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Heat Transfer Enhancement by using Al_2O_3-Water Nanofluid in a Liquid Cooling System for Microprocessors

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Abstract: - We have experimentally investigated the heat transfer performance as provided by the use of the water-Al_2O_3 nanofluid, for a liquid system that is destined for cooling of electronic components. Measured data have clearly shown that the inclusion of nanoparticles within the distilled water has produced a considerable enhancement of the cooling block convective heat transfer coefficient, which has been found to increase as much as 23% - with respect to that of the base fluid - for the nanofluid with 4.5% particle volume concentration. It has also been observed that an augmentation of particle concentration has produced a clear decrease of the junction temperature between the heated component and the water-cooling block.

Key-Words: - Electronics cooling, Forced convection, Heat transfer augmentation, Heat transfer enhancement, Nanofluids, Nanoparticles, Experimental study.

1 Introduction

Due to the increasing power of microprocessors and other electronic components, a search for an efficient heat dissipating system remains today a challenging task. In spite of researches and efforts deployed in the past, major improvements in heat transfer capabilities, especially for cooling of high heat output electronics devices, have still suffered a certain lacking [1,2]. Recent advances in nanotechnology have permitted the creation of a new and rather special class of fluids, called 'nanofluids', which can constitute, in our opinion, a very interesting alternative for electronic cooling applications [3]. The term nanofluid refers to a two-phase mixture where the continuous phase is usually a liquid and the dispersed phase is composed 'nanoparticles' i.e. extremely fine metallic particles of size usually below 50nm (note that some current nanoparticle dispersions of engineering interest are readily available from various commercially companies [4]. It has been shown that thermal properties of nanofluids appear well higher than those of the base fluid (see for example [5]). Some scarce experimental work [6,7] and recent numerical studies by the authors [8, 9] have clearly confirmed the beneficial effects due to the use of nanofluids in some confined flow situations, namely the flow in a uniformly heated tube and the radial flow between heated disks, as well as for cooling of high heat output microprocessors [10,11]. A recent preliminary experimental study of the authors [12] has revealed in fact such beneficial effect due to nanofluids in electronic cooling application. To our knowledge, there exists no other experimental data regarding the heat transfer performance of the nanofluids for cooling of microprocessors or other electronic devices.

In the present work, we have experimentally investigated the heat transfer enhancement of a liquid cooling system, by replacing the base fluid, in occurrence distilled water, by a nanofluid composed of distilled water and Al_2O_3 nanoparticles at various concentrations. Some most significant results and experimental data are presented and discussed.

2 Experimental Setup

The experimental apparatus is relatively simple and consists of a closed liquid-circuit, Fig. 1 and 3, which is primarily composed of a 5 litre open reservoir; a 12 VDC magnetically driven pump that ensures a forced circulation of the liquid; a heated block, of dimensions 60mm x 60mm x 75mm high, has an all-aluminium body and is electrically heated by mean of a 100W nominal power cartridge heater, which simulates heat generated by microprocessors. On top of the heated block is installed a water-block, which is of overall dimensions 60mm x 60mm x 15mm high and has an all-copper body jet-type water-block with an axial central injection orifice and a pin-finned thick base plate (Fig. 2). The contact junction between the heated block and its water-block is ensured by applying a thin film of high thermal conductivity paste (Omegatherm 201 from Omega, USA). The ensemble heated block-and-water-block was, thermally, very well insulated with respect to the surrounding environment by using a thick layer (50mm) of fiberglass covering all around its exposed surface.

A mini air-cooled radiator is used to dissipate heat into ambient air and a collecting-weighting station with a three-way valve has been used for measuring the mass flow rate of the circulating liquid. It is interesting to mention that most of major components came from a water-cooling kit, which is commercially available for cooling of CPU microprocessors or any other heated electronic components (Swiftech, USA).

