EXPERIMENTAL INVESTIGATION OF FLOW BOILING CHARACTERISTICS OF TWEEN 20/WATER IN INTERNAL THREADED COPPER TUBE

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ABSTRACT:

This paper presents the results of experimental investigations carried out with surfactant Tween 20 during flow boiling inside internal threaded copper tube. The boiling fluid was water with different concentrations of surfactant added to reduce surface tension. The effect of various concentration, heat flux, mass flux and inclination angle of tube on heat transfer coefficient was investigated. The experiments were conducted keeping constant fluid inlet temperature of 80℃. The test runs were carried out by varying mass fluxes from 100 to 300 Kg/m²s, heat fluxes from 10 to 90 kW/m² and inclination angles of 0° and 90°.The addition of small amount of surfactant showed heat transfer enhancement upto 100 ppm and above this concentration heat transfer enhancement was insignificant. The result showed that the maximum heat transfer coefficient increased by 16.34 % for horizontal position at mass flux 100 kg/m²s. The entire study is carried out at low mass flux values. There is considerable enhancement in heat transfer coefficients in nucleate boiling region as compared to convective region at all mass and heat flux. The heat transfer coefficients predicted by some available correlations are compared with the present data.

KEYWORDS: flow boiling, surfactants, sub cooled, inclined, internal threaded copper tube.

INTRODUCTION:

Flow boiling heat transfer has been studied extensively due to its wide applications in industries such as chemical, processing, refrigeration, air conditioning etc. A high cost of energy and material has resulted in an increased effort aimed at producing high performance heat transfer systems. Passive methods of heat transfer enhancement need no such external power for enhancement. One promising approach has been the use of surfactants that increase the heat transfer rate by reducing surface tension of the liquid. The boiling phenomena mainly depend on thermophysical properties of fluids that are density, surface tension and kinematic viscosity. The addition of small amount of surfactants doesn't affect the density of solution but it may slightly increase the viscosity in some cases. However, reduction in surface tension of liquid results in nucleate boiling heat transfer enhancement remarkably. Also one of the passive techniques to enhance heat transfer rate is use of internal threaded tube. It can enhance the heat transfer by creating turbulence and limiting the growth of thermal boundary layer by slight increase in pressure drop. The rough surface can create more number of nucleation sites that contributes to heat transfer enhancement in nucleate boiling zone. Thus by using surfactants in an internal threaded copper tube it is expected that it will result in heat transfer enhancement particularly in nucleate boiling region. In flow boiling, heat transfer characteristics generally keep changing as the flow pattern changes inside the test section and flow regime is influenced by interfacial shear stress, surface tension, buoyancy and gravitational force. The addition of surfactant may affect flow regimes with drag reduction thereby reducing frictional pressure drop. [1]

NOMENCLATURE

Bo	Bond number
C_p	specific heat, J/kgK
d_{in}	inner diameter, m
d_{out}	outer diameter, m
Fr	Froude number
G	mass flux, kg/m^{2}s
I	current, A
k	thermal conductivity, W/m^{o}C
l	length of test section, m
n_g	number of grooves
Pr_l	Prandtl number of water
Q	heat supplied, W
q"	heat flux, W/m^2
Re	Reynolds number
R_x	geometry enhancement factor
T	temperature, ^{o}C
u	velocity, m/s
V	voltage, V
x	quality
g	gravity, m/s^2

GREEK SYMBOLS

α	heat transfer coefficient, W/m^{2o}C
σ	surface tension, N/m
γ	apex angle
β	helix angle
μ	dynamic viscosity, Pa-s
μ_s	dynamic viscosity at surface temperature, Pa-s
ρ_l	density of water, kg/m^3
ρ_g	density of vapour, kg/m^3
Θ	angle of inclination of tube

SUBSCRIPTS

f	base fluid
GO	gas phase with total flow rate
eq	equivalent
in	inlet
out	outlet
ws	outer surface
wi	inner surface
wo	average outer surface

ABBREVIATIONS

CMC	critical micelle concentration
Coeff.	Coefficient
TW-20	Tween 20

LITERATURE SURVEY:

