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Changing bubble dynamics in subcooled boiling with TiO_2 nanoparticles on a platinum wire

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A B S T R A C T

Bubble dynamics in pool boiling provides a suitable platform for researchers to understand the mechanisms of subcooled boiling heat transfer. Besides, the effects of nanoparticles on this phenomenon have not been fully understood yet. In this study, the effect of TiO_2 nanoparticles (with two weight fractions, 0.002% and 0.005%) mixed in de-ionized water during subcooled pool boiling on a thin platinum wire with a diameter of 250 μm was experimentally investigated for working bulk fluid temperatures between 30 and 50 °C at atmospheric pressure, and new bubble dynamics phenomena were reported. Applied heat fluxes varied from onset of nucleate boiling point to higher heat fluxes up to nucleation jet flow. The experiments were visualized with a high speed camera system, and acquired videos and images were utilized for analysing prevalent phenomena, such as bubble-bubble and nucleation site-bubble interactions, surface tension and Marangoni convection, structural disjoining pressure, pinning and nanoparticles deposition effects as well as the main mechanisms. In general, migration, coalescence, leaping and detaching were recorded for nanofluids with weight fractions of 0.002 wt% and 0.005 wt%, while oscillation, dancing and stick processes were exclusively observed only in nanofluids with a weight fraction of 0.005 wt%. The images, results, and related discussion provide new knowledge and physics for pool boiling phenomena on platinum fine wires in the presence of nanoparticles.

1. Introduction

Despite being one of the most investigated topics in heat transfer studies by virtue of its potential of removing large amount of heat, many principles and mechanisms of boiling phenomenon remain elusive due to its complexity. Nucleate boiling has crucial importance in many fields such as manufacturing, power plants, nuclear reactors, refrigeration and chemical processing [1–3]. However, limited fundamental studies have been performed on bubbles dynamics and their effects on boiling heat transfer. On the other hand, alternative solutions were sought to augment heat transfer such as changing the surface by deposition of materials [4] or coating nano/micro porous structures [5], adding nanoparticles to the base fluids [6], using pin fins [7], jet impingement [8], taking the advantage of secondary or turbulent flows [9].

Nanofluids, which are prepared by dispersing nanoparticles into base fluids, have shown promising features from the heat transfer perspective in terms of thermophysical properties such as thermal conductivity and heat capacity [4,10–13]. Generally, the thermal conductivity of employed nanoparticles is higher than that of base fluids, such as water, ethanol and engine oil, and underlying mechanisms for enhancement in thermal conductivity of nanofluids can be attributed to layering at the solid/liquid interface, ballistic phonon transport, Brownian motion of the nanoparticles at the molecular and nano-scale level [14,15].

Nanoparticles within nanofluids can alter the heated surface characteristics leading to deposition of a thin layer of nanoparticles and influence the single-phase, flow and pool boiling heat transfer. According to many experimental studies, upon deposition of nanoparticles, a porous layer deposits on the surface and leads to a decrease in nucleation sites density [16,17]. Besides, the deposited layer introduces an extra thermal resistance. The aforementioned factors are found to be leading reasons behind pool boiling heat transfer deterioration. On the other hand, nanoparticles deposition, which can result in a decrease in contact angle, can cause an improvement in surface wettability and subsequent pool boiling critical heat flux (CHF) enhancement [18,19]. Another possible mechanism of this enhancement can be attributed to nanoparticle pinning effect at the contact line region owing to structural disjoining pressure, which is generated by ordered layering of nanoparticles in the evaporation meniscus contact line [20,21]. In addition, disjoining pressure enhances spreading and changes the force balance near contact line [22]. Furthermore, it is known that the deposition of

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nanoparticles and nanoparticle thin film coating affect surface roughness [16], wettability [17,23] as well as receding and advancing contact angles [23].

Unlike saturated boiling, the presence of temperature gradients along the bubble interface in subcooled boiling leads to Marangoni convection, which is a major heat transfer mechanism in this regime. Following natural convection regime, bubbles arise from the nucleation sites along with the augmentation of the heat flux. A bubble, which is attached to a heated surface and exposed to subcooled fluid from its cap, is subjected to condensation from its cap and evaporation from its base. However, in the case, where non-condensable gases are present inside the bubble, they accumulate near the condensation surface, inhibit condensation leading a temperature gradient at the bubble interface and hence induce a Marangoni convection around the bubble [24].