Several Type-K thermocouples (Omega, USA) have been installed in order to monitor fluid temperatures at various locations: T1 and T2, respectively, at the inlet and outlet of the water-block, T3 at the outlet of the mini radiator; while the ceramic-insulator-type thermocouple T4, precisely mounted inside a hole of the aluminium block, was especially chosen to monitor the junction temperature between the heated block and the water-block. Two other Type-K thermocouples were also used to monitor the fluid temperatures in the reservoir as well as the ambient air temperature in the local. All thermocouples were thoroughly calibrated by using a constant temperature water bath, and their accuracy has been estimated to be within 0.2 K. A multi-channel digital temperature indicator has been used to display all measured readings from these thermocouples.

In order to precisely evaluate the electric power that is supplied to the cartridge heater and so the heat supplied to the aluminium heated block, both the AC voltage and electric current were constantly monitored during the tests. In any case, the accuracy of the determined electric power supplied has been estimated to be ±3.5%. Regarding the heat losses from the heated-block-and-water-block ensemble towards the ambient air, the temperature drop across the fiberglass insulating layer was also monitored during the experiments, and the corresponding heat loss can then be easily estimated. Such a heat loss has been found to be negligible; so far, it did not exceed 1.5W even for the tests where relatively high temperatures of the heated block were encountered. Finally, with regard to the measurement of the mass flow rate of the liquid flowing inside the circuit, as stated previously, we have adopted, in this study, the classical and simple stop-watch-and-weighting technique. By using a digital balance and chronometer with good accuracies, respectively ±0.1g and ±0.01s, the maximum variation of the mass flow rates as determined by such a technique has been estimated to be ±5%, which appears quite reasonable in conjunction of the experimental uncertainties.

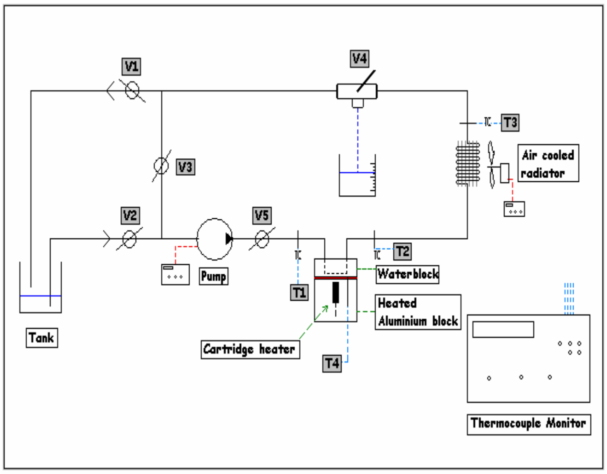

Fig. 1 Schematic illustration of the experimental liquid-cooling circuit

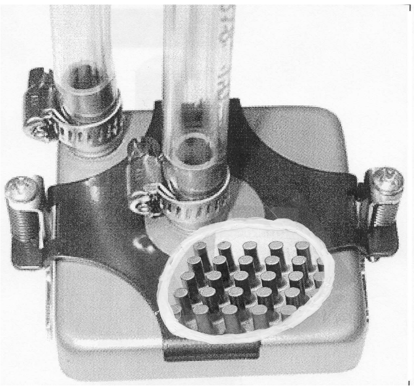

Fig. 2 Schematic view of the water-block with its internally pin-finned base plate

