DESIGN FABRICATION AND PERFORMANCE EVALUATION OF POOL BOILING USING SINGLE AND BINARY MIXTURE

Akhilesh Kumar[1], U. K. Nayak[2], R. S. Prasad[3], Anil Kumar[4], Ravi Shankar[5]

[1, 4, 5] M. Tech, Department of Mechanical Engineering, B.I.T Sindri, (India)
[2, 3] Assistant Professor, Department of Mechanical Engineering, B.I.T Sindri, (India)
V. B. U, Hazaribagh, India

ABSTRACT

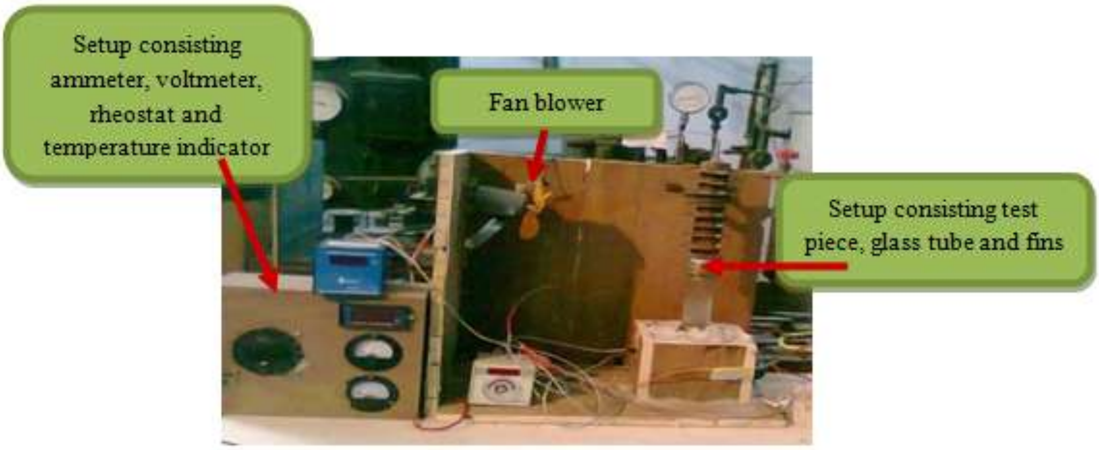
The present work focuses on the study of the effect of mass resistance on the rate of heat transfer in pool boiling. The nucleate pool boiling heat transfer coefficients for binary mixtures (2-propanol-water, ethanol-water) were measured at different concentrations of the more volatile components. The boiling binary mixture of water with 2-propanol or ethanol at atmospheric pressure has been taken and the critical heat flux (CHF) conditions are determined. The systems chosen covered a wide range of mixture behaviors. The experimental set up for the present investigation included electric heating element submerged in the test liquid mounted vertically. Thermocouple and a digital indicator measured the temperature of the heater surface. The multiplication of the voltmeter and ammeter readings gives the actual heat transfer rate. A water cooled coil condenses the vapor produced by the heat input and the liquid formed returns to the cylinder for re-evaporation. The boiling results show that when varying the concentration of 2-propanol and ethanol in water. Small addition of alcohol to water increased the critical heat flux (CHF) and higher concentration of alcohol decreasing the CHF condition to that of the pure alcohol. The nucleate pool boiling heat transfer coefficients of binary mixtures were always lower than the pure components nucleate pool boiling heat transfer coefficients. This confirmed that the mass transfer resistance to the movements of the more volatile component was responsible for decrease in heat transfer and that the maximum deterioration that was observed at a point was the absolute concentration differences between vapor and liquid phases at their maximum.

Keywords: Atmospheric Pressure, Critical Heat Flux, Heat Transfer Coefficient, Pool Boiling, Single $ Binary Mixture.