One of the earliest research works concerning the effect of surfactants on boiling phenomena is the study on flow boiling of water with a surfactant in a long tube vertical evaporator performed by Stroebe et.al.[2] in 1939. They found that flow boiling heat transfer coefficients were enhanced by addition of a surfactant Duponol and surface tension had a strong effect on the boiling heat transfer of water. Yang et.al. [3] took dynamic surface tension as one critical parameter in his study and investigated the effect of dynamic surface tension on boiling of aqueous surfactant solution. Frost and Kippenhan [4] also found that more boiling sites were nucleated and bubble growth was lower and thus flow boiling heat transfer was enhanced with Ultra wet 60L. Chang et.al. [5] investigated that flow boiling heat transfer was enhanced by addition of SLS. Hetsroni et.al. [6] conducted his study in vertical annular channel with Alkyl glycosides as surfactants and found that the average heat transfer coefficient may be enhanced upto four times. Klein et.al. [7] studied the effect of surfactants in microchannels. They used a kind of environmentally friendly surfactants and considered the environmental aspect. They concluded that an optimal value of mas flux was found for the flow boiling heat transfer. Quinn et.al. [8] studied the effect of surfactants on flow boiling heat transfer in a diverging open channel and found that surfactant solution created thick foam layer with high heat transfer rates and Nusselt numbers that are very weakly dependent on inlet flow rate or inlet Reynolds number. Akhavan Behabadi et al. [9] experimentally investigated evaporation heat transfer of R-134a inside a microfin tube for seven different tube inclinations ranging from -90^0 to +90^0. Results showed that at low vapour qualities the highest heat transfer coefficient was attained at +90^0 & at higher vapour qualities heat transfer coefficient was highest when tube is horizontal or was inclined at -30^0. The vertical tube with inclination angle of 90^0 had the lowest heat transfer coefficient for entire range of vapour quality. Bin sun et al. [10] experimentally studied the flow boiling heat transfer characteristics of four nanorefrigerants in an internal threaded tube. They found that maximum heat transfer coefficient of four kinds of nanorefrigerants increased by 17-25% and the heat transfer coefficient increased by 3-20%.

EXPERIMENTAL METHOD:

3.1 EXPERIMENTAL SETUP:

The schematic diagram of test apparatus has been shown in fig.1. It consists of a pre-heater, a pump, a rotameter, a test section, and water cooled condenser.

Initially the fluid is heated in preheater at 80°C, then it flows to test section through rotameter. The liquid-vapour mixture from outlet of test section flowed into the condenser, where it is condensed into liquid. The condensed liquid is passed through circulation pump to pre- heater. The pre-heater consists of a tank with 1.5 kW capacity heater installed in it and constant AC supply was given for preheating the fluid. The test section was heated by a cartridge heater (of 4 kW capacity) wrapped around the test tube. Heat input to heater was controlled with a variable AC voltage controller. The voltage and current were measured by analog meter to determine applied heat flux.

Fig. No. 1 Photographic Image of Experimental Setup

3.2 TEST SECTION:

The test section was made of copper tube. The specifications of test section were as follows: length of test section,1000 mm; outside diameter,9.52 mm; inner diameter,7.52 mm; bottom wall thickness, 0.76 mm; tooth depth, 0.24 mm; tooth apex angle, 60°; helix angle, 25°. The test section was heated by a cartridge heater (of 4 kW capacity) wrapped around the outside of test tube, and five cross sections are reserved in order to adhere thermocouples, as shown in fig2. Ten K- type thermocouples are located at top and bottom sides of above five cross sections of the test tube to measure the outside tube wall temperatures. The test section was insulated with glass wool to reduce heat loss to the surroundings. Also two thermocouples and one pressure sensor to measure temperature and pressure drop at inlet and outlet of test section were used.

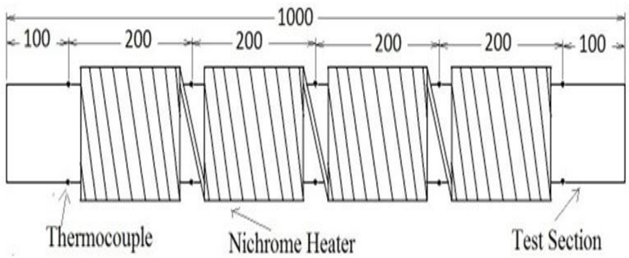

Fig. No. 2. Test Section and Layout (unit: in mm)

3.4 PROCEDURE:

The heat transfer coefficient was calculated by using following equation,

$$\alpha = \frac{q''}{(T_{wi} - T_f)} \qquad (1)$$

where, q" is the heat flux (W/m²), T_{wi} is the inner surface temperature (K), and T_f is the bulk mean fluid temperature (K). The bulk mean temperature of the fluid is taken as the average of the T_{in} inlet temperature (K) and T_{out} the outlet temperature (K) of fluid. The outside wall temperature of the test section was measured at five axial locations. At each location, the temperature of the tube was measured at top and bottom positions.

