Thermal Enhancement Using Nanofluids on High Heat Dissipation Electronic Components

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Abstract

Following today's needs for improvement on heat transfer, new technologies and innovative solutions must be found in order to meet current requirements for both active and passive thermal control. There has been substantial growth on the heat fluxes that need to be dissipated, which require different approaches from designers, especially those designed for defense purposes. With the increase of heat dissipation needs, conventional designs are not suitable due to several factors such as operation in hostile environments, high thermal density of electronics that need their temperature to be controlled, which require innovative designs. In such cases, the application of nanofluids can greatly contribute to give designers more degrees of freedom to face the project's requirements. The subject of this article is related to a surveillance system designed for defense purposes, which needs to dissipate high levels of heat loads. For this present investigation, a single-phase forced circulation loop has been designed to promote the thermal management of up to 50 kW of heat, being dissipated to the environment by a fan cooling system. Results show that with an addition of 20% by mass of copper oxide nanoparticles to the base fluid (water), enhancements of 12% on the heat transfer coefficients were achieved but the increase on the pressure drop was around 32%.

Keywords: thermal enhancement, electronics cooling, thermal control, pressure drop, nanofluids.

Introduction

The need for thermal management has increased dramatically over the last decade and the prediction is that a steeper increase is yet to come for the next years. Such an increase is directly related to more powerful electronics used for data processing in high-tech equipments used for satellites and defense/military purposes. Several investigations related to nanofluids applications have been conducted with important contributions to many areas [1,2].Considering previous experiences, current and future thermal management needs, the use of nanofluids is becoming inevitable. The use of nanofluids present to be an important approach to enhance the heat transfer capability of heat pipes and loop heat pipes systems, which has already been proven [3]. Similar investigation has also been performed [4] where it showed that smaller sizes heat pipes can be used when operating with nanofluids. Other applications are related to the use of nanofluids in regular heat exchanger devices already installed in industries in order to enhance their performance in face of the increase of heat dissipation needs [5]. Evaluation of nanofluids have been performed by many researchers in order to better understand the effects of the nanoparticles on transport properties, which are important for the prediction of the pumping requirements [6,7]. Applications related to PCB thermal management using nanofluids have also been reported [8]. However, important issues still require attention, especially when considering the verification of a nanofluid regarding its own design, since many authors have reported different results for the same combination of base fluid and nanoparticles [9]. An important application for today's needs for heat dissipation is related to surveillance systems designed for defense/military purposes. As more compact and powerful defense equipments are necessary, higher heat fluxes need to be properly addressed. Considering the need for designing a reliable and effective thermal management system that need to operate in hostile environments, with potential use of nanofluid, this article presents an investigation on this subject.

Nanofluid's Properties Consideration

The base fluid's transport properties is influenced by the addition of the solid nanoparticles, which in one hand enhances the fluid's thermal conductivity but also directly contribute to enhance its liquid density and viscosity. Proper consideration must be made regarding the addition of the solid nanoparticles as those properties might directly influence the overall thermal management and pumping analysis. Some models have been developed to better describe the influence of the addition of nanoparticles in pure substances and the gain on the liquid thermal conductivity that might represent [10] as usually the Maxwell model is applied on this case as

$$k_n = \frac{k_p + 2\ k_l + 2\left(k_p - k_l\right)\ f}{k_p + 2\ k_l - \left(k_p - k_l\right)\ f}\, k_l \,. \qquad \text{W/m°C} \qquad (1)$$

Equation (1) represents the effective thermal conductivity of a homogeneous nanofluid (k_n), while k_p, k_l and f are the particle and base fluid thermal conductivities and f is the nanoparticle mass fraction, respectively. Since the liquid thermal conductivity is affected by the addition of a nanoparticle in the substance, proper consideration and evaluation of the solid particles in a liquid must be taken according to the two-phase theory [11]. Thus, the nanofluid density (ρ_n) is then calculated as

$$\frac{1}{\rho_n} = \left(\frac{f}{\rho_p} + \frac{1-f}{\rho_l}\right), \qquad \text{kg/m}^3 \qquad (2)$$

