MEASURING TRANSPORT PROPERTIES OF NANOFLUIDS

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ABSTRACT

The study of nanofluids has lately gained scientific interest, due to their enhanced thermal conductivity, which would significantly improve the performance of heat transfer equipment. This work is part of a bilateral scientific program between the AUTh and the Institute of Chemical Process Fundamentals of the Czech Academy of Sciences, whose purpose is to study the rheological behaviour of nanofluids as well as their effect on the performance of commercial compact heat exchangers. The aim of the present work is to measure the thermophysical properties of nanofluids consisting of nanoparticles suspended in a conventional working fluid.

INTRODUCTION

The design of energy-efficient heat transfer equipment, as well as the research for enhancing thermal capability of conventional fluids, contributes to the effort for better energy management. In the past, the thermal conductivity of working fluids has been augmented by suspending millimetre- or micrometre-sized particles in a base fluid. However, it has not been of interest for practical applications due to problems such as sedimentation, erosion, clogging, fouling and increased pressure drop of the flow channel. Lately, technological progress has led to the development and production of metal particles in nanometre scale, which, when dispersed in a conventional base fluid, appreciably enhance its thermal conductivity. Water, ethylene glycol and various kinds of oils are usually employed as base fluids. It seems that these suspensions, called *nanofluids*, can possibly overcome the aforementioned problems, because the particles are ultra-fine and are usually used at low particle concentrations [1].

The aim of the present work is to measure the thermophysical properties (i.e. thermal conductivity, viscosity and surface tension) of nanofluids consisting of multi-wall carbon nanotubes (*MWCNT*) or copper and aluminium oxide nanoparticles suspended in a conventional working fluid (e.g. water, ethylene glycol).The ultimate goal is to investigate the effect of the use of nanofluids on the performance of commercial heat transfer equipment.

LITERATURE REVIEW

The majority of the work published on nanofluids concerns mainly their thermal conductivity, whose increase depends on many factors, such as the type and dimensions of the particles and their concentration in the nanofluid. Wang & Mujumdar [2] in a comprehensive review article summarize the work done on this field. The works included in the review report different levels of thermal conductivity enhancement, e.g. 20-55% for copper nanofluids, greater than 10% for

Al_2O_3 nanofluids. These differences can be attributed to the type, size and concentration of nanoparticles as well as the type of the base fluid.

Concerning the thermal conductivity of carbon nanotubes, Assael et al. [3] report a 20-35% increase for a 0.6 vol.% carbon nanotube nanofluid in comparison with the base fluid, depending on the dispersant used and its concentration. Ding et al. [4] also found a 25% increase of the effective thermal conductivity of water with 1.0 wt.% carbon nanotubes at 25^o C, while at 30^o C this enhancement rises to 80%.

When nanofluids are employed as working fluids in heat exchanging equipment, apart from thermal conductivity, their rheological characteristics are of great importance. However, papers concerning rheological studies of nanofluids are scarce in the literature [2]. The limited work published on viscosity measurements shows a dependence on the kind of the nanofluid (i.e. type and concentration of nanoparticles, type of base fluid). It is reported [5, 6] that for Al_2O_3-water and CuO-water nanofluids the viscosity increases with increasing particle concentration. This increase is more pronounced in the case of the CuO nanofluid, a fact that can be possibly attributed to the larger size of the CuO nanoparticles used [5]. Das et al. [6] also report that viscosity decreases with temperature and confirm a Newtonian behaviour of the Al_2O_3-water nanofluid. However, there is also a strong evidence that a nanofluid may be non-Newtonian, even viscoelastic in some cases [2], so further research is necessary in this direction. Concerning nanofluids containing nanotubes, Ding et al. [4] report a shear thinning behaviour.

Surface tension remains practically unaffected by the presence of nanoparticles according to Das et al. [6], who prepared a nanofluid without any kind of dispersant. It must be noted, however, that the surface tension of the suspension is affected by the stabilizing agents (mostly surfactants) usually employed during nanofluid preparation.

In many numerical studies available in the literature (e.g. [7]) the calculations of the nanofluid properties are based on either theoretical or empirical formulas and equations. Usually, the nanofluid is considered as a conventional single-phase fluid with properties that are to be evaluated as functions of its constituents and their respective concentrations. Density and specific heat are calculated using general relationships employed for classical two-phase mixtures, while the Einstein-Brinkman equation and the Hamilton-Crosser model are adopted for viscosity and thermal conductivity prediction respectively [7]. However, these formulations might not give appropriate estimations of the nanofluid properties, as they are not developed for particles with dimensions in the nanometre scale. Further experimental work is considered necessary in order to define more accurate models for the prediction of nanofluid thermophysical properties that could be reliably used in simulation studies.

PREPARATION OF NANOFLUIDS

In general, there are two methodologies used to produce nanofluids, namely the *single-step* method, where nanoparticles are produced and dispersed simultaneously into the base fluid, and the *two-step* method, where the two aforementioned processes are accomplished separately. A single-step method is usually employed for metal nanofluid preparation, while a two-step method applies better for nanofluids containing oxide nanoparticles. The main advantage of the single-step technique is the minimization of nanoparticle agglomeration [2].

