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POOL BOILING OF NANOLFUIDS ON FLAT HEATERS

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ABSTRACT

Water-based γ-Aumina and Carbon nanotubes nanofluids have been examined for pool boiling heat transfer in atmospheric pressure on horizontal flat heaters. The particle concentrations were 0.1wt% and 0.01wt%. All nanofluids were stable and set to pH7 before boiling. Depending on surface roughness, the copper heaters were categorised as smooth or rough. Nanoparticles were spherical or acicular shapes. Boiling heat fluxes were varied up to 189kW/m^2. Nanoparticles were of three different shapes, and the nanofluids were in three concentrations. It has been found that dilute nanofluids are capable of enhancing BHT. Particle deposition occurs on the heater which increases with concentration. Moreover, dense nanofluids introduce thermal instability to the system. The importance of the ability of a nanofluid to withstand boiling temperature is also highlighted.

INTRODUCTION

Boiling has been the preferred mode of heat transfer in a wide range of applications due to its inherent capability to transfer larger quantity of heat across a given temperature difference. Characterised by bubble nucleation on the heater, boiling is a phenomenon governed by a combination of factors such as fluid properties, surface geometry and topography, and operating conditions. Surface modifications are frequently introduced to enhance boiling performance by increasing surface area and introducing bubble nucleation sites (Webb, 1994). In recent times, nanofluids were investigated for their potential to replace conventional liquids in boiling heat transfer.

Investigations on boiling of nanofluids mainly progressed on two mutually inclusive fronts; boiling heat transfer (BHT) and critical heat flux (CHF), the latter being more favoured in terms of the number of technical publications. There are strong evidences that the addition of nanoparticles do enhance the CHF of the base liquid. However for BHT, the situation is different. Deterioration became the norm of the day with few exceptions (Wen and Ding, 2005, Vassallo et al., 2004, Das et al., 2003, Bang and Chang, 2005). The underlying reason is thought to be the particle deposition on heater which in turn changed the wetting dynamics (Kim et al., 2007, Golubovic et al., 2008). This speculation was experimentally substantiated by Narayan et al (2007) and Chopkar et al (2008) when they reported heat transfer performance changed with the heater roughness. While the bubble nucleation is influenced by surface roughness, their detachment from the heater could be supported by nanoparticle structuring under the bubble (Wen, 2008).

Another parameter that should draw attention is the solution chemistry. The pH of the nanofluid is of paramount importance for its long term stability. Especially at boiling conditions where the nanoparticles are fiercely dynamic, the pH might have larger impact on particle deposition. For evidence, Milanova and Kumar (2008) reported that a pH change from 10.2 to 9.2 could prevent deposition of silica particles on their Ni wire in pool boiling experiments.

The present work is aimed at broadening the understanding on nanofluids boiling and underlying mechanisms. The effect of heater roughness, particle shape and concentration, and nanofluid stability are systematically investigated.

EXPERIMENTAL METHOD

Pool boiling experiments were conducted on the boiling test rig shown in Fig 1. The boiling chamber is made of Borosilicate glass, and is 'superwool' insulated from outside. The condenser was cooled by external water supply. Pool temperature was measured at three vertical locations.