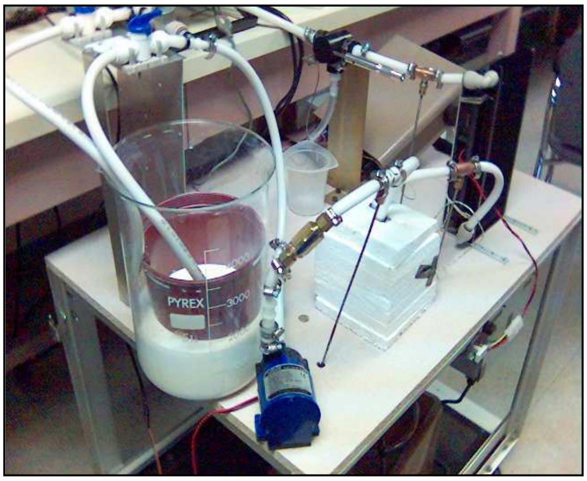

Fig. 3 A photo showing major components of the experimental liquid system used

2.1 Thermal Properties of Al_2O_3-Water Nanofluid

By assuming that 47nm mean-diameter Al_2O_3 nanoparticles (ρ_p= 3880 kgm^{-3} and C_p= 773 $Jkg^{-1}K^{-1}$) are well mixed within the base fluids i.e. the particle concentration may be considered uniform throughout the domain, the effective thermal properties of the resulting mixture can then be evaluated by using known formulas already developed for classical two-phase mixtures [6, 13]. For the nanofluid under study, all of the necessary formulas employed to compute its thermal properties have been detailed and discussed in previous studies, see [6, 10, 13] and hence, are not repeated here for the sake of space. Regarding the thermal properties of distilled water, they were computed using classical formulas published in [14].

2.2 Experimental Procedures and Data Processing

The experimental setup, after being carefully assembled, has been thoroughly checked with a particular emphasis on the detection of possible leaks from various connexions in the piping system, for which, some corrections were necessary. It was then used to perform nearly fifty tests for distilled water and Al_2O_3-water nanofluid at different particle concentrations ranging from 0.69% to 4.5% (in volume). It should be mentioned that the Al_2O_3-water nanofluid, for which the particle mean diameter is approximately 47nm (according to the manufacturer, Nanophase Technology, USA), has been purchased already mixed and prepared. In order to produce other solutions with particular particle volume concentrations from the originally delivered mixture - that was nearly at 15% of particle concentration- a proper diluting process with distilled water, followed by a vigorous mechanical stirring action, have always been required. It is interesting to mention that as dispersing agents were used by the manufacturer, the stability of particle suspension within the base fluid, water, has been found quite good, even after a relatively long period of rest, say several weeks to months, for which a vigorous mechanical stirring was normally sufficient in order to re-establish a good particle suspension. From the collected data of temperatures and mass flow rates, the convective heat transfer coefficient of the water-block, $h_{w\text{-}block}$ (W/m^2K), can simply be obtained from the heat balance equation, which is as follows:

$$\boldsymbol{m}\, C_p\,(T_2 - T_1) = h_{w\text{-}block}\, A\,(T_{m,\,base} - T_{m,f}) \qquad (1)$$

where $\boldsymbol{m}$ is the liquid mass flow rate, kg/s; T_1 and T_2 are, respectively, fluid temperatures at the inlet and outlet of the water-block, K or ºC; C_p is fluid specific heat, J/kgK; A is the total area of the augmented-surface of the base plate i.e. its nominal surface area plus fins area, $A \approx 0.01256 m^2$; $T_{m,base}$ is the mean temperature of the base plate, as given by the reading from the junction thermocouple T4; $T_{m,f}$ is the mean temperature of the liquid traversing the water-block, $T_{m,f} = (T_1 + T_2)/2$; all fluid (water and nanofluid) properties have been computed at $T_{m,f}$.

3 Results and Discussion

3.1 Temperature of the Heated Block

Figure 4 shows, at first, the results for the heated block average temperature, $T_{m,\,block}$, as function of mass flow rate, $\boldsymbol{m}$. It is very interesting to mention that for electronic systems such as the one in a PC for example, the temperature of microprocessors (or any other heated components) represents an important and practical variable, which gives a good indication on whether the system performs properly or not. We can clearly observe that $T_{m,\,block}$ has decreased considerable with an increase of mass flow rate. Such behaviour appears physically quite realistic since we know that increasing the mass flow rate would necessarily result, in principle, in an augmentation of the forced convection heat transfer coefficient. In spite of a visible dispersion of data shown in Figure 4, we can say that increasing the particle volume concentration has a clear influence on the heated block temperature. The latter has been found to decrease with an augmentation of particle concentration, thus indicating obviously a better heat transfer rate with the use of nanofluids.

