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Microwave irradiation based non-chemical method to manipulate surface tension of nanofluids

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ABSTRACT

Manipulation of the surface tension is one of the key pathways to enhance heat and mass transfer performances of nanofluids in thermal systems. Current practices and existing literature on the surface tension reduction indicate that surfactant is usually employed as a chemical-additive to manipulate surface tension. This study, on the other hand, aims to explore a physical method to manipulate the surface tension of nanofluids based on microwave irradiation. This paper, therefore, is the first publication to report surface tension behaviors of nanofluids during and after microwave irradiation. Experimental results show that after microwave treatment, lower surface tensions were observed for both TiO_2 and Fe_2O_3 based nanofluids for an extended period of time, even though the temperature has returned to its initial condition. These preliminary findings suggest that microwave irradiation treatment has the potential to be a non-chemical method to manipulate surface tension of nanofluids.

1. Introduction

Interests on nanofluids and their promising applications in heat and mass transfer systems have been significantly growing in the past two decades. These interests have been motivated by the reported findings that the suspensions of nano-sized particles (generally less than 100 nm) in a conventional heat transfer fluid are able to enhance the effective thermal conductivity and convective heat transfer coefficient [1–8]. Few studies have also reported that nanofluids can also be employed to improve mass transfer rates. Ever since Choi initiated the first work on nanofluid in 1995 [9], many related research activities have been devoted to the potential applications of nanofluids to improve the performances of heat and mass transfer systems including processes involving boiling and simultaneous heat and mass transfers. These are indicated by extensive publications in this area reporting findings from experimental and numerical studies [1–8,10–16].

Calculations and analyses of heat and mass transfer systems operated with nanofluids are regulated by key physical properties. One of these properties is surface tension, which determines the shape of a liquid droplet. As a result, heat and mass transfer across interfaces are strongly influenced by surface tension. Experimental studies have revealed that surface tension has a great influence on the performances of boiling heat transfer where lower surface tension is found to promote higher critical heat flux and boiling rate [8,10,17–19]. Lowering surface tension also had a positive impact on gas–liquid mass transfer especially in packed bed systems [20–23]. Hence, lowering surface tension is desirable to ensure better heat and mass transfers.

Manipulation of surface tension is usually performed by adding a chemical additive called surfactant. Addition of surfactant into the fluids has been acknowledged to effectively reduce surface tension and simultaneously promote boiling heat transfer of water [24–26] and nanofluids systems [19,27]. Surfactants have also been reported to be useful in improving stability of nanoparticles in aqueous suspensions [28–31]. Nevertheless, adding surfactant into nanofluids has negative impacts on other key physical properties such as thermal conductivity and viscosity. The presence of surfactant has been found to significantly increase the viscosity, which will lead to higher pressure drop and pumping cost of the nanofluids [32]. In heat transfer applications, surfactants may produce foam during heating and it was also found that surfactants introduce an additional thermal resistance between the nanoparticles and the base fluid which results in lower thermal conductivity of nanofluids [32]. Moreover, the increasing stringent environmental regulations on waste treatment discourage the excessive use of surfactants [33–37]. Summarily, an alternative stabilizer and surface tension reducer of nanofluids, which is more environmentally

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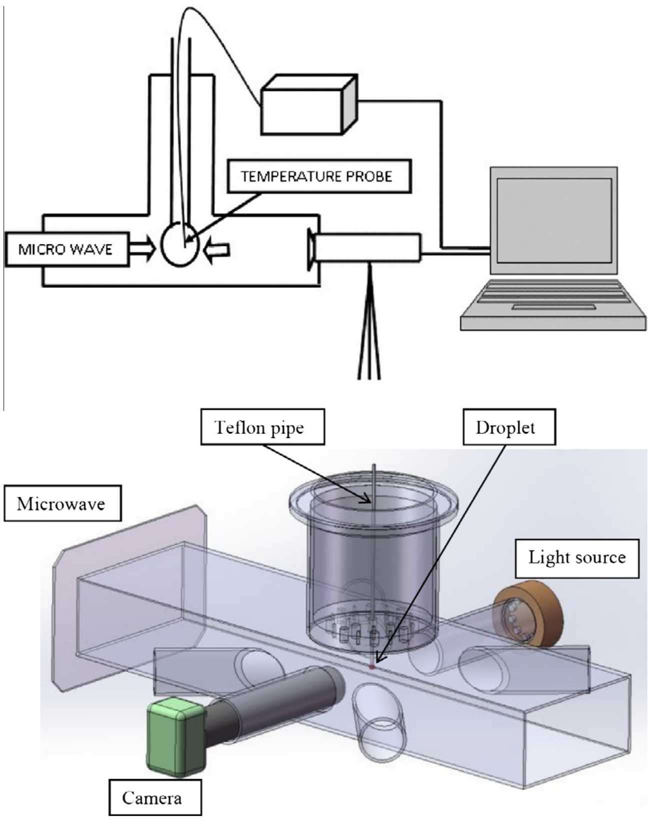

Fig. 1. Side and 3D view of the experimental apparatus.

friendly than chemical additive method, is preferable. Consequently, a physical based method without the use of chemical addition is being sought-after.

