NANOFLUIDS FOR IMPROVED THERMAL MANAGEMENT

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Introduction

A new generation of heat transfer fluid systems was introduced through the pioneering research work on nanofluids at the Argonne National Laboratory by Prof. Choi [1,2]. A nanofluid (NF) can be described as a liquid suspension of nanometer-sized solid particles or fibers, where the particle diameter is in the range of tens to hundreds of nanometers. The thermal conductivity (TC) of these systems can be much higher than those of commercial coolants. Recent studies on dilute colloidal suspensions of nano-metal oxides, metals and carbon nanofibers/nanotubes revealed good performance and extraordinary enhancement of TCs, without the drawbacks of system clogging, pressure drop and settling. A comprehensive review by Wang et al [3] summarizes the work done on nanofluids. Different levels of thermal conductivity enhancement are reported, indicating a direct dependence on variables such as the type and dimensions of the nano-filler, filler concentration and the inherent properties of the coolant. Choi et al. [4] observed extraordinary enhancement of the thermal conductivity, up to 150%, of poly (a-olefin) oil upon addition of as little as 1 vol. % of CNT. While morphologically different than CNTs, carbon nanofiber-based nanofluid suspensions have shown similarly high potential for boosting thermal conductivity. The CNF-structured nanofluids in this study hold potential to further increase energy efficiency while reducing lifecycle costs.

Experimental

Ethylene glycol (Reagent Plus, >99%) (EG) from Sigma Aldrich was used for the base fluid in the preparation of the CNF nanofluids. Selected CNFs were ultrasonicated in EG using a MISONIX Ultrasonic Probe 3000 for 20 minutes at a setting of 9.0 (84 W power). This technique was used to break up CNF bundles and disperse the nanofibers.

A range of different types and grades of fibers (PR25XT-PS, PR25XT-HHT and PR19XT-PS-OX) were studied to optimize any potential tradeoff between the quality of dispersion, the thermal conductivity and the viscosity of the suspension. The prepared formulations also included different fiber concentrations and fiber lengths (represented by the fiber's bulk density. The different fiber length were obtained by ball-milling the CNF at room temperature using an Attritor mill , equipped with 5 mm stainless steel balls, following an internal protocol optimized for the specific fibers. Knowing the apparent density of the fibers is inversely proportional to the fiber length, this quantity was used as a measure for the fibers length reduction, therefore as the apparent density of the fibers increases, the length of the fibers decreases.

Kerocom® polyisobutene succinimide (PIBSI) was used to aid the CNF dispersion. Different ratios of dispersing agent/CNF were also investigated. The different NF formulations are represented in Table 1.

An apparatus was designed and constructed to measure the convection heat transfer coefficient of the NFs flowing through a horizontal pipe. The instrumented pipe is shown in Figure 1.

Table1. Nanofluids formulations used in this study.

NF	Fiber			PIBSI/CNF ratio
	Type	vol. %	Bulk density [lb/ff^3]	
A1	25PS	0.3	10	1
A2		0.7	10	1
A3		1.0	10	1
A4		0.7	10	1.6
A5		0.7	10	1.8
B1	25HHT	0.3	10	1
B2		0.3	15	1
B3		0.7	10	1
C1	19PSOX	0..7	9	1

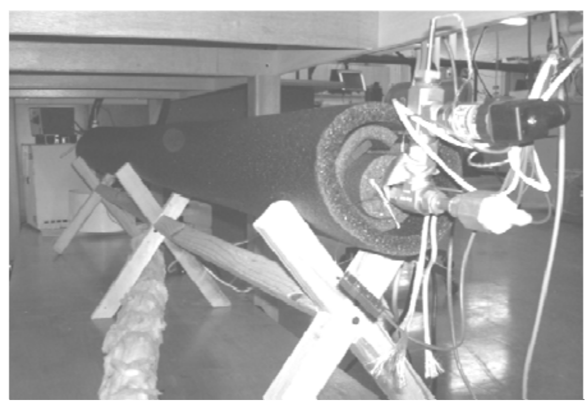


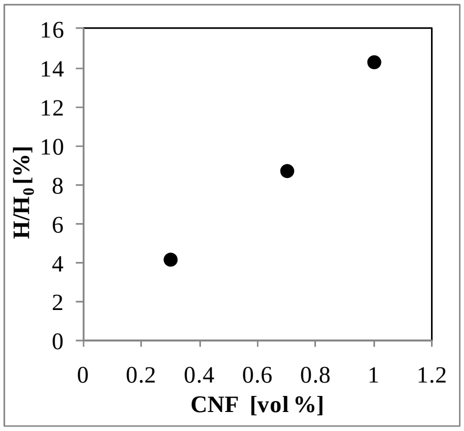
Fig. 1 Instrumented Pipe Flow Test System.