Some of the interesting events observed in de-ionized (DI) water based pool boiling experiments related to bubble dynamics are sliding [25–31], oscillation [30,32,33], collision [25,26,29–31], leaping [30,31, 34–36] circling [37,38] accompanied with bubble top jet flow [12,13, 14,15]. However, only few investigations have been conducted with nanofluids [39]. The common point of these pioneering studies is that Marangoni convection plays a major role in subcooled pool boiling and augments heat transfer. However, more studies on the investigation of bubble-bubble interactions and nucleation site-bubble interactions are crucial to fully understand the Marangoni convection and its contribution to heat transfer.

The goal of this study is to provide detailed information about bubble dynamics on a platinum wire and give insight about bubble-bubble interactions and nucleation site-bubble interactions as well as the role of nanoparticles in this bubble dynamics at different applied heat fluxes

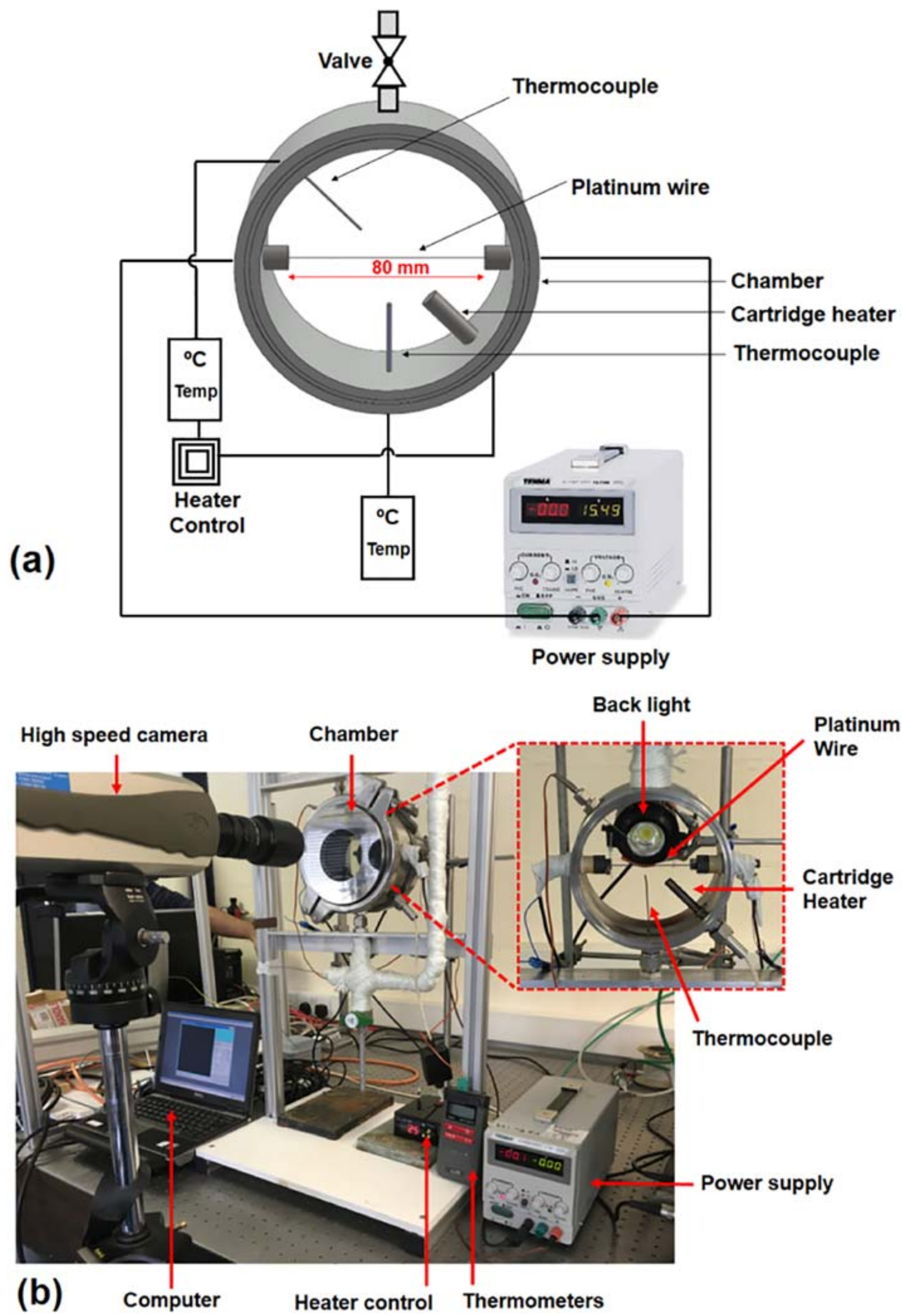

Fig. 1. (a) Schematic and (b) an image of the pool boiling experimental setup.