$$T_{ws} = \frac{T_t + T_b}{2} \qquad (2)$$

Thus, the average outside tube wall temperature of the test section, T_{wo}, was calculated as the arithmetic mean of outside tube wall temperature at five axial locations.

$$T_{WO} = \frac{\sum_{i=1}^{5} T_{WS}}{5} \qquad (3)$$

Thermal resistance was used to measure the outside surface temperature of the tube, but the inner surface temperature was required to calculate the heat transfer coefficient. Therefore, according to Fourier's one-dimensional, radial, steady-state heat conduction equation for a hollow cylinder, based on the assumption that the heat flux is uniform inside the tube and a negligible heat loss to the surroundings, the inner surface temperature was calculated as follows:

$$T_{wi} = T_{wo} - \frac{Q_{test} \ln\left({d_{out}}/{d_{in}}\right)}{2\pi l k} \qquad (4)$$

where, d_{out} is the outer diameter (m), d_{in} is the inner diameter (m), is the thermal conductivity of copper (W/mK), is the length of the test section (m), and Q_{test} is the heat flow to the test section (W) calculated from the voltage (V) and current (I) of the test section.

3.5 EXPERIMENTAL DATA VALIDATION:

To verify the experimental data, obtained results for pure water have been compared with known correlations for the horizontal position (Θ = 0⁰) of test section. To examine the verification of obtained data related to single-phase convection region, Sider-Tate equation has been employed. Sider- Tate equation for predicting the forced convection heat transfer coefficient as follows [5]:

$$Nu = \frac{\alpha d_{in}}{k} = 0.0013\, Re^{1.2} Pr^{1/3} (\mu/\mu_s)^{0.14} \quad (5)$$

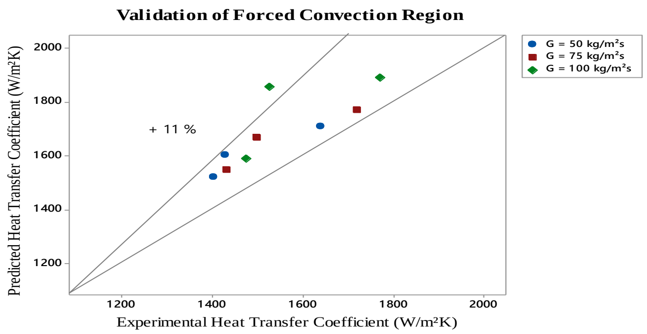

Fig. No. 3 Comparison of Experimental and Theoretical Results in Convective Region

Results of this comparison demonstrate the well agreement of about 11% between the experimental data and the calculated results for single- phase convection zone. To examine the verification of obtained data related to nucleate boiling region, the experimental results of pure water were compared with the results obtained using the formula of Cavallini et al. [6].

The Cavallini pure working fluid experimental correlation is as follows:

$$Nu = \frac{\alpha d_{in}}{k} = 0.05 (Re_{eq})^{0.8} Pr_l^{0.8} Rx^2 (Bo.Fr)^{-0.26} \quad (6)$$

Where, $Pr_l = \mu_l C p_l / k$

$$R_X = \{[2h(1 - sin(\gamma/2))]/[\pi d_{in} cos(\gamma/2)] + 1\}/cos(\beta)$$

$$Fr = u_{GO}^2 / (\rho_g^2 g d_{in}), \quad Bo = g \rho_l h \pi d_{in} / (8\sigma n)$$

$$Re_{eq} = 4M\,[(1 - x) + x(\rho_l/\rho_g)] / (\pi d_{in} \mu_l)$$

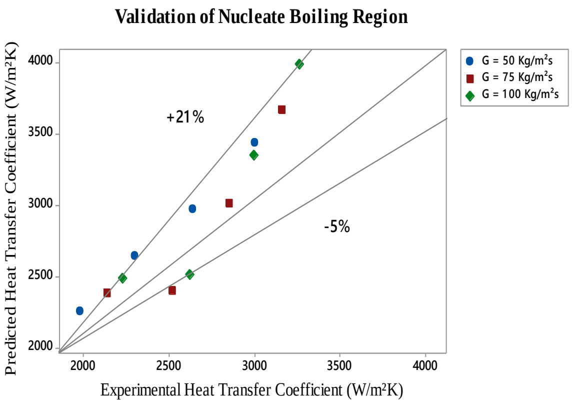

Fig. No.4 Comparison of Experimental and Theoretical Results in Nucleate Region

RESULTS AND DISCUSSION:

4.1 EFFECT OF CONCENTRATION:

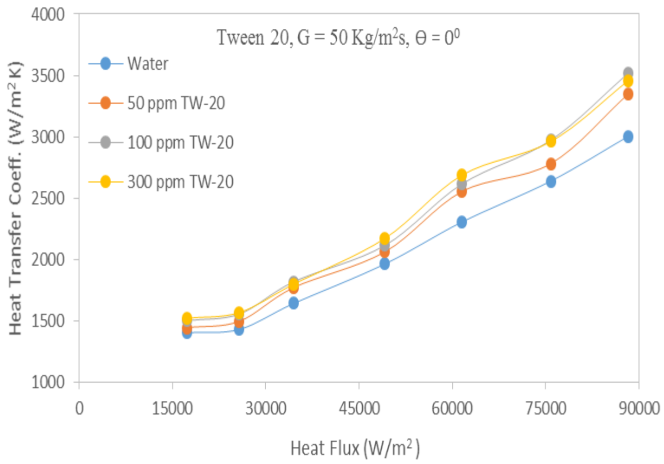

Fig. No. 5 Effect of Concentration on Heat Transfer Coefficient

The enhancement at 50 ppm for forced convective region 1-3.95% and nucleate boiling region 7.4-12.68% , at 100 ppm for forced convective region 2.9%- 5.68% and nucleate boiling region 8.23%-16.34 %. It shows that as the concentration of surfactant increases upto cmc value, heat transfer coefficient increases. Above the cmc value, there is slightly less enhancement as compared to optimum concentration.

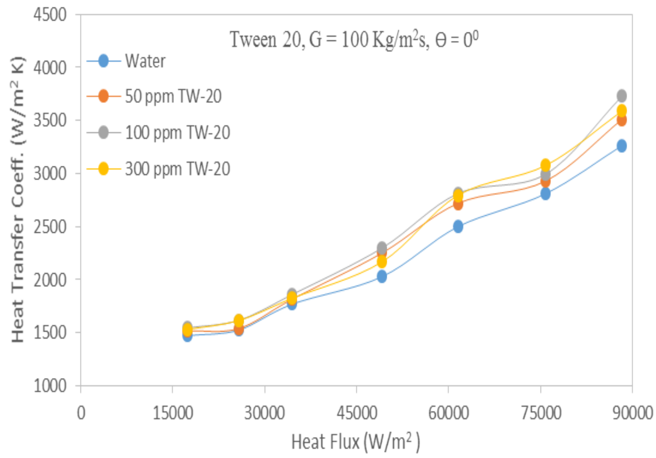

Fig. No. 6 Effect of Concentration on Heat Transfer Coefficient

However, in forced convective region, heat transfer coefficient increases slightly while for nucleate boiling region it increases significantly. The enhancement of nucleate boiling heat transfer is connected to decrease in surface tension of base fluid as the process of nucleate boiling is the total sum of bubble initiation, growth and departure.

4.2 EFFECT OF HEAT FLUX AND MASS FLUX:

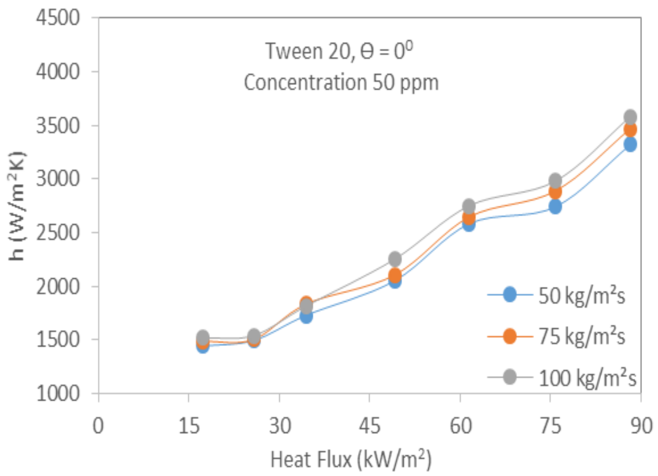

Fig. No. 7 Effect of Heat Flux and Mass Flux on Heat Transfer Coefficient

Results show that as heat flux increases heat transfer coefficient increases. For convective heat transfer zone increase of heat transfer coefficient with heat flux is less than in comparison with nucleate boiling zone. As seen in convective zone, slope of curve is less than that in nucleate boiling zone. This was attributed to local turbulence agitations.