3.2 Heat Transfer Performance of Nanofluid

The heat transfer enhancement resulting from the use of nanofluids can be better scrutinized in Fig. 5 that shows the variation of the convective heat transfer coefficient $h_{w\text{-}block}$ as function of mass flow rate and particle volume concentration. As one may expect, it is very interesting to observe that the inclusion of nanoparticles into distilled water has, indeed, clearly enhanced the heat transfer of the water-block. Thus, in spite of a visible dispersion of data shown, which is obviously due to experimental uncertainties, we have found that the coefficient $h_{w\text{-}block}$ has considerably increased with an

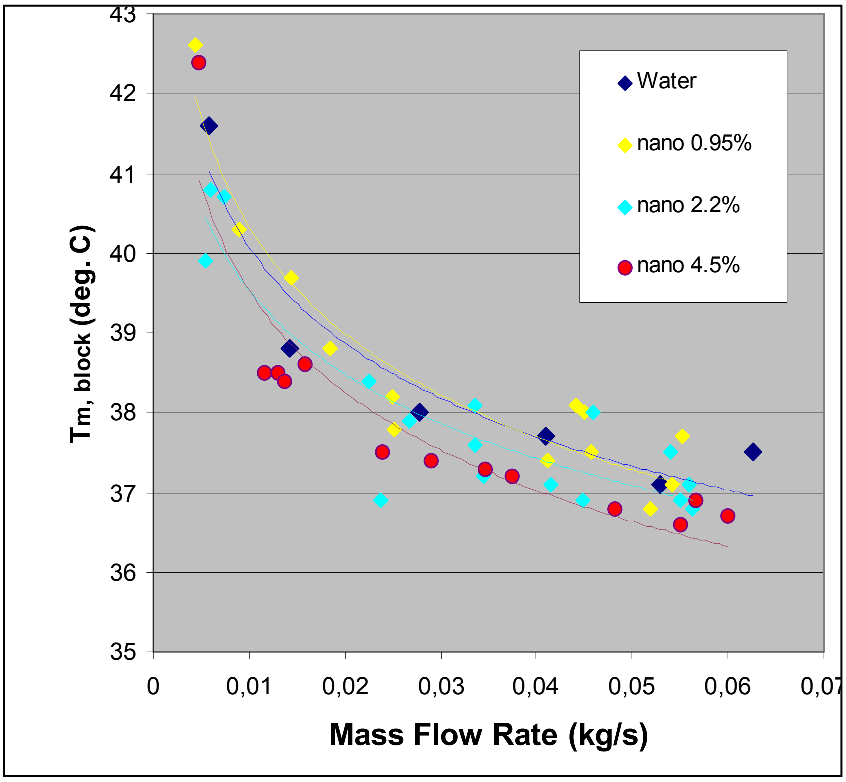

Fig. 4 Effect of mass flow rate and particle volume concentration on $T_{m,block}$

