International Communications in Heat and Mass Transfer 84 (2017) 94–101

Contents lists available at ScienceDirect

International Communications in Heat and Mass Transfer

journal homepage: www.elsevier.com/locate/ichmt

Thermo-physical properties of water based SiC nanofluids for heat transfer applications

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ARTICLE INFO

Keywords:
SiC nanoparticles
nanofluids
thermo-physical properties
heat transfer characteristics

ABSTRACT

The aim of current paper consists in the fabrication, characterization and preparation of water based on SiC nanofluids and the experimental investigation of their thermo-physical properties. Thermal conductivity, viscosity and surface tension of SiC/water nanofluids were measured for two two weight concentrations of nanoparticles 0.5 and 1.0 wt% respectively, within the range 20 °C to 50 °C. Concerning the thermal-properties of studied nanofluids, the experimental results show that the thermal conductivity increases with the increasing both of the weight concentration of the nanoparticles and temperature. Also, the dynamic viscosity of the SiC/water nanofluids increases with increasing nanoparticles concentration and decreases with the increasing temperature. Furthermore, the surface tension of studied nanofluids increases with the increase of the weight concentrations of the nanoparticles, but the results show that at a concentration of the nanoparticles of 0.5 wt%, the surface tension was lower than the surface tension of the water, while at 1.0 wt% nanoparticles, the surface tension of the nanofluids was close to the surface tension of the water. Measurements were compared with experimental data available in literature and theoretical models. Finally, SiC/water nanofluids were used as working fluid inside of the two-phase closed thermosyphon in order to study of the heat transfer from point of view both of operating temperature and the nanoparticles concentration.

1. Introduction

The nanofluids can be defined as systems containing very small particles with sizes (under 100 nm) (nanoparticles) suspended in conventional liquids as water, oils or glycols. Generally, the introduction of nanoparticles in the base fluid enhances the thermal properties of the system, such as the thermal conductivity and the heat transfer coefficient.

Silicon nanoparticles have attracted attention due their intriguing physical properties, active surface state and biocompatibility [1] being used in various fields as thermoelectrics, photovoltaics, nanoelectronics, and nanomedicine [2]. Combining Si structure with a conducting carbonaceous layer can get many benefits, such as excellent flexibility, high conductivity, lightweight, electrochemical and thermal stability [3,4]. Thermal conductivity and dynamic viscosity of the silicon carbide were experimental investigated in Refs [4–11]., but researches concerning the surface tension of the SiC/water nanofluids not are available in the literature. Furthermore, only few papers [12–14] investigated the heat transfer in two-phase thermosyphons using silicon carbide. On the other side, silicon nanoparticles were seldom reported for nanofluid applications. We can cite the study of silicon nanoparticles prepared by pulsed-laser ablation in deionized water, where the resulted low concentration (0.01 and 0.001% vol.) nanofluids presenting slightly lower surface tension and a very weak viscosity increasing compared to the corresponding values from pure water [15]. Also, the silicon-containing nanofluids reveal a slightly higher CHF (critical heat flux) than that for the water [15]. Moreover, polydisperse (40–250 nm) silicon nanoparticles (made by thermal plasma) were successfully used as aqueous nanofluis for enhanced heating and vaporization of water under sunlight due to the broadband absorption spectrum from UV to NIR of the silicon nanoparticles [16]. The observed vaporization rates were enhanced for a wide range of concentrations (from 0.001 to 0.1% vol.) with a maximum efficiency at 0.01% vol. [16] possibly due to the solar radiation shielding at the highest tested concentration.

The current study is divided in two parts: first part is dedicated to fabrication, characterization and preparation of water based on SiC nanofluids and second part for the investigation the effects of the temperature and weight concentration on the thermo-physical (thermal conductivity, dynamic viscosity and surface tension) and heat transfer characteristics of SiC/water nanofluids used in two-phase closed

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http://dx.doi.org/10.1016/j.icheatmasstransfer.2017.04.006

thermosyphon.

2. Experimental procedure

2.1. Synthesis of SiC nanoparticles

The nanopowders were synthesized using the laser pyrolysis technique. The laser pyrolysis method requires the presence of a sensitizer (laser energy transfer agent) besides the nanoparticles precursors. For the synthesis of the nanopowders, a mixture of silane and acetylene was used. The silane plays the double role as sensitizer and as silicon donor. Also, acetylene (C_2H_2) plays the role of carbon donor. Due to the strong absorption of silane (SiH_4) molecules at the 10P(20) line (wavelength = 10.59 μm)of CO_2 laser [17], they become excited on higher vibrational levels and transfer this excess energy by collisions with other molecules from the gas mixture(such as C_2H_2 molecules that not have vibrational modes near CO_2 laser frequency [17]) which is rapidly heated and pyrolysed with the formation of silicon-based nanoparticles. The high productivity gas-phase laser pyrolysis method was widely reported for the nano-SiC synthesis from this precursor in the presence of acetylene or other hydrocarbons [18–22]. A Coherent CO_2 pulsed laser with 400 W nominal power, working at 10.59 μm was used for the synthesis of the nanopowders (80 KHz frequency and a duty factor around 60%). Some parametric studies were performed in order to find proper conditions for nanoparticles production with elemental composition as SiC at stoichiometric composition and then as SiCx with x less than 1.In order to obtain a near stoichiometric SiC composition, the Si to C atomic ratio in precursors must to be 1/1 which is translated in a SiH4/C2H2flow ratio of 2/1.