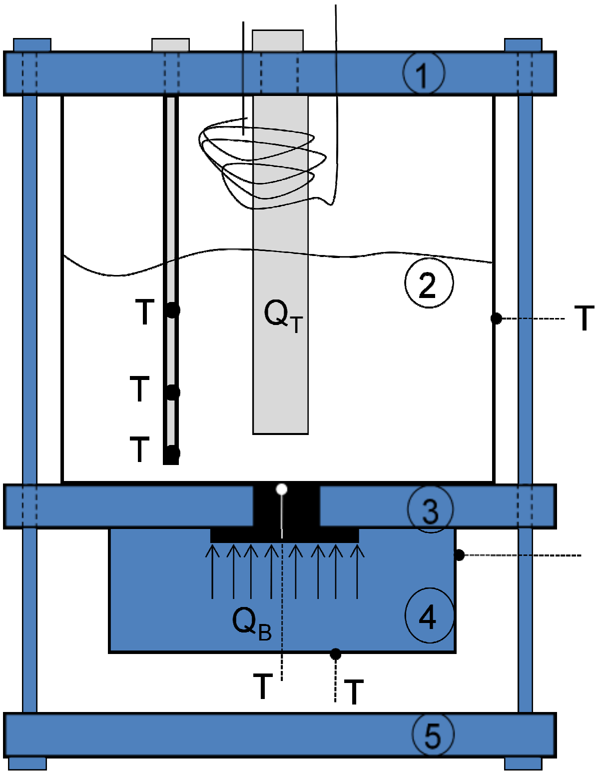

Figure 1: Apparatus; T-thermocouples, Q_B-heater for copper coupon, Q_T-auxiliary heater

There were two heaters; top heater was to raise and maintain the pool temperature at saturation value. m Bottom heat was the heat input to the test surface (copper coupon), Q_B, which was fed through a variac. The thermocouples were of accuracy ±0.1°C. Temperature readings were logged using National Instruments-Lab view data logging system. Once a particular heat flux was applied to the coupon, the steady state was awaited.

The nanofluids were formulated by suspending nanoparticles in distilled water. Stability was achieved by ultrasonication and pH adjustment. For Alumina nanofluids, there was no use of surfactants or dispersants. For CNT nanofluids, 0.25wt% of Gum Arabic was used to help dispersion. Supplier-specified (nanopowder as purchased) particle sizes were 45nm for spherical Alumina and 10*150nm for acicular Alumina. However once suspended, particles were found to be aggregated 6-8 times the primary size.

RESULTS

Experimental results obtained from boiling on smooth coupons and rough coupons are presented in Gig 2. The smooth coupons (S) were of Ra=0.04µm, while the rough coupons (R) were of Ra=1µm. A substantial enhancement (enhancement ratio $h_{nf}/h_w>1$)) is evident on rough coupons. Moreover, acicular Alumina (‘nee’) shows more promising than spherical (‘sp’). However on smooth coupons (Fig 2b), the enhancement was positive beyond a particular heat flux, while CNT has displayed some consistent increase. Also an effect of spherical alumina particle concentration is evident on b.