I. INTRODUCTION

When evaporation occurs at a solid-liquid interface, it is termed boiling. Nucleate boiling is characterized by the formation of vapor at preferred sites (“nucleation” sites) on a heating surface that is submerged in the liquid and maintained at a temperature above the saturation temperature of the liquid. Boiling of mixtures is of considerable practical significance. Nucleate pool boiling of liquid mixtures find many applications in chemical and petrochemical process industries, air-separation, and refrigeration and power generation. In addition it has applications in the high heat flux in the high heat flux cooling in the electronics industry. Over the past three decades, researchers have investigated different passive enhancement techniques to increase the heat transfer coefficient and the critical heat flux (CHF). They have used different working fluids, e.g.; water, refrigerants, binary mixture, and more recently nano-fluids in pool boiling systems. The performance of a pool boiling system is characterized by the pool boiling curve depicting heat flux verses wall superheat, and critical heat flux. The heat transfer coefficient was readily obtained from the boiling curve and plots were compared and analyzed in experiments is also distinguished surface temperature of heating material at the same heat flux. In the recent past alcohols and aqueous mixtures have also been investigated to combine the advantages of water (excellent thermal performance) and alcohols (lower saturation temperature). Nishikawa et al (1976) studied nucleate boiling of saturated water and ethanol on a horizontal smooth copper surface. They observed intermittent boiling in the low heat flux region at low pressures without any steady nucleation sites. McGillis et al (1992) investigated the boiling behavior of water/methanol and water/2-propanol at sub atmospheric pressures. They conclude that small addition of alcohol to water results in increasing CHF above that of water. Pastuszko (2012) recently investigated narrow tunnel structures in water, ethanol and R-123 at atmospheric pressure. For ethanol, a maximum heat flux of 500 kw/m^{2} at 20^{0} c wall super heat was obtained.

II. EXPERIMENTAL MODEL AND PROCEDURE

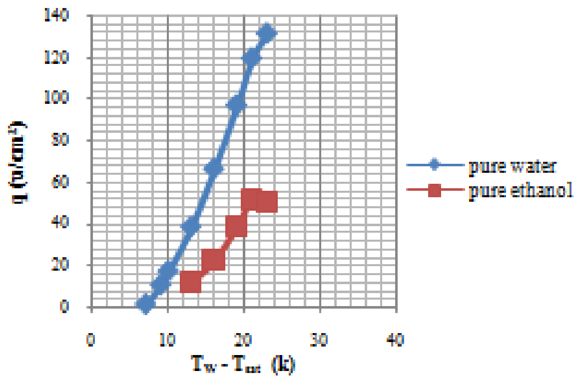


“Fig. 1” Experimental Setup of the Pool Boiling

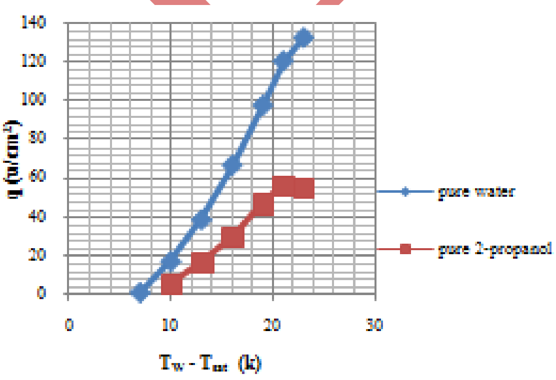
The thermo siphon used in this study could operate in a variety of boiling regimes, from low heat flux, evaporative heat transfer, through nucleate boiling, to critical heat flux. Before starting the boiling process the boiling vessel was sealed completely by using epoxy at the interface of copper and the glass tube. The epoxy surface was then bonded to the end of a glass tube to allow observations. The clear tube fit inside an O-ring fitting at the bottom of the condenser so that repeated assembly was simple. The condenser was made of a long section of copper tubing which had radial copper fins wound and soldered onto its O.D. Heat was removed from the fins with an air blower. The top end of the condenser tube was equipped with a thermocouple probe extended down through the inside of the tube and could be positioned vertically to monitor fluid or vapor temperatures. The electric heater was adjusted to 80 to 100 watts and the water flow rate was adjusted until the desired pressure was about (1atm) and then voltage, current, vapor pressure, liquid temperature and metal temperature were observed. When boiling of single component (pure) fluids, the thermo siphon is charged with pure fluids i.e. pure water, pure ethanol and pure 2-propanol one by one. The electricity is supplied to cartridge heater and copper is heated by regulating the voltage through rheostat. On the onset of nucleate boiling when the test fluid reached saturation temperature and steady state conditions, the current, voltage, condensation temperature and thermocouple readings at various sections were recorded. Similarly, when boiling of binary mixtures the thermo physical properties of the fluid mixture must be determined before boiling performance can be predicted. For example, incipience, heat transfer coefficients and critical heat flux are heavily dependent on the fluid properties. Different compositions are formed by mixing water-ethanol and water 2-propanol. This binary mixture is then boiled inside the glass tube at atmospheric pressure. Similar to pure fluid case, when saturation temperature is achieved and boiling starts the current, voltage, condensation temperature, and thermocouples readings at various sections were recorded.