The most well-known single-step methods are the direct evaporation approach (*VEROS*) and its modifications, as well as the "*vacuum submerged arc nanoparticles synthesis*" [2]. Zhu et al. [8] proposed a novel one-step chemical method for preparing copper nanofluids by reducing copper sulfate pentahydrate with sodium hypohosphite in ethylene glycol under microwave irradiation. They reported that the nanofluid produced contains 10 nm average diameter copper particles, which exhibited a 9% increase of the base fluid thermal conductivity.

In the two-step methods low agglomeration and stabilization of the nanofluid are the major concerns. To produce an even and stable suspension several techniques are applied, such as use of ultrasonic equipment, *pH* control or addition of stabilizers.

EXPERIMENTAL SETUP AND PROCEDURE

In the present work the thermophysical properties of nanofluids are systematically measured. Two methods are adopted for the preparation of the nanofluids during this study, namely the one-step method proposed by Zhu et al. [8] and the two-step method. According to the one-step method [8] a copper sulfate pentahydrate ($CuSO_4{\cdot}5H_2O$) solution in ethylene glycol is mixed with a polyvinylpyrrolidone (PVP-K30)-ethylene glycol solution and finally a sodium hypohosphite ($NaH_2PO_2{\cdot}H_2O$)-ethylene glycol solution is added. After stirring, the mixture is put into a microwave oven where it is left to react for 5 minutes under medium power. After the reaction the mixture color turns from blue to dark red.

Nanofluids consisting of commercially available multi-walled carbon nanotubes (*MWCNTs*) and aluminium and copper oxide nanoparticles are also prepared using the two-step method. The carbon nanotubes and the aluminium and copper oxide nanoparticles were provided by “Nanostructured and Amorphous Materials”. The nanoparticles are suspended in the base fluid with a suitable dispersant, such as sodium dodecyl sulphate (SDS), and are stabilized using a high intensity ultrasonic processor (*Vibra Cell^{TM} -VCX600*).

The viscosity is measured using rheometers (*Haake RheoStress RS100* & *CONTRAVES® Rheoscan*) and the dependence of the viscosity on the applied shear rate is determined. The “pendant drop” method is adopted for surface tension measurements (*KSV® CAM 200*). Thermal conductivity is determined using the transient hot-wire technique, which is employed by the Thermophysical Properties Laboratory of the Aristotle University of Thessaloniki, where the measurements are conducted.

RESULTS

First a copper nanofluid was prepared using the one-step method described earlier. The thermal conductivity measurements of the resulting nanofluid exhibited a very small increase compared to that of the base fluid (ethylene glycol), i.e. less than 3%, a value that is close to the uncertainty of the measuring technique. This result suggests that the type and dimensions of the particles formed during the preparation process are different than the ones reported in the literature [8]. Furthermore, the stability of the suspension was not satisfying, since in less than 2 hours after their preparation precipitation was visible, even if ultrasonic treatment was employed. Due to the above results the use of the one-step method was abandoned.

Following this, the two-step method was adopted. Thus, in a preliminary stage, two nanofluids consisting of 0.5 wt.% and 1.0 wt.% carbon nanotubes respectively and 0.2 wt.% SDS as surfactant were prepared using distilled water as base fluid. The mixtures were ultrasonically vibrated for about 10 minutes to achieve a stable and homogeneous suspension. The density and viscosity of both nanofluids, as expected, are very close to that of pure water, i.e. ρ=1010 kg/m^3 and μ=1.033x10^{-3} kg/ms, while their surface tension has been reduced to 0.036 kg/s^2. This reduction can be attributed to the presence of the surfactant (SDS), used as a stabilizer during the nanofluid preparation. The measurements show an increase of 15% and 20% in thermal conductivity respectively, compared to that of pure water at 27^o C. The preliminary results of the present study are presented in Table 1 along with the results by Assael et al. [3] for comparison.

Table 1. Thermal conductivity measurements and comparison with literature.

#	*MWCNT Concentration (wt.%)*	*SDS Concentration (wt.%)*	*Thermal conductivity enhancement (%)*
1	0.5	0.2	15
2	1.0	0.2	20
3	1.2 [3]	0.5	23
4	1.2 [3]	2.0	30

CONCLUDING REMARKS

Inspection of the limited data reveals that the thermal conductivity enhancement is affected by both the nanotube concentration and the amount of the surfactant used as stabilizing agent. Consequently, more experiments are needed, and indeed are currently in progress, in order to show the relative effect of:

- the type and concentration of nanotubes/nanoparticles (*MWCNT, CuO,* Al_2O_3),
- the type of base fluid (water, ethylene glycol) and
- the type and concentration of the stabilizing agent

on the transport properties of the nanofluids.

Information provided by this study is expected to help the efforts towards optimizing the design of compact heat exchanging equipment working with nanofluids.

Acknowledgement: Financial support by the General Secretariat for Research & Technology (*Czech-Greece Joint Research and Technology Programmes 2005–2007*) is greatly acknowledged. The authors also wish to acknowledge Prof. M.J. Assael, Dr I.N. Metaxa and K.D. Antoniadis for their contribution to this work.

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