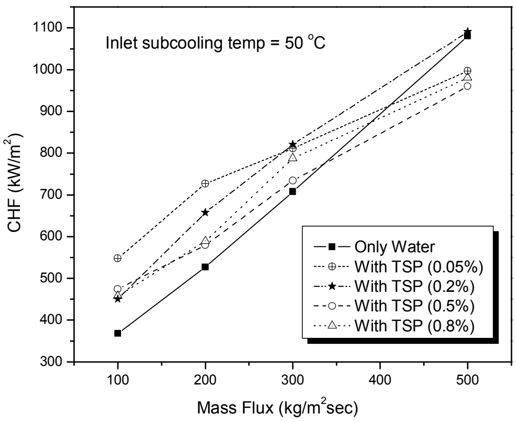

Fig. 2. Variation of CHF with mass flux for various surfactant solutions

Using the plot of Hewitt and Roberts for vertical upward flow, flow patterns were explored at different mass flux levels. [4] At low mass flux (100~300 kg/m^{2}sec) the flow patterns were bubbly-slug, while for relatively high mass flux (~500 kg/m^{2}sec) the flow pattern was in annular region. We can explain the increase/decrease of the CHF with TSP addition based on the flow instability and liquid film dryout model. The decreased CHF under high mass flux and annular flow is because of liquid film instability and the decrease in surface tension due to addition of TSP as shown in Figure 3.

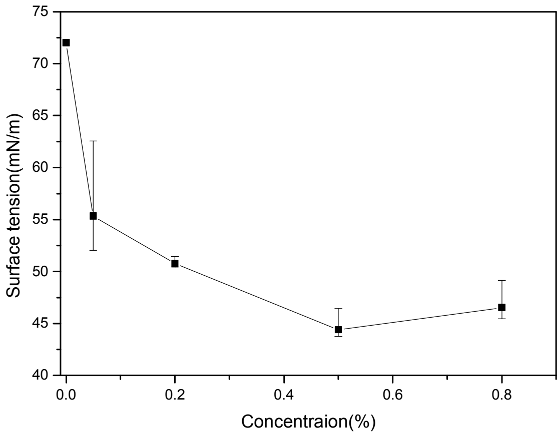

Fig. 8. Surface tension of pure water and TSP solutions at a temperature of 25 ^{o}C

Surfactant caused a decrease in contact angle associated with an increase of CHF. Contact angle measurement was performed to investigate the relationship between wettability and an increase of CHF with surfactant addition. Surfactant solutions showed decrease in contact angle, means high wettability. The Contact angles for different concentrations of surfactant solutions drop on Teflon strip are shown in Figure 4.

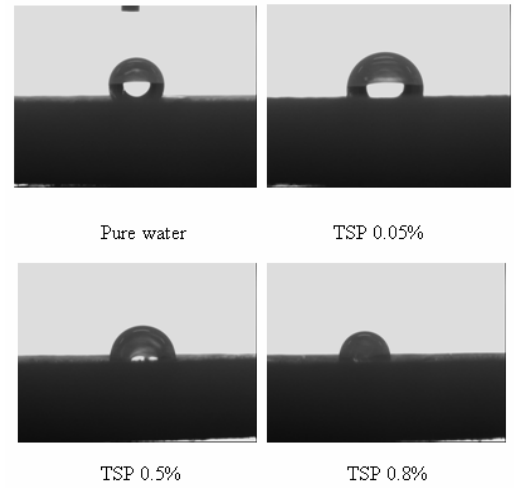

Fig. 4. Contact angle measurement for water and surfactant solutions drop on Teflon strip

CHF enhancement was more pronounced at very low mass flux (~ 100 kg/m^{2}sec), which is due to increased wettability of the heater surface and promoted liquid supply under bubbly or slug flow conditions. CHF enhancement is greater at inlet subcooling temperature of 50^{o}C than at 75^{o}C. CHF decreased at 500 kg/m^{2}sec, which is due to instability of liquid film during annular flow under reduced surface tension because of TSP. By increased net entrainment, CHF can be reduced under annular flow condition.

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