



Technical Note

An experimental investigation of transient pool boiling of aqueous nanofluids with graphene oxide nanosheets as characterized by the quenching method

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ABSTRACT

Quenching experiments with copper spheres were performed to characterize the transient pool boiling of aqueous nanofluids in the presence of graphene oxide nanosheets (GONs) at various dilute concentrations (≤ 0.001 wt.%). The CHF enhancement was found to vary non-monotonously with increasing the concentration of GONs. This non-monotonic variation was in accordance with the surface wettability change due to the deposited GONs after quenching. In addition to the primary effect of the deposition layers, the non-negligible influence of the suspended GONs was also identified, especially at relatively higher concentrations.

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1. Introduction

Engineered colloidal suspensions in the presence of highly-conductive nanoparticles, coined as nanofluids, have attracted increased attention for a couple of decades [1]. Intensive efforts have been dedicated to enhancement of critical heat flux (CHF) using nanofluids for pool boiling applications [2–4]. Based on the existing experimental results, the CHF enhancement of nanofluids has been interpreted as a consequence of modification of surface properties by nanoparticle deposition on the boiled surfaces [4–6]. Besides the surface wettability, the surface density of nanoparticles on the boiling surfaces [7], the presence of suspended nanoparticles [8], as well as the surface tension of nanofluids [9] have also been identified to have non-trivial impact on CHF.

From the materials point of view, a great number of available nanoparticles with various sizes and shapes have been attempted. Graphene, with a specific two-dimensional planar shape, has shown much better performance than conventional nanomaterials in increasing the thermal conductivity of nanofluids [10]. Using a steady-state method, Park et al. [11] demonstrated a remarkable enhancement of pool boiling CHF up to 180% for aqueous

nanofluids in the presence of graphene and graphene oxide nanosheets (GONs) at dilute concentrations (0.001 vol.%). On the other hand, transient pool boiling is of great practical interest with applications to materials processing and nuclear safety. The quenching method has been employed to characterize transient pool boiling of aqueous nanofluids in available literature [12–16].

In a preliminary work [17], transient pool boiling and CHF of aqueous nanofluids in the presence of GONs at extremely dilute concentrations were studied via the quenching method. This paper aims at extending the concentration of GONs to a wider range to further explore its influence. The effects of surface modification and suspended GONs on CHF enhancement were identified by performing repetitive quenching experiments.

2. Experimental

The quenching facility consisting of various components is shown in Fig. 1a. Copper spheres, with a diameter of 50 mm, plated with nickel were used as the quenching object. The surface roughness of the spheres was determined to be approximately 60 nm on a profilometer with a sensitivity of 0.001 μm . The temperature at the center of the spheres, as illustrated in the upper inset in Fig. 1a, was monitored during quenching. Details regarding the experimental procedure and data reduction have been presented elsewhere [17].

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Nomenclature

q'' heat flux, kW/m²
 q''_{CHF} critical heat flux, kW/m²

Greek symbols
 ΔT wall superheat, °C

A series of dilute aqueous GON nanofluid samples with elevated concentrations (0.0001, 0.0002, 0.0005, and 0.0010 wt.%) were prepared by diluting the original suspension (1.0 wt.%). As claimed by the supplier, there was an absence of any surfactants in the original suspension due to the hydrophilic nature of GONs. The size distributions of GONs in the various samples, inspected by the dynamic light scattering (DLS) technique, are compared in Fig. 1b. The majority of the size of the GONs was found to range between 200 and 500 nm, as confirmed by the transmission electron microscope (TEM) image on the dispersion of the GONs, as illustrated in the lower inset in Fig. 1a. In addition, long-term stability of the samples was characterized quantitatively by monitoring the absorbance change on a UV–Vis spectrophotometer. As shown in Fig. 1c, the agreement on the absorbance curves clearly indicates the desirable stability of the samples after 2 weeks.

3. Results and discussion

As presented in Ref. [17], a lumped capacitance model was utilized to establish the boiling curves from the instantaneous temperature variations despite the invalidity of this model during

transition and nucleate boiling regimes. As good reproducibility was observed by performing parallel experiments on multiple specimens for each sample, with a relative spreading of the measured CHF being about 3%, only the data (boiling curves) from single runs are presented.