III. EXPERIMENTAL WORK

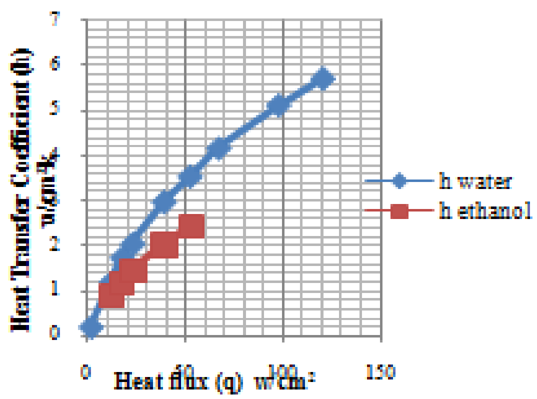
Boiling of Single Component Liquid



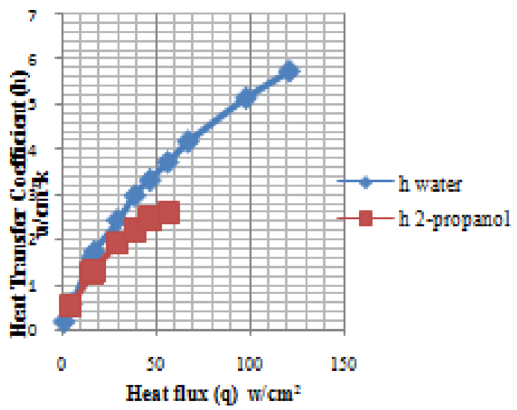
"Fig. 2" Pool Boiling Curve Of Pure Water & Pure Ethanol



"Fig. 3" Pool Boiling Curve Of Pure Water & Pure 2-Propanol



"Fig. 4" Variation of Boiling Heat Transfer Coefficient With Heat Flux of Pure H Water

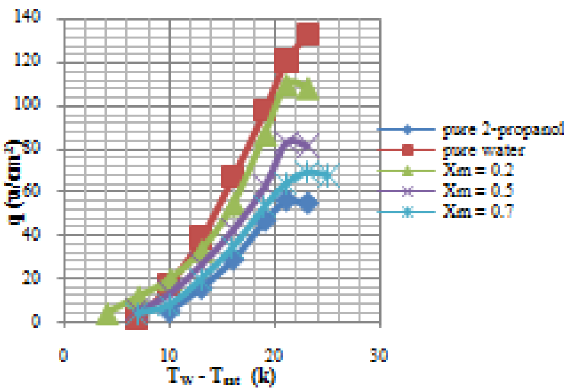


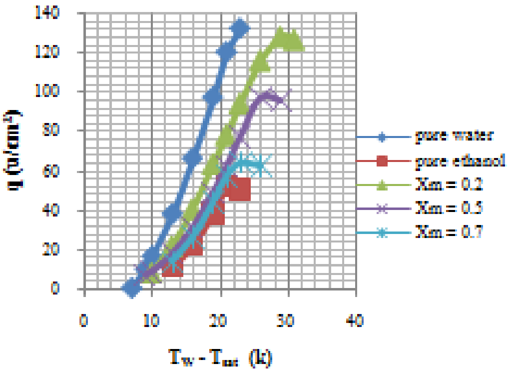
"Fig. 5" Variation of Boiling Heat Transfer Coefficient with Heat Flux of Pure H Water &

& Pure H Ethanol.