Recently, microwave assisted preparation of nanofluids have been tested and found to work well in stabilizing nanofluids [38] since through microwave treatment a homogeneous colloidal system can be obtained in a very short period [39]. In order to serve as an alternative to chemical additive methods, a physical based method using microwave treatment has to be proven in both stabilizing the colloidal systems of nanofluids and reducing surface tension. To date, however, there is no report yet on the effect of microwave irradiation on the surface tension reduction of nanofluids. Our previous work indicated that microwave irradiation treatment has a lasting effect on the surface tension reduction of water where its value is lower than of before the treatment even after the temperature returns to its original condition [40]. Thus, an interesting question now arises on whether this effect also exists on nanofluids. In view of the aforementioned, this study aims to report experimental investigations on the surface tension of nanofluids under microwave irradiation. It is envisaged that the results from this study will further contribute to the fundamental aspects of microwave irradiation as a promising and greener physical method to manipulate surface tension.

2. Experimental

2.1. Materials

Two nanoparticles, TiO_2 and Fe_2O_3 based nanofluids, were selected for this study. The solutions were prepared by dispersing nanoparticles in distilled water at different concentrations. To evenly disperse particles in the base fluid, magnetic stirring and sonication treatment were then performed. Sonication was conducted in a ultrasound water bath manufactured by SND Co., Ltd, Japan (Model us101, frequency 38 kHz, power 55 W). TiO_2 with diameter of 7 nm was purchased from Ishihara Sangyo Kaisha LTD, Japan and Fe_2O_3 having diameter of 15 nm was obtained from Kanto Chemicals Co., Japan.

2.2. Main apparatus

Schematic diagrams of the microwave apparatus can be seen in Fig. 1. This apparatus was designed and constructed by Shikoku Instrumentation Co., Inc., Japan. Pendant method was employed for the measurement of surface tension of nanofluids. Teflon pipe with the dimensions of 1.4 cm long, 1 mm inside diameter and 2 mm outside diameter was used in the experiments. Droplet with its volume of 17 μl was produced by injection using syringe.

Temperature sensor (model: FL-2000 Optical fiber: FS100-M), was supplied by Anritsu meter Co., LTD, Japan. This probe was inserted from the top of the reactor to measure droplet temperatures during and after microwave irradiation. This probe was also inserted inside the droplet to ensure uniform shape of the droplet for all experiments. Light source was used from one end of the microwave reactor and high speed camera (Sigma Koki Co., LTD Model SK-TC202USB-AT) was employed from installed at the other end to capture the shape of the droplet.

2.3. Methods

Experimental conditions of the surface tension measurement are listed in Table 1. Experimental analysis consists of two steps:

1. Confirmation of initial surface tension of nanofluid droplet before microwave irradiation.
2. Capturing the images of the droplets during and after microwave irradiation.

Axisymmetric drop shape analysis (ADSA) was employed to measure surface tension by analyzing the edge profiles of the droplet [41,42]. Fig. 2 shows an example of raw image and the fitting results. ADSA software estimates the surface tension by fitting the whole droplet profile (Fig. 2b).

3. Results and discussions

Fig. 3 shows the surface tensions and temperatures of nanofluids at different concentrations of nanoparticles as a function of time. Initially (at time = 0 s), temperatures were at around 20 °C and surface tensions were around 72 mN/m. This initial surface

Table 1
Experimental conditions of the surface tension measurements.

Run	Nanoparticle	Particle concentration (wt%)	Particle size (nm)	Microwave power (W)	Duration of microwave irradiation treatment (s)
1	TiO_2	0, 0.1, 0.5, 1	7	600	120
2	Fe_2O_3	0, 0.05, 0.1, 0.5	15	600	120
3	Fe_2O_3	0.1	15	150, 300, 450, 600	120
4	Fe_2O_3	0.1	15	600	30, 60, 120