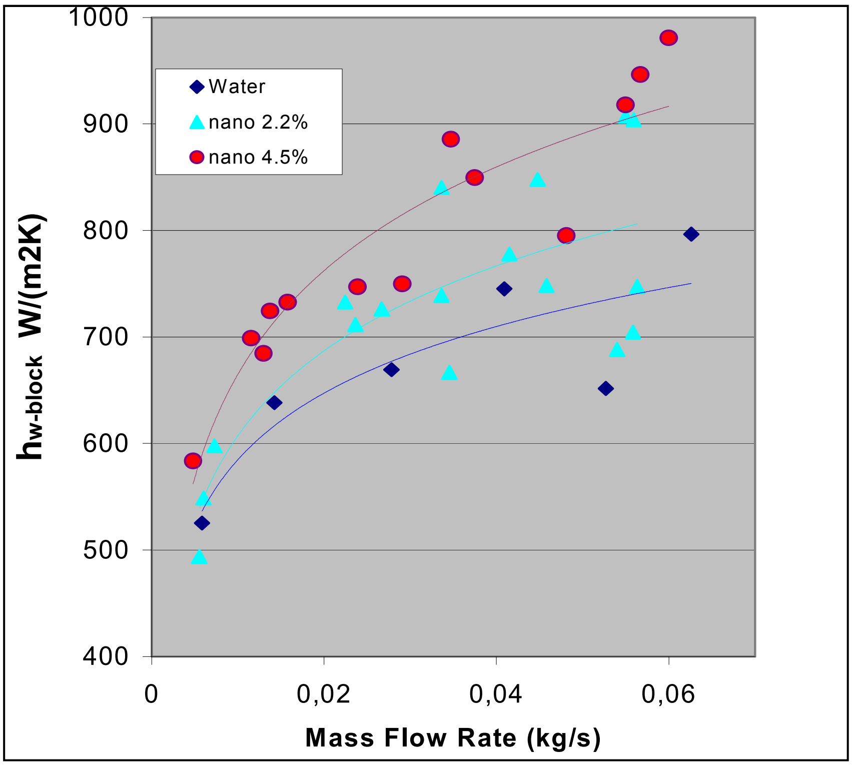

Fig. 5 Effect of mass flow rate and particle volume concentration on $h_{w\text{-}block}$

increase of particle volume concentration. Thus, for the particular mass flow rate of 0.04kg/s for example, the approximate values of $h_{w\text{-}block}$ are, respectively, 705 W/m^{2}ºC (distilled water), 775 W/m^2 ºC (2.2%) and 870 W/m^{2}ºC (4.5%), for an enhancement of approximately 10% and 23% respectively for nanofluids with 2.2% and 4.5% particle concentrations while compared to the corresponding heat transfer rate of distilled water. A similar heat transfer enhancement has also been found for higher mass flow rates; for $\boldsymbol{m}$ =0.06kg/s for example, $h_{w\text{-}block}$ has, as approximate values, 750 W/m^2 ºC (water), 820 W/m^2 ºC (2.2%) and 920 W/m^2 ºC (4.5%). Such a heat transfer enhancement, although existing, appears less significant for very low mass flow rates, say for $\boldsymbol{m} \leq 0.005$ kg/s. We can also observe that the heat transfer coefficient has considerably increased with an augmentation of liquid mass flow rate, for the same reason mentioned earlier. One can then expect that a judicious combination of the use of nanofluids and very high flow rates can provide a more important heat transfer rates. It should be mentioned that the flow regimes for the tests performed were mostly laminar or mildly turbulent. It is then expected that a strongly turbulent flow regime combined with the use of nanofluids would provide more significant effect on heat transfer - see for example [10]. Although there are notable differences due to the geometries used between the actual (and real) water-block and the ones considered in the authors' recent numerical studies [10, 11], it is very interesting to mention that similar behaviour regarding the heat transfer enhancement with respect to nanofluid particle concentration as well as to liquid mass flow rate has been found in these studies.

3.3 Water-Block Nusselt Number

Figure 6 shows the dependence of the water-block convective Nusselt number as function of the Reynolds number and particle concentration. The parameters Nu and Re are defined as follows:

$$Re = 4\boldsymbol{m}/(\pi D_i\,\mu) \qquad (2)$$

$$Nu = h_{w\text{-}block}\,D_i/k \qquad (3)$$

where D_i is the inside diameter of the inlet orifice, D_i=0.007m (Fig. 2); k and μ are fluid (distilled water or nanofluid) thermal conductivity and dynamic viscosity, both evaluated at temperature $T_{m,f}$ (see paragraph 2.1 above). For comparison and discussion purposes, the tendency curves generated by using Excel are also shown.