3.1. Transient boiling characteristics

The sphere surfaces after quenching were subjected to visualized observation by scanning electron microscope (SEM) imaging. The static contact angle of the boiled surfaces was also measured via the sessile-drop method with water drops of a volume of 3 μ L. Comparison of the variations of surface pattern and wettability among the various samples is displayed in Fig. 2, in order to assist data interpretation of the boiling curves (Fig. 2g). It is clear that the CHF of water was enhanced up on introduction of GONs, even at such dilute concentrations. Having presented in the previous work [17], the CHF was found to increase remarkably by 13.2% and 25%, respectively, for the nanofluid samples with 0.0001 and 0.0002 wt.% of GONs. The enhancement, however, did not increase monotonously with further increasing the concentration to 0.0005

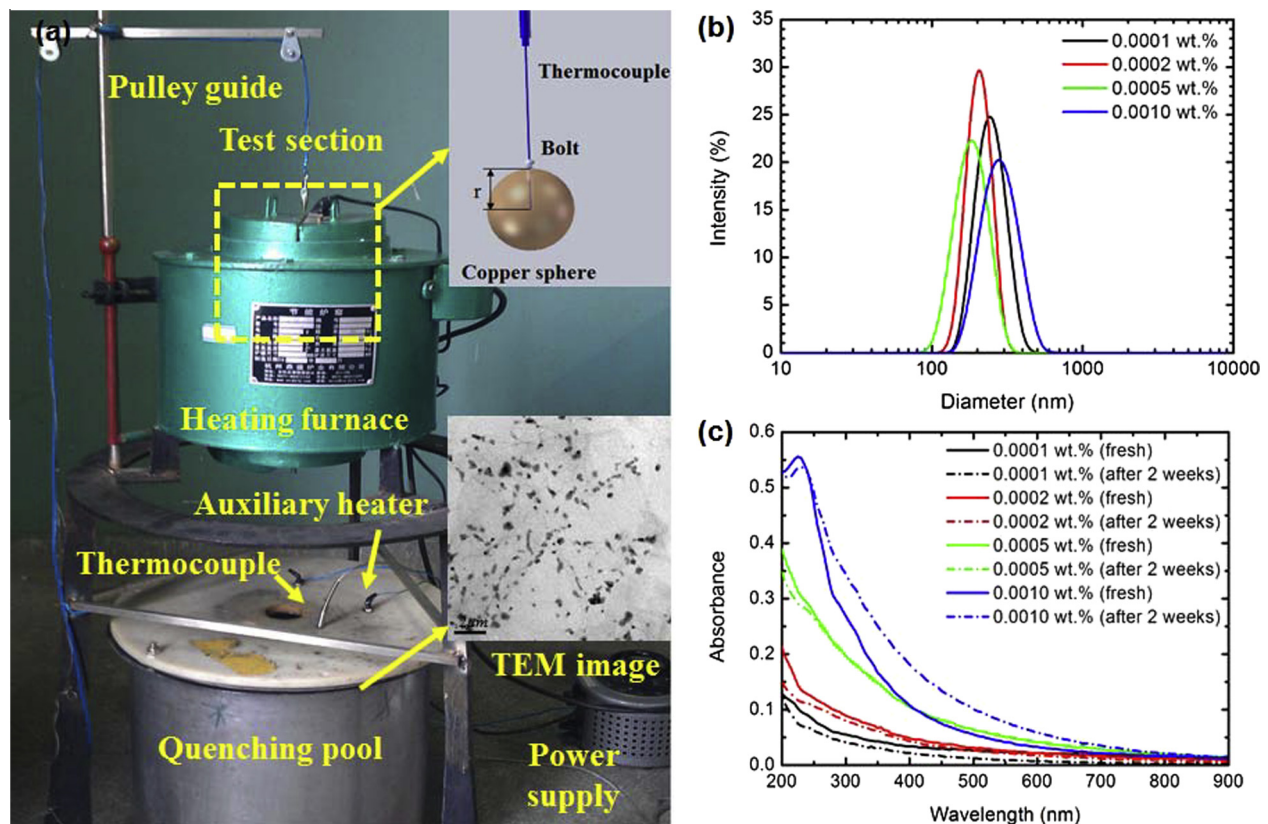


Fig. 1. (a) Photograph of the experimental setup with the upper and lower insets showing the assembly of the quenching object and the TEM image on GONs in suspension, (b) comparison of size distributions of GONs, measured by DLS, among samples with various concentrations, and (c) comparison of absorbance variations, measured by UV–Vis spectrophotometer, between fresh and old (placed on the shelf for 2 weeks) samples.

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