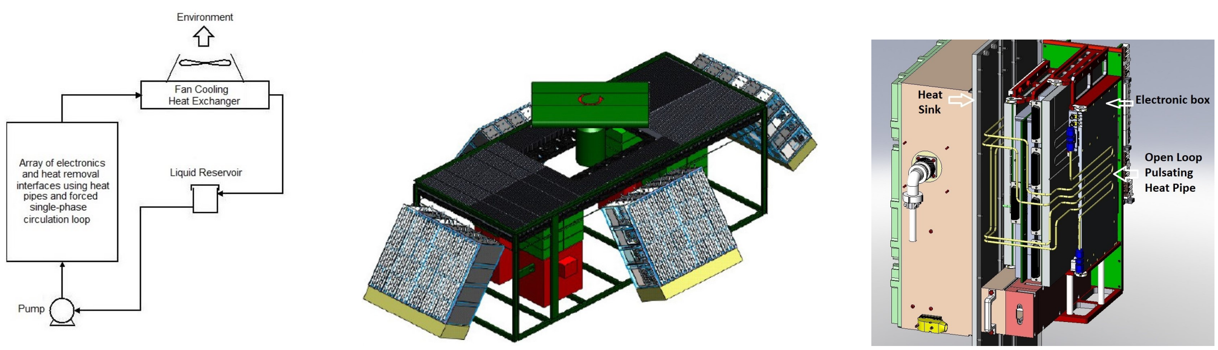
where ρ_p and ρ_l are the nanoparticle and the base fluid densities, respectively. The nanofluid dynamic viscosity (μ_n) can then calculated as [12]

$$\mu_n = \mu_l \frac{1}{\left(1-f\right)^{2.5}}, \qquad \text{Pa.s} \qquad (3)$$

where μ_l is the base fluid dynamic viscosity. The modification of the transport properties indicated in Eqs. (1) to (3) should be included in any analysis to correctly address their influence on the system's thermal performance. In the present analysis, Eqs. (1)-(3) were implemented in a design model to predict the nanofluid influence on the overall thermal and hydraulic performance of the surveillance thermal management system.

Equipment Design and Operation

A specific design for a surveillance system has been conceived to operate in hostile environments where the ambient temperatures can range from +5 to +50 °C and humidity levels up to 95%. In this case, a single-phase thermal control loop has been designed to use a nanofluid, presenting a forced circulation using a pump to move the working fluid throughout the circuit to remove heat from the electronic components, rejecting this heat to the environment by a fan cooling system. For this thermal management system, a hybrid design has been applied where the heat generated by all PCBs are removed by open loop pulsating heat pipes, delivering the heat to the heat sinks allocated thorough the surveillance equipment (cold plates). The heat sinks are then connected to the single-phase thermal control loop that collects all the heat and dissipate it to the environment. The schematics of such arrangement is presented by Fig. 1a and the surveillance equipment where it is installed is shown by Fig. 1b, whilst Fig. 1c presents the hybrid setup where the pulsating heat pipe and the heat sink are connected.



(a) (b) (c)

Figure 1: Schematics of the thermal control system arrangement.

As the base fluid, water has been selected for this approach. The CuO nanoparticles present an average diameter of 29 nm and purity of 99.8%. The nanoparticles concentration (f) shall vary from 3.5% to 20% (by mass of the base fluid) to verify their effect on the overall thermal performance of the system.

Results and Discussion

The presented results were well correlated to the thermal tests applied to this equipment, and further analysis will be disclosed in future reports. For the sake of presenting the most important results obtained so far, the following data were selected among several hours of operation and follow the NDA (non-disclosure agreement) set between all parts.

Figures 2a and 2b present some results for the pressure drop and heat transfer coefficients, respectively, on a comparison between the use of pure water and the addition of copper nanoparticles at different concentrations (*f*), by mass percentage of the working fluid in the system. The results are related to each individual electronics module (composed of 3 PCBs), which dissipate a maximum of 50 W of heat, thus, based on the module's footprint and heat dissipation, the calculation for the heat transfer coefficient was performed. As shown by Fig. 2c, less volumetric flow rate is necessary to promote the heat dissipation when using the nanofluid, as the heat transfer coefficient increases. It is clear that as the nanoparticle concentration increases, the pressure drop also increases up to 32% for *f*=20% as more solid nanoparticles are present in the system (Fig. 2d). The pump needs to overcome the extra resistance as the transport properties are changed with the addition of the nanoparticles. However, the increase on the heat transfer coefficients is also clear and can represent a gain around 12% for the same *f*=20% which cannot be neglected.

