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Review

Electronics cooling with nanofluids: A critical review

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ABSTRACT

With increase of heat generated by new electronic components, a combination of nanofluid characteristics and minichannel attributes has been introduced as a hot research topic. Development of such technology can result in further miniaturization of electronic equipment and also improve energy efficiency. In this article, the recent studies performed on use of nanofluids in electronics cooling are reviewed considering several aspects such as liquid block type, numerical approach, nanoparticle material, energy consumption, and second law of thermodynamics. Besides, some interesting aspects about employing nanofluids in cooling of electronic components are introduced. Furthermore, the opportunities for future studies as well as the challenges existing in this field are presented and discussed. It is found that applying nanofluids as novel coolants in different liquid blocks and heat pipes can considerably improve electronics cooling technology in the future.

1. Introduction

In spite of significant growth during the past years, electronics industry and semiconductor technology have still some essential problems related to the cooling of their products with great performance and high heat flux. In fact, ordinary cooling methods and common coolants do not meet the cooling requirements for high heat producing electronic chips. As a result, high efficiency electronic devices require new approaches and coolants having great thermal performance to dissipate their generated heat for reaching expected efficiency and reliability [1]. The investigations performed show that the minichannel cooling systems with liquids as coolant are the most efficient approaches in modern electronics cooling [2].

On the other hand, suspensions containing solid nanoparticles, termed nanofluids, demonstrate noticeably greater thermal attributes compared with conventional coolants [3]. Several researchers have reviewed the investigations conducted on nanofluids in different sectors such as friction factor and convection heat transfer of nanofluids [4], employing nanofluids in boiling heat transfer [5], particle migration in nanofluids [6], mass transfer in nanofluids [7], and entropy generation in nanofluids [8]. In general, the performed studies show excellent characteristics of nanofluids in heat transfer systems [9]. Furthermore, the reports from the limited evaluations conducted on using nanofluids in liquid blocks also justify that this new class of suspensions act better in electronics cooling in comparison with ordinary fluids. Indeed, the innovative cooling methods like minichannel systems along with these new fluids can considerably enhance heat dissipation efficiency and can meet the cooling requirements of high heat producing electronic equipment. Hence, nanofluid based liquid blocks are a promising candidate for next generation electronics cooling devices.

In this survey, the research investigations carried out on application of nanofluids in electronics cooling are reviewed. Different aspects such as liquid block geometry, nanoparticle material, numerical approach, and second law of thermodynamics are considered. Moreover, shortcomings and challenges in this filed are identified and discussed, and several directions for future research are recommended. It should be noted that different researchers have employed various parameters for evaluating thermal performance of heat sinks. Thermal resistance of heat sinks, average temperature of heating surface, maximum temperature of heating surface, convective heat transfer coefficient, Nusselt number as well as the temperature uniformity have been most utilized characteristics for comparing thermal performance of different heat sinks or different nanofluids.

2. Nanoparticle materials used in electronics cooling

Different nanoparticles have been utilized so far for preparing the nanofluids to be used in liquid blocks. Oxide nanoparticles have been most utilized materials in this field. In the following, various materials used for this purpose are evaluated.

2.1. Carbon based nanoparticles

Nanofluids containing Carbon Nanotubes (CNTs) and graphene

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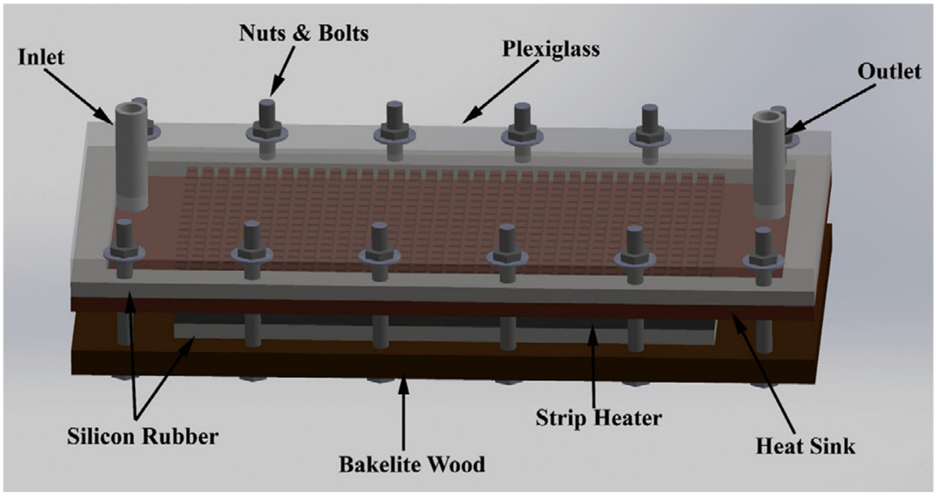

Fig. 1. Schematic of problem under study [11]. Reprinted with permission from Elsevier.

sheets have been employed significantly for cooling in heat sinks. This is because they possess excellent thermal conductivities and therefore, can result in very good thermal characteristics.

