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A review on enhancement of pool boiling heat transfer using different structured surfaces with nanofluids

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ABSTRACT

Recently researchers have acknowledged the ability of nanofluids that exhibits enhanced thermal performance and increasing interest in boiling nanofluids and their applications. Among many articles being published, the dramatic enhancement of nanofluids has drawn special attention. This article includes recent studies on the enhancement of pool boiling heat transfer by the use of different structured surfaces using nanofluids as working fluids. It presents a review with the aim of identifying the reasons for enhancement and the limitation of the nanofluid application based on various published reports. At last the surface modification method along with nanofluids is introduced and recommended as a useful way.

Keywords: *Nanofluid, Different structured surface, Enhancement.*

1. INTRODUCTION

The efficiency of the heat transfer fluids can be improved by enhanc- ing their thermal conductivity and heat transfer properties. Since nanostructures typically show higher thermal conductivity than conventional fluids (water, ethylene glycol, transformer oil, etc.) and microstructures, the use of nanostructures into fluids had been proposed. Heat transfer performance of fluids can be improved by adding up nanostructures that have to be stable on the fluids. For increasing the stability of nanoparticles into fluids, a variety of techniques has been applied. As Graphene shows an extremely high thermal conductivity about 5000 W/mk, it will be interesting to study such behavior (thermal conductivity) as a two-dimensional structure.

With this regards, Graphene was chosen as a nanostructure but it could not disperse in the water for a long time. There are usually two methods to disperse nanostructures in fluids: mechanical and chem- ical. Mechanical methods generally include ultra-sonication using a probe or a bath. Based on the results of the primary our tests, this method cannot disperse Graphene nanosheets into the water. Chemical methods include the application of surfactants and are functionalized by using acid or alkaline treatment. The surfactant method changes the wetting or adhesion behavior of the surface that helps to good disper- sion of nanomaterials. Based on the results of our primary tests, using SDS as a surfactant cannot disperse Graphene nanosheets into fluids and its sample settling is rapidly less than 5 min. Therefore, chemical functionalization of Graphene is remaining as a treatment method. Chemical functionalization generally involves treating Graphene with a mixture of acids or alkaline media. The use of acid method on Graphene nanofluids has been studied in various papers. However, acid chemical functionalized, can damage the structure of Graphene and even cut the sheets. Until now, the published data on the factors that in- fluence the nanofluid stability and thermal conductivity have been focused on the acid methods. However, no other studies have been found to directly point out the effects of alkaline dispersion method on enhancing the thermal conductivity and stability of Graphene nanofluids. In particular, the alkaline chemical method has great potential for use in cost-saving industrial mass production processes. In this study, in order to prevent nanosheet cutting a combination of a mechanical method through ultra sonication and alkaline chemical method was used. This method, without the need for organic solvents and acids, is a low-cost, eco-friendly and convenient method to modify Graphene nanosheets.

2. LITERATURE REVIEW

The literature related to phase change material and nanoparticles will be considered for the review of the indoor and outdoor solar cooker application.

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Ahmad Ghozatloo et al. [1]: In this study nanofluids from functionalized Graphene were prepared by the alkaline method. The nanosheet Graphene was synthesized by using CVD method.
For dispersion of Graphene in water, it was hydrophilic by treating with the new alkaline method. Herein, it was reported as a facile and effective approach in preparing water-soluble Graphene by considering the potassium carboxylate (—COOK) as a mild oxidation process using potassium persulfate (KPS). Different parameters of time and temperature effects on thermal conductivity variations of alkaline functionalized Graphene (AFG) at different concentrations have been studied. The best result shows enhancement of thermal conductivity around 14.1% for the sample with 0.05 wt.% of AFG compared to water at 25 °C and 17% at 50 °C.