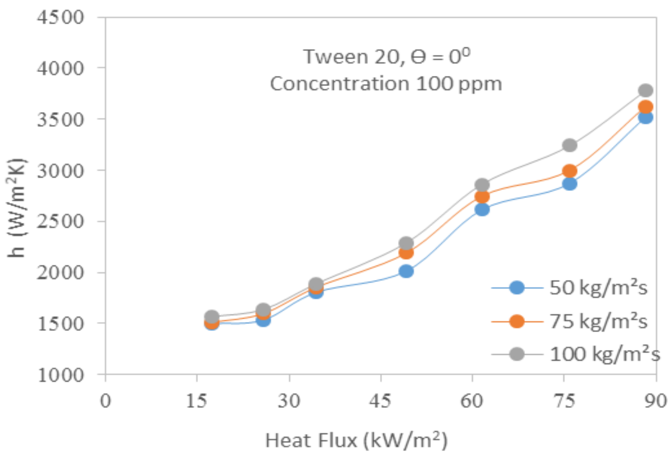

Fig. No. 8 Effect of Heat Flux and Mass Flux on Heat Transfer Coefficient

At lower heat flux the rate of bubble generation around heated surface will be less, as heat flux increases rate of bubble generation also increases thus there is rigorous interaction between bubbles at heated surface resulting in heat transfer enhancement. As mass velocity increases heat transfer coefficient slightly increases in nucleate boiling region over the entire range of mass velocity. Thus bubbles may slide along the heated surface or may be detached earlier also, micro layer evaporation process underneath growing bubbles may also be affected.

4.3 EFFECT OF INCLINATION ANGLE:

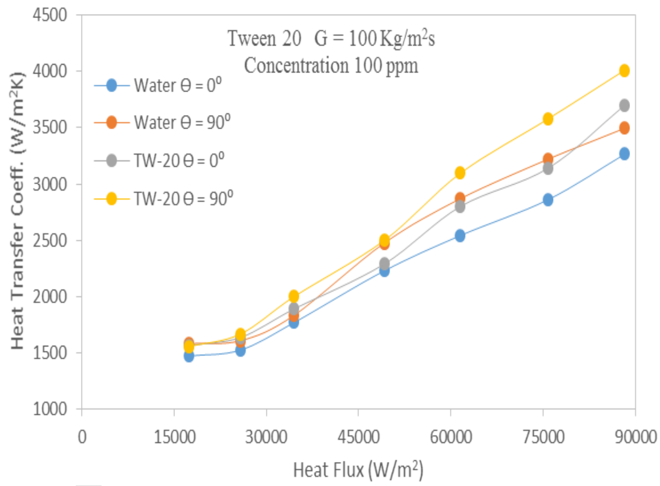

Fig. No. 9 Effect of Inclination Angle on Heat Transfer Coefficient

The result shows that as the inclination angle increases heat transfer coefficient also increases. For all flow rates increase in heat transfer coefficient for vertical position of test section is higher as compared to horizontal. This was attributed to favorable flow of liquid inside grooves in convective region and due to high interfacial turbulence in nucleate region. The gravitational force affects the two phase flow in a considerable manner. Buoyancy force and fluid flow are unidirectional in nucleate boiling region as a result flow accelerates enhancing heat transfer from heated wall of test section.

CONCLUSION:

1. In case of Tween 20, for horizontal position of test section maximum enhancement is obtained at 100 ppm concentration and 100 kg/m²s. At 100 ppm for forced convective region 2.9%-5.68% and nucleate boiling region 8.23%-16.34.

2. The effect of heat flux is significant on heat transfer coefficient. At 50 kg/m²s enhancement in convective region 3.2%-9.24% and nucleate region 7.93%-18.87%,

100 kg/m²s convective region 4.15%-11.03% and nucleate region 9.24%-21.33%

3. The effect of mass flux at lower values is considered. At 100 kg/m²s for 100 ppm TW-20, enhancement in convective region 2.6-6.78%, nucleate region 4.8-11.86% .

4. The inclination angle of test section has significant effect on heat transfer coefficient. In case of tween 20, at 100 kg/m²s and 50 ppm concentration heat transfer enhancement is 18.67%. The heat transfer enhancement is highest i.e. 19.32% at 100 ppm concentration and 100 kg/m²s for 90^0 inclination of the test section.

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