Nazari et al. [10] examined the CPU cooling of alumina and CNT nanofluids and compared the obtained outcomes with the cooling performance of the ordinary fluids (i.e. water and ethylene glycol). The results indicated a 4% increment in the convection heat transfer coefficient in the case of using ethylene glycol. A 6% increase was also obtained by using the alumina nanofluid at concentration of 0.5%.

Ali and Arshad [11] reported an experimental study to assess the angle effect of pin fin heat sink channel on thermal resistance, convection heat transfer coefficient, log mean temperature difference by use of nanofluids containing Graphene Nanoplatelets (GNPs). Three heat sinks with channel angles, relative to positive *x*-axis, 22.5°, 45° and 90° were investigated. Fig. 1 displays the schematic of problem under study. The heat sink having channel angle of 22.5° showed superior thermal performance in comparison with other liquid blocks.

Ebrahimi et al. [12] presented a numerical method for evaluating the cooling performance of a microchannel heat sink with CNT nanofluids. It was shown that with increasing the nanolayer thickness of MWCNTs, the microchannel heat sink temperature gradient reduces. Moreover, thermal resistance of microchannel heat sink with the nanofluid containing MWCNTs was lower than the nanofluid containing spherical nanoparticles.

Arshad and Ali [13] compared thermal and hydrodynamic performances of graphene nanoplatelets nanofluids in comparison with distilled water on integral fin heat sink. Greater pumping power was observed for GNPs nanofluids in comparison with the distilled water. With using GNPs nanofluids, the minimum base temperature and highest convective heat transfer enhancement were achieved respectively as 36.81 °C and 23.91% at Reynolds number of 972. Pumping power depended on the flow rate and heat flux, and it was maximum for the GNPs nanofluid at heat flux of 47.96 kW/m^2.

It can be mentioned that carbon based nanofluids result in significant improvement in the thermal performance of liquid blocks. However, an essential challenge of using them is their poor stability in aqueous media because they are naturally hydrophobic and so cannot be dispersed in polar liquids like water. Recently, in order to improve the dispersion of these nanoparticles, they are functionalized through acid treatment and hence, become hydrophilic. It should also be noted that applied organic solvents and strong acids commonly cause environmental pollution, corrosion and health problems. Consequently, use of green and eco-friendly methods for functionalization is very important. For the future studies in this context, the scholars should pay a significant attention to the mentioned points, and the nanofluids containing biologically produced graphene nanoplatelets can be suggested as appropriate candidates for utilization in electronics cooling.

2.2. Oxide nanoparticles

Among different nanoparticles, spherical oxide nanoparticles have been employed significantly to synthetize nanofluids for use in liquid blocks. The reasons of extensive utilization of these nanoparticles include very good stability, low cost, suitable thermal conductivity, and so forth. Alumina and titania nanoparticles have been applied more than other oxide nanoparticles. A review on different oxide materials employed in electronics cooling such as alumina, titania, CuO, and silica is carried out as follows.

2.2.1. Al_2O_3 nanoparticles

Hasani et al. [14] investigated the influences of different interruptions of fin on the transport attributes of a nanofluid-cooled electronic heat sink with chevron configuration. Water and water-based nanofluid with Al_2O_3 nanoparticles at volume concentrations of 0.5% and 1% were experimented. The results indicated that using the interrupted fins causes a better heat transfer process because of reduction in the fin surface temperature and increment in the outlet coolant temperature. Meanwhile, it resulted in significant decreases in the pressure loss due to the increase in the fin porosity of the heat sink.

Nguyen et al. [15] experimentally researched the attribute and heat transfer improvement of the water–Al_2O_3 nanofluid within a closed system that was made for cooling of processors or other electronic devices. The outcomes showed that the dispersion of the nanoparticles in the pure water results in a significant increase in the convection heat transfer coefficient. For 6.8% concentration, heat transfer coefficient enhanced 40% compared with the base liquid.

Kamyar et al. [16] investigated the thermal performance of a two-phase closed thermosiphon filled with the water–Al_2O_3 and water–-$TiSiO_4$ nanofluids. Various heat values (40, 70, 120, 180 and 210 W) were used in the evaporator part. The results indicated that both nanofluids enhance the performance with reduction in thermal resistance by 65% (at concentration of 0.05% for Al_2O_3) and 57% (at concentration of 0.075% for $TiSiO_4$). Other improvements were also observed in forms of enhancement in heat transfer coefficient and reduction in the wall temperature of the evaporator. The authors stated that higher thermal conductivity, deposition of a porous layer on the surface and Brownian motion are responsible mechanisms for the achieved improvements in the heat transfer efficiency.

Nnanna et al. [17] investigated the thermal efficiency of a thermoelectric module using nanofluid-based heat exchanger. The system