Pure H 2-Propanol.

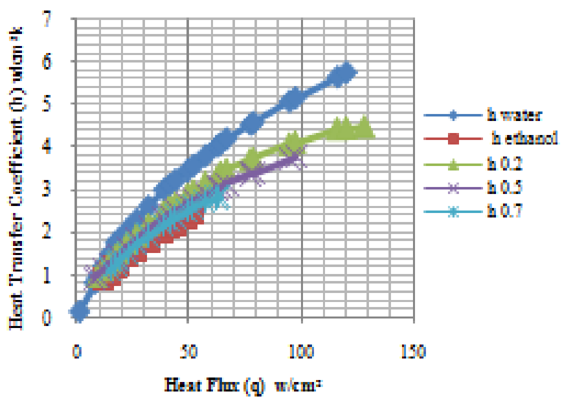
Boiling of Binary Mixtures

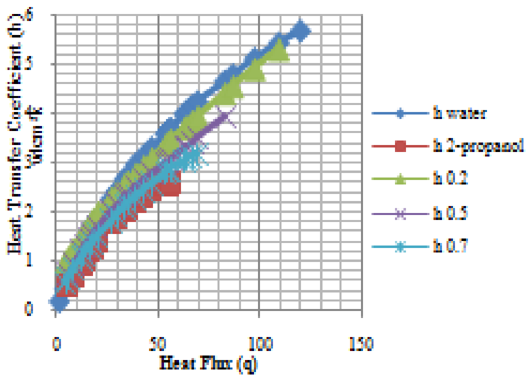




"Fig. 6" Pool Boiling Curve Of Pure Water 2-Propanol & 0.2,0.5, 0.7 Of 2-Propanol/Water .

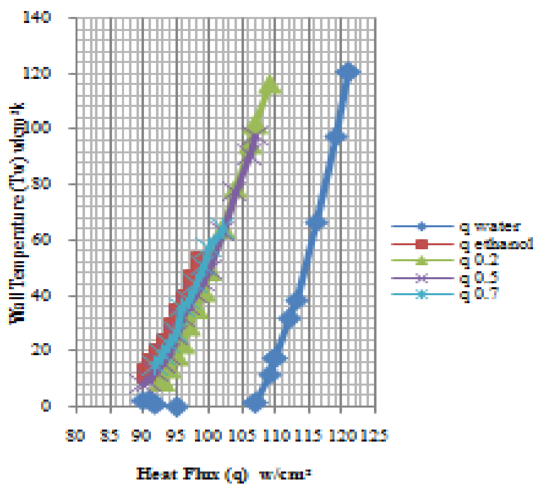
"Fig. 7" Pool Boiling Curve Of Pure WaterPure Pure Ethanol &0.2, 0.5, 0.7 Of Ethanol/Water.

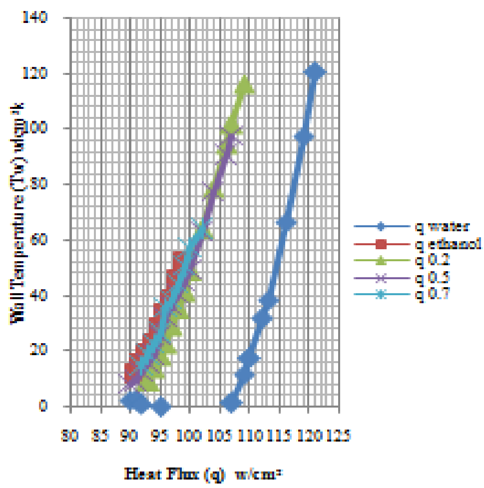




"Fig. 8" Variation Of Boiling Heat Transfer Coefficient With Heat Flux Of Water, 2-Propanol, 0.2,0.5, 0.7 Of 2-Propanol/Water.