Results and Discussion

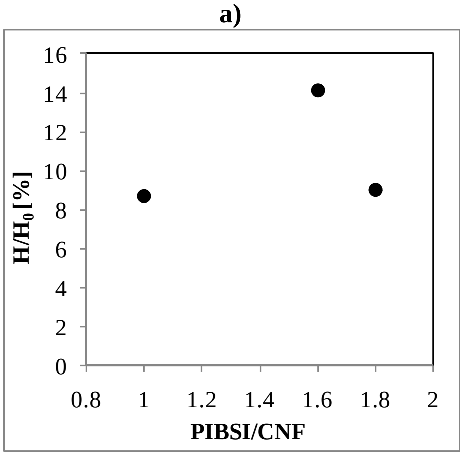
The convection heat transfer coefficients determined for the different NFs, are represented in Table 2, together with the percentage improvement over the pure EG.

For a better observation of the influence of the different parameters on the heat transfer coefficient of the resultant nanofluids, some of the results in Table 2 were plotted and are illustrated in Fig. 2.

As can be observed from Fig. 2 a), the heat transfer coefficient is directly dependent on the CNF concentration. It should be noted, however, that such tendency is not continuous, since increasing the concentration above 1.0 vol. % (at the specific bulk density) results in a detrimental increase in viscosity, which results in lower heat transfer capacity.



a)



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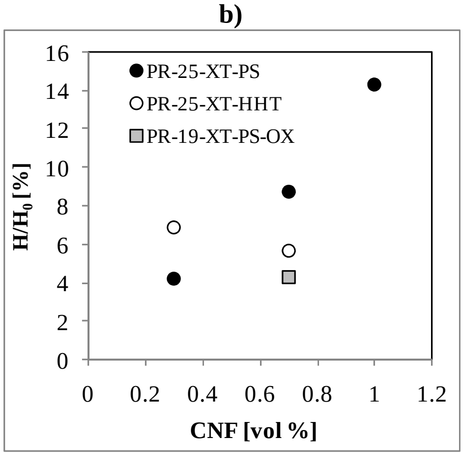

c)

Fig. 2 Percent improvement of the convection coefficient (h) for the measured nanofluids as a function of a) fiber concentration, b) dispersing agent / fiber ratio concentration and c) fiber type and concentration.

By changing the dispersing agent/fiber concentration ratio, Fig.2 b), an optimum concentration of the dispersing agent, which corresponded to the highest thermal capacity, was identified.

The length of the fibers was also determined to be an important parameter in the fibers dispersion and suspension stability. Long fibers lengths (equivalent bulk density of 3.5 lb/ft^3) resulted in highly agglomerated suspensions that settled. Recent studies revealed that a controlled fiber breakage can actually lead to an improved dispersion and suspension stability [5]. When comparing NF samples B2 and B3, one can observe that the fiber length which translates in the best heat transfer coefficient is the one that corresponds to the bulk density of 10 lb/ft^3. Finally, in Fig. 2 c) the influence of different grades of CNF on the improvement of the heat capacity coefficient over pure EG can be evaluated. It appears at low fiber concentrations increasing the degree of graphitization leads to an improved heat capacity, whereas for higher concentrations, the fibers with a lower degree of graphitization is preferred over the highly orientated and functionalized fibers.

Table 2. Percent thermal property enhancement for measured nanofluids.

NF	Convection coefficient [W/m^2K]	Improvement over pure EG [%]
EG	815.4	-
A1	849.4	4.2
A2	886.3	8.7
A3	931.8	14.3
A4	888.7	9.0
A5	930.7	14.1
B1	871.1	6.8
B2	826.0	1.3
B3	861.6	5.7
C1	850.1	4.3

Conclusions

The nanofiber doped fluids seem to provide increased thermal performance, however the fluid must be carefully designed to provide a high carbon loading while preventing a large increase in viscosity. Fiber length and concentration were determined to be the main parameters responsible for the improvement of the heat transfer coefficient of EG fluids. The presence of a dispersing agent was also found to be crucial in order to maintain dispersion and suspension stability.

References

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