We observe that, in general and despite of certain dispersion in computed values of the Nusselt number, the latter has clearly increased with an increase of particle volume concentration and/or flow Reynolds number. Such an increase of Nu number appears relatively small for the 2.2% nanofluid; it is very significant for the other nanofluid with 4.5% concentration. Thus, for a particular value Re= 5000 for example, Nu has as approximate values, 7.6, 7.7 and 8.7, respectively for water, 2.2% and 4.5% nanofluids. On the other hand, for Re=10000 in particular, Nu has respective values of 8.3 (water), 8.5 (2.2%) and 9.7 (4.5%). The corresponding increase of the Nusselt number with respect to the flow Reynolds number is obviously very significant.

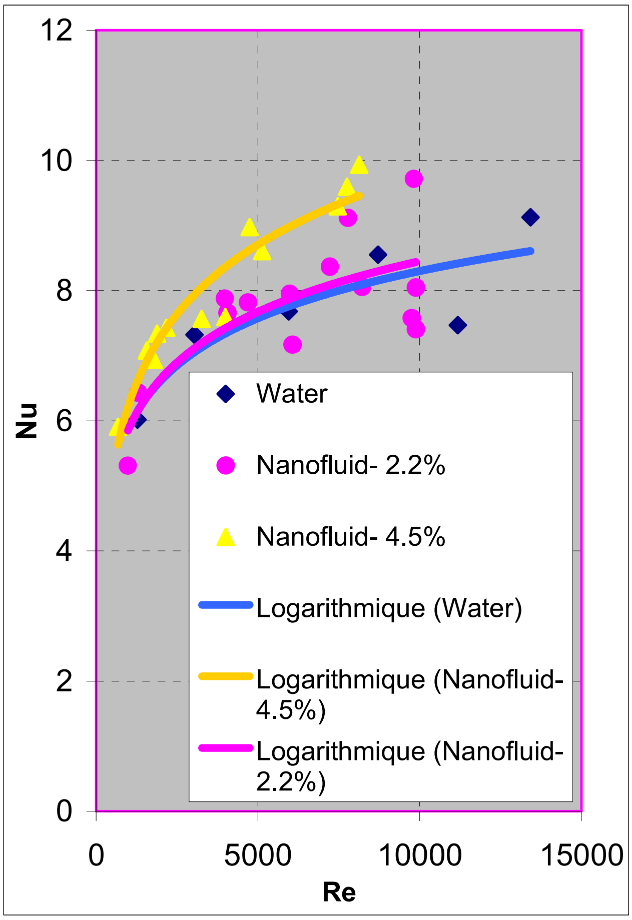

Fig. 6 Nu as function of Re and particle volume concentration

We are currently undertaking further tests in order to thoroughly investigate the heat transfer enhancement due to the use of Al_2O_3-water nanofluid under turbulent flow regime and other nanofluids such as those based on CuO-nanoparticles, and this for the same liquid closed system that is destined for cooling of microprocessors and other electronic components.

4 Conclusion

In this paper, we have experimentally studied the heat transfer enhancement provided by a particular nanofluid, Al_2O_3-water mixture, for a water closed system that is destined for cooling of microprocessors and other heated electronic components. Data obtained for distilled water and nanofluids with various particle concentrations, namely 0.95%, 2.2% and 4.5%, have eloquently shown that the use of such a nanofluid appears particularly advantageous for cooling of heated component. The convective heat transfer coefficient provided by the water-cooling block has considerably increased with an increase of mass flow rate and/or particle volume concentration. For the particular concentration of 4.5%, a heat transfer enhancement as much as 23% with respect to that of distilled water has been achieved. In general, the heated block mean temperature has been found to decrease with an increase of particle concentration as well as of mass flow rate. The results obtained for the water-block Nusselt number have also been shown.

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