"Fig. 9" Variation Of Pool Boiling Heat Transfer Coefficient with Heat Flux Water,





"Fig. 10" Variation of boiling wall temperature with temperature of water, 2-propanol, 0.2,0.5, 0.7 of 2-propanol/water.

"Fig. 11" Variation of boiling wall heat flux With heat flux of water, ethanol, 0.2,0.5,0.7of ethanol/water.

IV. RESULTS AND DISCUSSIONS

Boiling of Single Component liquid

"Fig. 2 and 3" shows the boiling curve of pure water, pure ethanol, and pure 2-propanol. It was found that the boiling curves of pure ethanol & pure 2-propanol could never exceed that of the boiling curve of water. "Fig. 2 and Fig. 3" depends on the value of the nucleate boiling heat transfer coefficient which dependent on the physical properties (k_L, C_p, μ_L, Δh_{LG}, $\sigma, \rho V$) and temperature difference (which is wall temperature minus the liquid saturation temperature) for pure ethanol & pure 2-propanol so that pure water has larger values of nucleate boiling heat transfer coefficients than that of pure ethanol & pure 2-propanol because pure water has high values of thermal conductivity, liquid density and specific heat as compared with the pure ethanol & pure 2-propanol. "Fig. 4 and Fig. 5"shows that the nucleate pool boiling heat transfer coefficients of pure ethanol & pure 2-propanol as a function of heat fluxes. It observed that the nucleate pool boiling heat transfer coefficient for pure ethanol & pure 2-propanol increases with increasing heat fluxes because of higher number of bubbles generated as flux increases.

Boiling of Binary Mixtures

The nucleate pool boiling heat transfer coefficient data for different compositions (0.2, 0.5, and 0.7) of the more volatile components, aqueous mixture of ethanol, 2-propanol and the non-aqueous mixtures of ethanol-water and 2-propanol-water. "Fig. 6 & 7" compares boiling curves of pure water, pure ethanol, pure 2-propanol, ethanol/water, 2-propanol/water mixtures at different compositions. It was found that on addition of ethanol or 2-propanol to water, the critical heat flux condition of mixtures is not monotonic with concentration. With small addition of alcohol to water results in the increased CHF but higher concentration of alcohol to water we found decreasing CHF to that of pure alcohol. The boiling curves of ethanol/water & 2-propanol/water mixtures shift towards higher superheat with increasing concentrations of ethanol/water & 2-propanol/water. The "fig. 8 & 9" compares the heat transfer coefficient curve of pure water, pure ethanol, ethanol/water & 2-propanol/water mixtures at different compositions as a function of heat flux. "Figure 8 & 9" shows that for a given heat flux, the heat transfer coefficients of the mixtures are lower than the values obtained by the pure components constituting the mixture. This is due to the utilization of part of the temperature driving force to overcome the mass transfer resistance caused by diffusion of the light components to the bubble interface. Therefore, to obtain a given heat flux, an additional temperature driving force is required for binary mixtures; hence the heat transfer coefficients are lower than those of constituent pure components. In "fig. 10 and 11" shows a given wall temperatures as the function of heat flux of pure water, pure ethanol and pure 2-propanol, and mixtures of 2-propanol/water and ethanol/water at atmospheric pressure. It conclude that the mixtures provide a means of maintaining low wall temperatures and temperature fluctuations are smaller relative to pure water and bubble sizes are also reduced as compared to pure water.