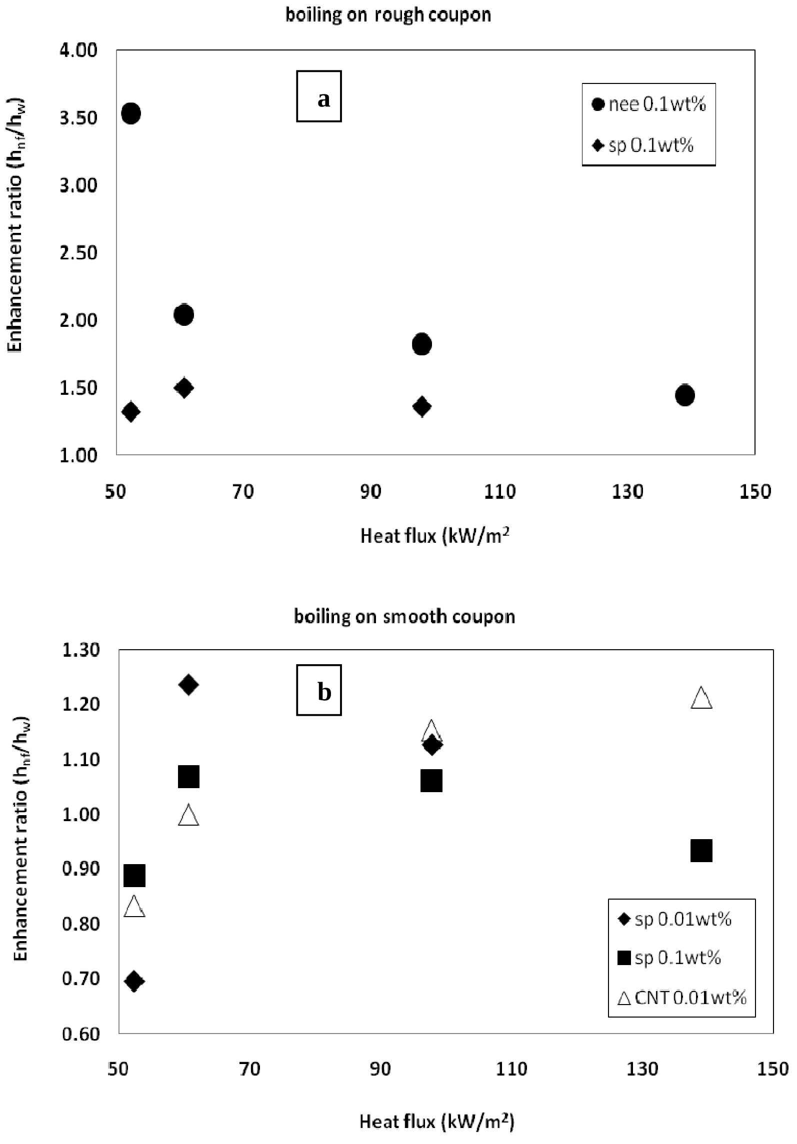

Figure 2: Dependence of heat transfer enhancement on roughness, particle type and shape and concentration

In literature, there were many instances where alumina nanofluids boiling were reported. Some were on different geometries to the present work conducted by us. Some did not mention surface roughness. However to draw comparison, few sets of closely-related literature data were selected and presented on Fig 3. Wen & Ding (2005), and Bang & Chang (2005) boiled on stainless steel horizontal flat surface. Das et al (2003) conducted boiling on stainless steel horizontal tubes. However out of these references, the Ra values were made available only by Das et al (2003).

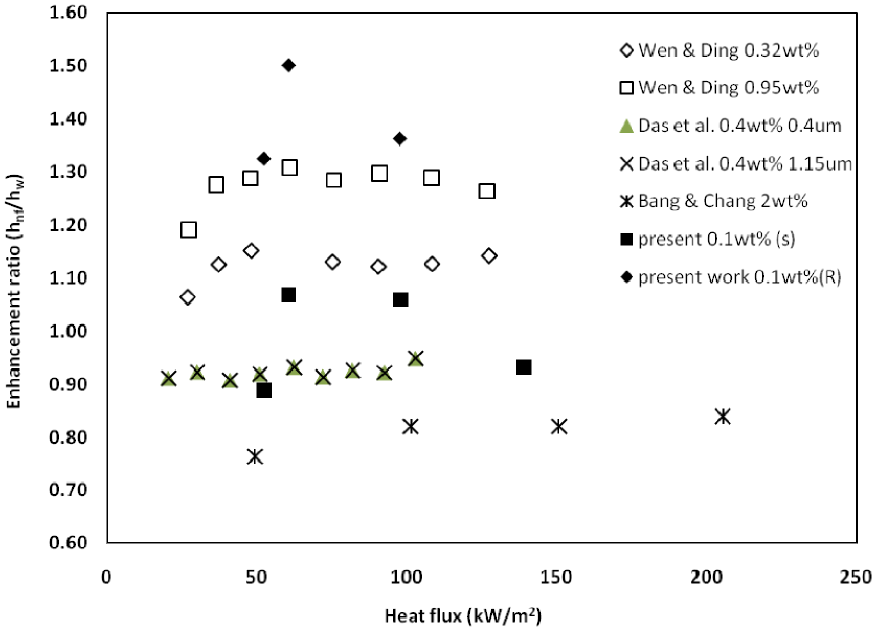

Figure 3: Comparison with literature data

Fig 3 further demonstrates a comparison between R & S coupons in present work. Accordingly, the R coupon has shown significant superiority in heat transfer. Moreover in the present work, the enhancement appears to be heat flux dependant, in contrast to prior art.

We found all Alumina-water nanofluids separated upon cooling down in the boiler. Particle sizes measured using Malvern Nanosizer indicated heavy agglomeration. We compared SEM images before and after boiling. The SEM images given in Fig 4 demonstrate considerable particle deposition. Yet the original nanofluids were in-tact. This shows boiling had destabilised the Alumina-water nanofluids.