Mohammad Mehrali et al. [2]: In the present study, stable homogeneous graphene nanoplatelet (GNP) nanofluids were prepared without any surfactant by high-power ultrasonic (probe) dispersion of GNPs in distilled water. The concentrations of nanofluids were maintained at 0.025, 0.05, 0.075, and 0.1 wt.% for three different specific surface areas of 300, 500, and
750 m2/g. Transmission electron microscopy image shows that the suspensions are homogeneous and most of the materials have been well dispersed. The stability of nanofluid was investigated using a UV-visible spectrophotometer in a time span of 600 h, and zeta potential after dispersion had been investigated to elucidate its role on dispersion characteristics. The rheological properties of GNP nanofluids approach Newtonian and non-Newtonian behaviors where viscosity decreases linearly with the rise of temperature. The thermal conductivity results show that the dispersed nanoparticles can always enhance the thermal conductivity of the base fluid, and the highest enhancement was obtained to be 27.64% in the concentration of 0.1 wt.% of GNPs with a specific surface area of 750 m2/g. The electrical conductivity of the GNP nanofluids shows a significant enhancement by dispersion of GNPs in distilled water. This novel type of nanofluids shows outstanding potential for replacements as advanced heat transfer fluids in medium temperature applications including solar collectors and heat exchanger systems.

Hyungdae Kim et al. [3]: To investigate the characteristics of CHF (Critical Heat Flux) enhancement using nano-fluids, pool boiling CHF experiments of two water-based nano-fluids with titania and alumina nanoparticles were performed using electrically heated metal wires under atmospheric pressure. The results showed that the water-based nano-fluids significantly enhanced CHF compared to that of pure water. SEM (Scan- ning Electron Microscopy) observation subsequent to the pool boiling experiments revealed that a lot of nanoparticles were deposited on the heating surface during pool boiling of nano-fluids. In order to investigate the role of the nanoparticle surface coating on CHF enhance- ment of nano-fluids, pool boiling CHF of pure water was measured using a nanoparticle-coated heater prepared by pool boiling of nano- fluids on a bare heater. It was found that pool boiling of pure water on the nanoparticle-coated heater sufficiently achieved the CHF enhancement of nano-fluids. It is supposed that CHF enhancement in pool boiling of nano-fluids is mainly caused by the nanoparticle coating of the heating surface.

Davood Toghraie et al [4]: In this study, the thermal conductivity of Silica and Water-Ethylene glycol as the base nanofluid, was measured with- in the temperature range of 25–50 °C for samples with volume fractions of 0.1, 0.5, 1, 1.5, 2, 3, and 5%. According to our measurements, thermal conductivity increased with increasing temperature and volume fraction. In com- parison, volume fraction showed a greater incremental effect on thermal conductivity. Measurements showed that the highest thermal conductivity (45.5%) occurred in the volume fraction of 5% at 50 °C. Due to the lack of a precise and appropriate equation for the prediction of thermal conductivity of Silica/Water-Ethylene glycol nanofluid, an equation was provided based on the measurement results, which was a function of volume fraction and temperature. Investigations showed that maximum value for the margin of deviation for the proposed equa- tion was equal to 2.2%, which is acceptable for an experimental equation

Terry J. Hendricks et al [5] Enhanced pool-boiling critical heat fluxes (CHF) at reduced wall superheat on nanostructured substrates are reported. Nanostructured surfaces were realized using a low-temperature process, microreactor- assisted-nanomaterial-deposition. Using this technique we deposited ZnO nanostructures on Al and Cu substrates. We observed pool-boiling CHF of 82.5 W/cm2 with water as fluid for ZnO on Al versus a CHF of 23.2 W/cm2 on bare Al surface with a wall superheat reduction of 25–38 °C. These CHF values on ZnO surfaces correspond to a heat transfer coefficient of ~23,000 W/m2 K. We discuss our data and compare the behavior with conventional boiling theory.

Ali Ijam.et al [6]: Stability, thermal conductivity, viscosity, specific heat, density and electrical conductivity of graphene oxide nanosheets-(60:40) deionized water/ethylene glycol (GONs-DW/EG) were experimentally examined. The stability of the nanofluids is examined with sedimentation time. Experiments were carried out with a weight fraction of (0.01–0.10)% and different temperatures. Nanofluids were found to be stable for more than 2 months. The thermal conductivity is improved by 6.67–10.47% at a weight fraction of 0.10% and temperature of (25–45) °C. The nanofluids showed a shear thinning behavior at a low shear rate; however, it behaved in a Newtonian manner with the higher shear rate. The viscosity of
0.10 wt.% GONs-DW/EG nanofluid is increased by 35% compared to the base fluid at a temperature of 20 °C. However, it decreased by 48% with increasing the temperature from 20 to 60 °C for the same loading of GONs. The specific heat of the GONs-DW/EG nanofluid increased by 3.59–5.28% with a weight fraction of 0.05% and decreased by 9.05–8.215% with a weight fraction of 0.10% with a temperature range of 20–60 °C. The density of the GONs-DW/EG nanofluid at a weight fraction of 0.10% is decreased by 1.134–1% with a temperature of 25–45 °C. An improvement in electrical conductivity of about 1664% is achieved at a weight fraction of 0.10% and temperature of 25 °C. Correlations were developed for predicting thermo-physical properties and electrical conductivity of the nanofluids based on the experimental data.

