Energy Conversion and Management 154 (2017) 180–190

Contents lists available at ScienceDirect

Energy Conversion and Management

journal homepage: www.elsevier.com/locate/enconman

Optimizing energy efficiency of a specific liquid block operated with nanofluids for utilization in electronics cooling: A decision-making based approach

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ARTICLE INFO

Keywords:
Nanofluid
Electronics cooling
Optimization
Liquid block
Decision-making
Genetic algorithm

ABSTRACT

This paper attempts to investigate and optimize the energy efficiency of a specific liquid block working with the water–Al_2O_3 nanofluid for utilization in electronics cooling. The effects of Reynolds number, nanoparticle size and volume concentration are evaluated. The uniform flow distribution in the liquid block results in a rather uniform temperature distribution on the surface of the electronic processor. Moreover, the surface temperature reduces while the power consumption intensifies by increasing either Reynolds number or particle concentration. The processor temperature and pumping power are considered as two objective functions in the optimization problem. A multi-objective optimization method and a decision-making based approach are employed to find the optimum points with minimum processor temperature and minimum power consumption. The optimal cases are obtained considering different states for relative importance of the objective functions. It is found that even in the conditions that the pumping power is of high importance, the nanofluids with great concentration and small nanoparticle size can be utilized. The results show that the effect of the concentration and particle size on the surface temperature is greater than that on pumping power, while the Reynolds number has a rather similar effect on the two objective functions.

1. Introduction

Enhancement of thermal efficiency is an important challenge in electronics industry. Recently, the integrating and compacting electronic chips have risen to a great level with the need to introduce high processing power. Thermal management of electronic components has newly become very critical thanks to significant increment in transistor density, reduction in characteristic size, and increase in computation speeds resulting in great heat fluxes. The next production 3D integrated chip designs also require appropriate cooling methods. In fact, cooling type and thermal management can affect the lifetime and energy performance of the electronic devices. For instance, reduction in performance of Central Processor Units (CPUs) because of overheating is still one of the key challenges in electronic systems and computer technology [1–3].

Nowadays, progress in the efficacy and speed of computers is continuously noticed, which is due to the application of the most advanced technology. This causes higher electric power consumption and therefore greater heat generation, which can reduce performance or destroy the electronic processor. Although in previous decades, the passive cooling of electronic chips caused no important issue, today the heat dissipation from a processor with a very small surface is an essential challenge.

So far, many researchers have utilized air cooling to solve the problem of high heat flux in electronics. Gases, however, have poor potential for cooling of electronic chips. In contrast, liquids have excellent cooling potential owing to high thermal conductivity and great specific heat. Therefore, liquids have recently gained a great deal of attention for utilization in electronics cooling. Commonly, two methods are used in order to optimize the efficiency of liquid cooling systems. The first technique is to improve geometry of liquid blocks whereas the second approach involves the enhancement of thermophysical properties of conventional fluids in order to increase thermal efficiency [4–8].

Improvement in thermal attributes of fluids results in more appropriate cooling and hence, smaller electronic systems can be applied. A recent progress in nanotechnology is introduction of suspensions containing solid nanoparticles called nanofluids [9]. Compared with ordinary suspensions with millimeter or micrometer-sized particles, applying nanofluids results in superior heat transfer performance in different applications due to the small size of solid particles [10–17].

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http://dx.doi.org/10.1016/j.enconman.2017.10.055
Received 12 August 2017; Received in revised form 29 September 2017; Accepted 20 October 2017

Therefore, nanofluids can be an appropriate coolant for electronics cooling.

Several researchers have studied characteristics of nanofluids in liquid blocks for cooling of electronic components. Al-Rashed et al. [18] evaluated the effect of nanofluids on the performance of a heat sink for CPU cooling experimentally and numerically. For the range of mass flow rate and heat load under study (115 and 130 W), up to 7.7% of thermal conductance improvement was observed in case of using nanofluids in comparison with water. Sohel et al. [19] investigated the efficacy of a nanofluid passed through a custom-made copper minichannel heat sink which was normally attached with the electronic heat source. The experimental results revealed that the nanofluid successfully minimizes the heat sink temperature compared to the conventional coolant. It was also found that the thermal entropy generation rate is reduced via using nanofluid instead of the pure water. Sarafraz et al. [20] examined the thermal efficiency of a cooling liquid block working with gallium, CuO-water nanofluid and water. The CPU employed was evaluated at three states of standby, normal and overload working modes. The CuO-water nanofluid presented a greater thermal performance compared with pure water, whereas had lower pressure drop offering a trade-off situation against the gallium. Bahiraei and Heshmatian [21] investigated hydrothermal characteristics of a biological nanofluid in a liquid block for cooling of an electronic processor. The liquid block had 20 channels, and its bottom surface was placed on the processor. By increasing Reynolds number and particle concentration, temperature distribution became more uniform in processor surface and heat transfer coefficient also increased. Furthermore, the surface temperature decreased with increasing concentration and Reynolds number. Moreover, the results showed that at a constant power consumption, the nanofluid presents better cooling compared with water.