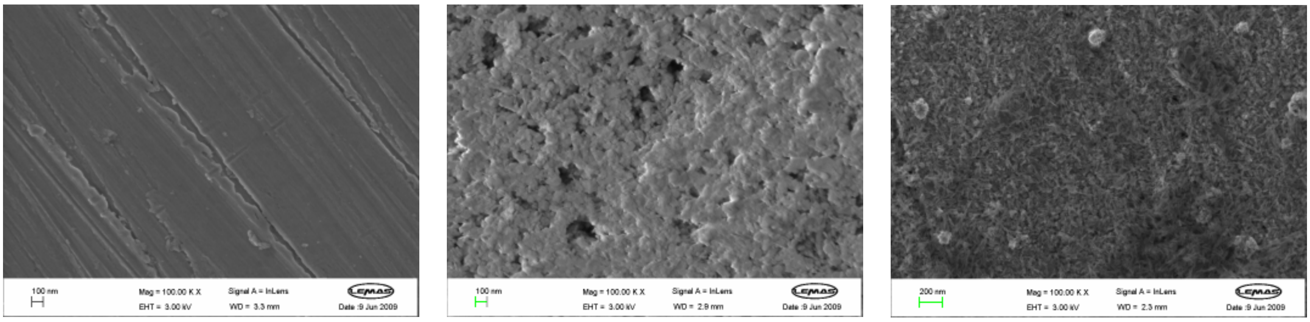

Figure 4: On left, middle & right; A smooth copper coupon, after boiling alumina spheres & alumina needles

CONCLUSIONS

Present experiments demonstrate that dilute aqueous Alumina and CNT nanofluids have the ability to enhance boiling heat transfer. The enhancement to various degrees had previously been reported in literature, although particle concentrations were larger. Moreover, the nanofluids which were stable at the outset, settled upon cooling after boiling. The heavier Alumina-water nanofluids, where wt%=1, could not achieve thermal equilibrium and hence the tests had to be abandoned. These observations shed light to existing understanding on boiling of nanofluids and demands closer investigations on their high temperature stability.

REFERENCES

BANG, I. C. & CHANG, S. H. (2005) Boiling heat transfer performance and phenomena of Al2O3-water nano-fluids from a plain surface in a pool. *International Journal of Heat and Mass Transfer,* 48**,** 2407-2419.

CHOPKAR, M., DAS, A. K., MANNA, I. & DAS, P. K. (2008) Pool boiling heat transfer characteristics of ZrO2-water nanofluids from a flat surface in a pool. *Heat and Mass Transfer,* 44**,** 999-1004.

DAS, S. K., PUTRA, N. & ROETZEL, W. (2003) Pool boiling characteristics of nano-fluids. *International Journal of Heat and Mass Transfer*, 46**,** 851-862.

GOLUBOVIC, M. N., HETTIARACHCHI, H. D. M., WOREK, W. M. & MINKOWYCZ, W. J. (2008) Nanofluids and critical heat flux, experimental and analytical study. *Applied Thermal Engineering,* In Press, Corrected Proof.

KIM, S. J., BANG, I. C., BUONGIORNO, J. & HU, L. W. (2007) Surface wettability change during pool boiling of nanofluids and its effect on critical heat flux. *International Journal of Heat and Mass Transfer,* 50**,** 4105-4116.

MILANOVA D. & KUMAR, R. (2008) Heat transfer behaviour of Silica Nanoparticles in Pool boiling Experiment. *Journal of Heat Transfer,* 130.

NARAYAN, G. P., ANOOP, K. B. & DAS, S. K. (2007) Mechanism of enhancement/deterioration of boiling heat transfer using stable nanoparticle suspensions over vertical tubes. *Journal of Applied Physics*, 102.

VASSALLO, P., KUMAR, R. & D'AMICO, S. (2004) Pool boiling heat transfer experiments in silica-water nano-fluids. *International Journal of Heat and Mass Transfer,* 47**,** 407-411.

WEBB, R. L. (1994) *Principals of Enhanced Heat Transfer*, John Wiley & Sons Inc.

WEN, D. S. (2008) Mechanisms of thermal nanofluids on enhanced critical heat flux (CHF). *International Journal of Heat and Mass Transfer,* 51**,** 4958-4965.

WEN, D. S. & DING, Y. L. (2005) Experimental investigation into the pool boiling heat transfer of aqueous based gamma-alumina nanofluids. *Journal of Nanoparticle Research,* 7**,** 265-274.