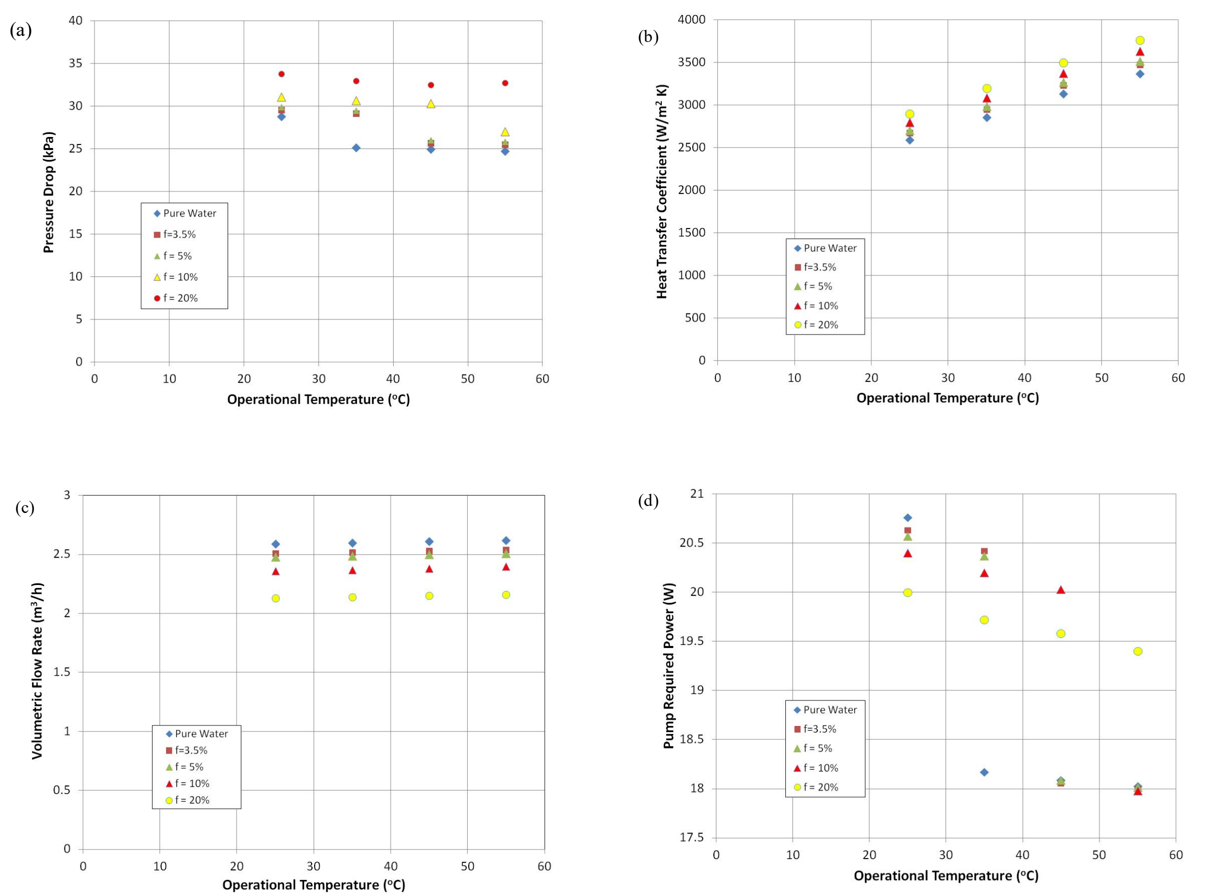


Figure 2: Results for (a) pressure drop and (b) heat transfer coefficient (c) volumetric flow rate and (d) required pumping power.

Conclusions

In general, the main conclusions that can be derived from this investigation are:

1. Higher heat transfer coefficients can be reached with the increase of the solid nanoparticles concentration, representing an enhancement of up to 12% for *f*=20% at 55 °C when compared with the operation with water;
2. The pressure drop also increases as the concentration of nanoparticles increases, which could compromise the pump operation;
3. Lower volumetric flow rates are observed for higher concentration of nanoparticles, as this factor contributes to increase the working fluid's viscosity and density;

4. Even with the use of solid nanoparticles, the required pumping power does not represent to be the major issue on this specific project, as this requirement can be easily addressed as the calculated values are rather low;
5. The overall analysis indicates that the application of the nanofluid with higher concentrations can be used, as the major parameter for this analysis is the heat transfer coefficient, which is reducing the size of the thermal management system applied to control the temperature of the electronics components.

When considering that the thermal management system is operating at higher capacities, while keeping the working fluid's temperature differences between the fan cooling inlet and outlet within certain required parameters, the use of a nanofluid presents to be an important innovative approach for this project. This is directly resulting in more gains than loses for the overall thermal system analysis and should remain as the most indicated solution for this application.

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