Since by adding solid nanoparticles to conventional fluids, both heat transfer and pressure drop may increase, it is very essential to find the optimal conditions with minimum pressure drop and maximum heat transfer. Indeed, increase of pressure drop causes pumping power increment. The need for this kind of optimization becomes more important in geometries such as heat sinks which possess many applications in thermal systems. A few studies have been performed with optimization viewpoint in problems in which nanofluids are utilized as working fluid. Sajedi et al. [22] provided a multi-objective optimization in a finned heat exchanger operated with nanofluids. Two objective functions of exergy efficiency and total cost were considered. The Genetic Algorithm (GA) was used for different parameters to generate the Pareto front. The results revealed that despite of positive thermal effect of nanofluid, the negative influence of nanofluids on the hydrodynamic characteristics leads to zero concentration in the optimal operating point. Yang et al. [23] simulated a nanofluid convection in a rib-grooved channel with constant wall temperature. The optimization of this problem was carried out by using the genetic algorithm approach. The objective function was defined as the performance factor with four design variables. It was concluded that the objective function is more optimal at $Re = 10{,}000$, and rib-grooved showed an 18.2% enhancement. Vahdat Azad and Vahdat Azad [24] evaluated application of alumina nanofluid to enhance the efficiency of heat exchangers while reducing energy consumption and overall cost. They used the genetic algorithm for optimization. Increased heat transfer coefficients by the nanofluid decreased the needed tube length resulting in reduction in the pressure drop. Consequently, the overall cost of the heat exchanger decreased more than 55%. Ahmadi Boyaghchi and Chavoshi [25] performed the thermodynamic, economic and environmental analyses of a solar-geothermal system integrated with flat plate collectors containing water–CuO nanofluid as the absorbing medium. The daily exergetic efficiency, total product cost rate and total product environmental impact associated with exergy rate were chosen as the objective functions. GA was employed to find the final optimum solutions. Based on their results, R134a was the best fluid with 4.194% daily exergetic efficiency so that the minimum volume fraction was required.

Heat sinks frequently possess several parallel flow channels, such that these small channels result in a great heat exchange surface for heat transfer augmentation. However, the role of inlet and outlet manifolds is also critical since they distribute the flow between the channels. Indeed, a non-uniform flow distribution reduces liquid block efficacy because it leads to high local temperatures, and increases pressure drop which consequently intensifies pumping power required for heat sink operation. Hence, some scholars have tried to recognize the flow maldistribution concerning conventional flow configurations such as Z-type and U-type manifold connections to parallel channels. Tan et al. [26] investigated the flow distribution in three different designs of microchannel heat sink. One of them had a singular inlet and outlet, while two others had dual inlet and outlet. This distinctive feature of dual input resulted in shortening the flow path by splitting the flow region into four quarters. Hence, the friction and pressure drop were decreased. Moreover, the flow uniformity demonstrated a significant improvement, which reflected positively on the thermal efficiency. Wen et al. [27] characterized the turbulent flow structure in the entrance of a plate-fin heat exchanger. The numerical and experimental results revealed that the performance of fluid maldistribution in conventional entrance is deteriorated, whereas the enhanced configuration with punched baffle efficiently improved the performance in both axial and radial directions. Wang [28] developed an analytical model to obtain the flow and pressure distributions in fuel cell stacks. The influence of geometrical structures and parameters on flow performance of fuel cell stacks was examined. It was found that friction and momentum effects work in opposite directions, such that the former decreased the pressure while the latter increased it. The proper balance of the two effects led to more uniformity and an optimum design. Ramos-Alvarado et al. [29] utilized a modern flow distributor designed with T-shaped symmetric divisions of flow between the channels for pure water as the coolant. This new design can cause a more uniform flow distribution than other outlines.

For developing the use of this new idea, energy efficiency of the mentioned liquid block with the water–Al_2O_3 nanofluid as coolant is optimized in the current work. Flow and heat transfer attributes of this specific liquid block for utilization in electronics cooling are investigated. The effects of parameters such as Reynolds number, nanoparticle size and volume concentration are considered. Finally, a multi-objective optimization method and a decision-making based approach (i.e. GA combined with compromise programming) are employed to find the optimum points with minimum CPU temperature and minimum power consumption. The main contribution of the present research is optimization of the liquid block based on energy efficiency.

2. Definition of the liquid block

The liquid block under study is shown in Fig. 1. It is a specific liquid block with T-shaped distributors. The material of the liquid block is aluminum. The parallel flow channels and flow distributors are clearly seen in Fig. 1. In this design, the flow is distributed between the channels in four stages (i.e. four levels) before reaching main parallel channels. This results in a uniform flow distribution between the channels, which can reduce pressure drop and enhance uniformity of cooling for an electronic processor. It is noteworthy that Fig.1b illustrates outside of the liquid block, in which the locations of the flow inlet and flow outlet are observed.

The width of the liquid block is 53.89 mm, and the diameter of both inlet and outlet is considered 1.9 mm. The number of channels is 20 in this liquid block, while the length and width of each of the channels are 29.23 mm and 1.2 mm, respectively. Thickness of the bottom surface for the liquid block is 1 mm. In this configuration, flow arrives a preliminary channel and then divides at four levels before reaching 20 parallel channels. The length and width of the channels related to each level have been summarized in Table 1.