V. CONCLUSION

It is observed by boiling curve of pure water, pure 2-propanol and pure ethanol at atmospheric pressure and after addition of water to 2-propanol and ethanol that there is reduction in wall temperature due to binary mixture. For

2-propanol/water and ethanol/water mixtures at atmospheric pressure, the critical heat flux (CHF) condition of the aqueous mixtures is not monotonic with concentration. The critical heat flux is increased with small additions of ethanol or 2-propanol to water but at higher concentration of ethanol or 2-propanol, decrease in the critical heat flux condition is observed. The CHF condition for pure ethanol and pure 2-propanol is small relative to pure water. For a given heat flux, the heat transfer coefficients of mixtures are lower than the values obtained by the pure components constituting the mixture. This is due to utilization of part of the temperature driving force to overcome the mass transfer resistance caused by diffusion of the light component(s) to the bubble interface. Water/2-propanol and Water/ethanol mixtures at atmospheric pressures provide a means of maintaining low wall temperatures without the large wall temperature fluctuations characteristic of pure water systems. In pure alcohol and pure ethanol systems, bubble sizes are reduced relative to pure water and temperature fluctuations are smaller so that the convective heat transfer coefficient of mixtures are lower than pure water.

NOMENCLATURES

H	Heat transfer coefficient (w/cm^2k)
K	Thermal conductivity (w/mk)
C_p	Specific heat (J/kg k)
Q	Heat flux (w/cm^2)
T	Temperature (k)
T_w	Wall temperature (k)
T	Saturation Temperature (k)
μ	Viscosity (Ns/m^2)
ρ	Density (kg/m^3)
σ	Surface tension (N/m)
Δ h_{LG}	Latent heat of vaporization (KJ/kg)

REFERENCES

[1] Wenzel, U., Balzer, F., Jamialahmadi, M., and Muller- Steinhagen, H.: *"Pool Boiling Heat Transfer coefficients for binary mixtures of Acetone, Isopropanol, and Water"* Heat tran.Eng. Vol.16, pp.36-43, Published 1995.

[2] Fujita, Y., Bai, Q., and Tsutsui, M.: *"Heat transfer of binary Mixtures in Nucleate Pool Boiling"* , 2 nd Eur. Thermi. And 14 th UIT Nat. Heat trans, Published 1996.

[3] Y. Fujita, M. Tsutsui, *"Experimental investigation in Pool Boiling Heat Transfer of Ternary mixture and Heat Transfer Correlation"*, Exp.Therm. Fluid Sci. 26, pp. 237-244, Published 2002.

[4] G. Vinayak rao, A. R. Balakrishnan, *"Nucleate Pool Boiling Heat Transfer of Multicomponent mixtures"*, Trans. I ChemE Chem. Eng. Res. Des.82 (AI) , pp.43-52, Published 2004.

[5] Sultan, A. j., *"Heat Transfer of Single and Binary Systems in Pool Boiling"*, M.Sc Thesis University of Technology, pp. 13-22, Published 2006.

[6] Sakashita, H., Ono, A., and Nakabayashi, Y., *"Measurements of Critical Heat Flux and Liquid-Vapor Structure Near the Heating Surface in Pool Boiling of 2-propanol/water Mixtures"* Int. J. Heat Mass Transfer, PP. 1554-1562, Published 2010.

[7] Pastuszko, R., "*Pool boiling for Extended Surfaces with Narrow Tunnels Visualization and a Simplified Model",* Exp. Them. Fluid Sci., 38, PP. 149-164, Published 2012

BIOGRAPHICAL NOTES

Mr. Akhilesh Kumar is presently pursuing M. Tech. final year in Mechanical Engineering Department (Specialization in Heat Power) from B.I.T Sindri, Dhanbad, India.

Mr. U. K. Nayak is working as a Assistant Professor in Mechanical Engineering Department, B.I.T Sindri, Dhanbad and presently pursuing Ph. D. from B.I.T sindri, Dhanbad, India.

Mr. R. S. Prasad is working as a Assistant Professor in Mechanical Engineering Department, B.I.T Sindri, Dhanbad and presently pursuing Ph. D. from I.S.M, Dhanbad, India.

Mr. Anil Kumar is presently pursuing M. Tech. final year in Mechanical Engineering Department (Specialization in Heat Power) from B.I.T Sindri, Dhanbad, India.

Mr. Ravi Shankar is presently pursuing M. Tech. final year in Mechanical Engineering Department (Specialization in Heat Power) from B.I.T Sindri, Dhanbad, India.