Tessy Theres Baby et al. [7]: Nanofluids are having a wide area of application in electronic and cooling industry. In the present work, hydrogen exfoliated graphene (HEG) dispersed deionized (DI) water, and ethylene glycol (EG) based nanofluids were developed. Further, thermal conductivity and heat transfer properties of these nanofluids were systematically investigated. HEG

was synthesized by exfoliating graphite oxide in the H2 atmosphere at 200°C. The nanofluids were prepared by dispersing functionalized HEG (f-HEG) in DI water and EG without the use of any surfactant. HEG and f-HEG were characterized by powder X-ray diffractometry, electron microscopy, Raman and FTIR spectroscopy.
Thermal and electrical conductivities of f-HEG dispersed DI water and EG based nanofluids were measured for different volume fractions and at different temperatures. A 0.05% volume fraction of f-HEG dispersed DI water based nanofluid shows an enhancement in thermal conductivity of about 16% at 25°C and 75% at 50°C. The enhancement in Nusselts number for these nanofluids is more than that of thermal conductivity.

Huaqing Xie et al. [8]: Increasing interests have been paid to nanofluids because of the intriguing heat transfer enhancement performances presented by this kind of promising heat transfer media. We produced a series of nanofluids and measured their thermal conductivities. In this article, we discussed the measurements and the enhancements of the thermal conductivity of a variety of nanofluids. The base fluids used included those that are most employed heat transfer fluids, such as deionized water (DW), ethylene glycol (EG), glycerol, silicone oil, and the binary mixture of DW and EG. Various nanoparticles (NPs) involving Al2O3 NPs with different sizes, SiC NPs with different shapes, MgO NPs, ZnO NPs, SiO2 NPs, Fe3O4 NPs, TiO2 NPs, diamond NPs, and carbon nanotubes with different pretreatments were used as additives. Our findings demonstrated that the thermal conductivity enhancements of nanofluids could be influenced by multi-faceted factors including the volume fraction of the dispersed NPs, the tested temperature, the thermal conductivity of the base fluid, the size of the dispersed NPs, the pretreatment process, and the additives of the fluids. The thermal transport mechanisms in nanofluids were further discussed, and the promising approaches for optimizing the thermal conductivity of nanofluids have been proposed.

Irnie Zakaria et al. [9]: Nanofluid is an alternative promising cooling liquid with superior performance characteristic compared to conventional cooling liquid for Proton Exchange Membrane fuel cell (PEMFC). In this paper, new findings on the ratio of thermal conductivities and electrical conductivities of nanofluids in water: ethylene glycol (EG) mixtures
are established. Thermal conductivities and electrical conductivities of base fluids which are water: EG mixtures with concentration ranging from 0 % ethylene glycol up to 100 % ethylene glycol were measured. These base fluids are then dispersed with Al2O3 at 0.1, 0.3 and 0.5 % of volume concentration and thermal conductivities and electrical conductivities are then measured at a temperature of 20 °C. The result demonstrates that thermal conductivities reduced as the EG content percentage increases in the water: EG mixture. Thermal conductivities for 0.5 % volume concentration of Al2O3 is 0.6478 W/m.K and 0.2816 W/m.K for 0 and 100 % EG content in water: EG mixture. However, at a specific EG percentage, thermal conductivities also increased as a function of volume concentration. Electrical conductivities measured in 0.1, 0.3 and 0.5 % volume concentration of Al2O3 in base fluid also observed to decrease as the EG concentration increased even though the base fluids' electrical conductivity behave differently. Thermo-electrical conductivity ratio (TEC) has also been established based on both thermal and electrical.