In the first experiment, for the SiC-1 nanopowder synthesis, a mixture consisting in 24.1 sccm C_2H_2 and 110 sccm SiH_4 was injected through a central thinner nozzle with the diameter of 2.0 mm, whereas 4015 sccm Argon was simultaneously introduced through an external annular nozzle of 10 mm diameter. The velocity values for both inner gas mixture (C_2H_2 + SiH_4) and outer Argon were kept equal in order to preserve the laminar flow of the reaction mixture in the laser irradiation zone. In the secondexperiment, for the SiC-2 nanopowder synthesis, a 50 sccm C_2H_2 + 100 sccm SiH_4 mixture was injected through the central nozzle and 5000 sccm Argon through the annular one. The SiC nanopowders synthesis occurred at a pressure of 450 mbar (kept constant with the aid of a throttle valve) and under higher laser power of 400 W.

2.2. Characterization of SiC nanoparticles

The SiC nanoparticles have been characterized using XRD and TEM techniques. Fig. 1 shows the XRD patterns along with phase's identification, based on their relative maxima of as synthesized SiC nanoparticles. The X ray diffractograms (XRD) of both sample (see Fig. 1) showed a nanometric nature of analyzed materials revealed by the presence of broad peaks. The identified diffraction maxima correspond to Si and most probable 3C–SiC phase. The main peaks were well fitted by pseudo-Voight function and this fact was a sign for a narrow size distribution of crystallite dimensions. The presence of nanocrystalline Silicon was attested only in SiC-1 sample (Fig. 1, the black line) by the peaks placed at 2θ = 28.6, 47.4, 56.2, 69.1, 76.4 and 88.1°. Based on full width half maximum (FWHM) of the (111) Si peak centered at 2θ = 28.6° and using the Debye –Scherrer equation the mean crystallite size was calculated to be 23.4 nm. In the same SiC-1 sample using again the FWHM, yet for the (111) 3C–SiC centered at 2θ = 35.7°, the mean crystallite size of this phase was 5.3 nm. For the SiC-2 sample the X ray pattern (Fig. 1, red line) showed only SiC peaks, their mean crystallite size being measured in the same manner and the resulted value was 10.7 nm. The absence of silicon phase in this sample corresponds with the near unitary silicon to carbon atomic ratio extracted from EDX measurement. EDX analyses evaluate the following mediated elemental proportions: 42.02 at.% C, 4.44 at.% O and 54.54 at. % Si for SiC-1sample, and 52.55 at.% C, 1.24 at.% O and 46.21 at.% Si for SiC-2 sample. The presence of both elemental silicon and silicon carbide (as (β)-3C SiCpolytype) crystalline phases, in conjunction with the observed higher atomic silicon content vs. the carbon content in the SiC-1 nanopowder can be related with the introduction of an excess of silane reactant. Also, even if the synthesis of those nanopowders was performed in anoxic atmosphere and without oxygen-containing precursors, the EDX analyses show the presence of a small percent of atomic oxygen in both samples due to their post-synthesis exposure at ambient air. The higher oxygen percent in SiC-1 sample can be correlated with the presence of elemental silicon which is much more reactive towards oxygen than silicon carbide. Due to reaction of these nanoparticles with molecular oxygen amorphous silica and/or silicon oxycarbide superficial thin layer can be formed [23].

TEM image of SiC nanoparticles is shown in Fig. 2. As depicted, some nanoparticles are arranged in ramified/chained aggregates or small clusters. Their sizes are in more or less correlated with the mean crystallite sized extracted from X-ray measurements, generally under 25 nm for both samples. The aggregation of these nanoparticles can be explained by the welding of hot fresh nanoparticles due to their collision in the crowded laser pyrolysis flame.

2.3. Preparation of SiC nanofluids

In this study, homogeneous and stable water-based SiC nanofluids with different weight fractions were prepared. For the aqueous nanofluid preparation, the low viscosity dry carboximethylcellulose white

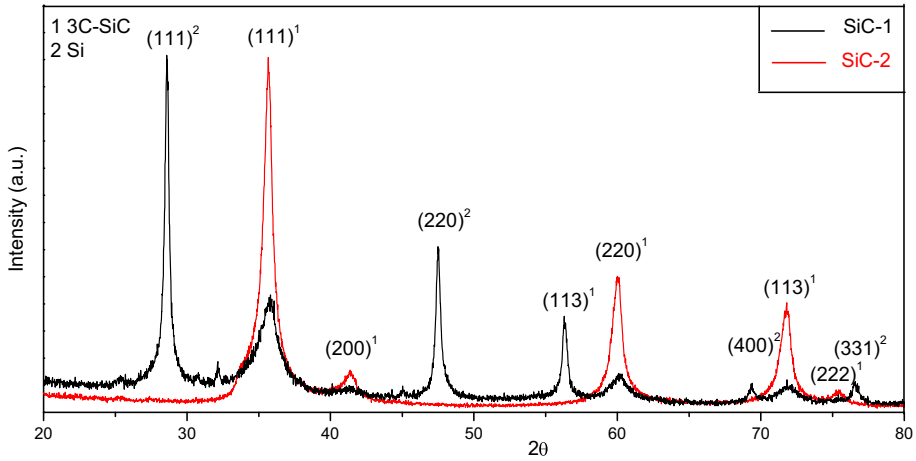

Fig. 1. Superposed X ray pattern for the SiC-1 and SiC-2 powders.