3. BOILING ENHANCEMENT TECHNIQUES

I) Passive techniques

a) Coated surfaces:
They involve metallic or nonmetallic coating of the surface.
Examples include a nonwetting coating, such as Teflon, to promote dropwise condensation or a hydrophilic coating that promotes condensate drainage on evaporator fins, which reduces the wet air pressure drop. A fine-scale porous coating may be used to enhance nucleate boiling
b) Rough surfaces:
They may be either integral to the base surface or made by placing a "roughness" adjacent to the surface. Integral roughness is formed by machining, or "Restructuring" the surface. For single-phase flow, the configuration is generally chosen to promote mixing in the boundary layer near the surface, rather than to increase the heat transfer surface area.
c) Extended surfaces**:**
They are routinely employed in many heat exchangers. As shown in former Equation, the thermal resistance may be reduced by increasing the heat transfer coefficient (h), or the surface area (A), or both h and A. Use of a plain fin may provide only area increase. However, the formation of a special shape extended surface may also provide increased h.
d) Surface tension:
Surface tension devices use surface tension forces to drain or transport liquid film. The special "flute" shape promotes condensate drainage from the surface by surface tension forces.
e) Additives for liquids:
Additives for liquids include solid particles or gas bubbles in single-phase flows and liquid trace additives for boiling systems.
f) Additives for gases:
Additives for gases are liquid droplets or solid particles, either dilute-phase (gas-solid suspensions) or dense-phase (packed tubes and fluidized beds)

II) Active Techniques:

a) Mechanical aids:
They involve stirring the fluid by mechanical means or rotating the surface. Mechanical surface scrapers, widely used for viscous liquids in the chemical process industry, can be applied to duct flow of gases. Equipment with rotating heat exchanger ducts is found in commercial practice.
b) Surface vibration:
Surface vibration at either low or high frequency has been used primarily to improve single-phase heat transfer. A piezoelectric

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device may be used to vibrate a surface and impinge small droplets onto a heated surface to promote "spray cooling."
c) Fluid vibration:
It is the more practical type of vibration enhancement because of the mass of most heat exchangers. The vibrations range from pulsations of about 1 Hz to ultrasound. Single-phase fluids are of primary concern
d) Electrostatic fields:
They are applied in many different ways to dielectric fluids. Generally speaking, electrostatic fields can be directed to cause greater bulk mixing of fluid in the vicinity of the heat transfer surface.

4) Use of Nanoparticle:

There has been increasing interest of late in nanofluid boiling and its use in heat transfer enhancement.
Suspended nanoparticles inside the nanofluids can modify the characteristics of heated surfaces and the physical properties of the base liquids, offering a great opportunity to optimize boiling heat transfer.
Nanoparticles suspended in the liquid alone can affect bubble formation significantly by modifying bubble dynamics such as bubble departure volume and departure frequency. Both roles are likely co-existent in a typical nanofluids boiling system. Depending on different applications, properly surface engineering could minimize the particle deposition effect yet still contribute to the modification of heat transfer through this mechanism.
Nanofluids are colloidal suspensions of nanoparticles (length scales 1-100 nm) in a base fluid. These particles can be metallic (Cu, Au) or metal oxides (Al_2O_3, TiO_2, ZrO_2), carbon (diamond, nanotubes), glass or another material, with the base fluid being a typical heat-transfer fluid, such as water, light oils, ethylene glycol (radiator fluid) or a refrigerant. The base fluids alone have rather low thermal conductivities. Suspending particles in a base liquid to improve the thermal conductivity is not a new idea; previously the setback for scientists was the particle size.
Recently, graphene nanofluids have been developed. Their ability to modulate the Rayleigh–Taylor instability wavelength is quite interesting. Shorter wavelengths increase the CHF.

4. CONCLUSION

a) An optimized boiling surface should be designed from the stand point of main parameters like wettability and capillarity effects such surfaces could dramatically increase the boiling heat transfer.
b) The shape of nanoparticles is very important for their properties, methods with controllable micro-structure will be an interesting topic.
c) Long-term of stability and stability after a long working cycle is critical for both research and real-life applications.
d) Development of suitable surfactants for better stability of nanofluids may be a topic of interest.
e) High temperature may accelerate the degradation of the surfactants used as dispersants in nanofluids and may produce foams.

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