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Design of a CPU Heat Sink with Minichannel-Fins & its Thermal Analysis

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In this paper, the design and the thermal analysis of a tribled microprocessor cooler combining the advantages of strong swirl flow and minichannel-fins and CuO nanofluid, have been presented. It is thought that the results will contribute to the understanding of the effects of parameters on the cooling flux of the heat sink and the decline at the microprocessor temperature, as Reynolds number in the minichannels and CuO % volume fraction. The results have exhibited that the total performance of the heat sink cooled with the mixture of water–CuO-EG nanofluids increases with the increase of Re number and the %load of nanoparticles in the coolant. It has been determined that the energy withdrawn from the microprocessor was 241 times higher than the energy generated for maximum CuO load and Re number conditions. Besides, the highest temperature decrease has been measured at the maximum CuO load value and maximum Re number.

Keywords: CPU; heat sink; cooling; nano fluid; fin.

INTRODUCTION

A heat sink is a kind of cooler that absorbs especially unwanted thermal energy from a microprocessor (or called Central Processing Unit, CPU) and distributes it to surrounding. Besides the cooling of CPUs, heat sinks have extensive usage areas, such as the cooling of microturbines, microreactors, micro electromechanics, military technology, and space applications. Heat transfer in the heat exchangers generally occurs between two fluids and a metal wall separating them. Generating strong turbulent flows on both sides of this wall, using a nanofluid as a heat transfer fluid, and using minichannel-fins to enhance the surface area of the wall will have affirmative effects on the heat transfer. This process has been accomplished by enhancing the heat transfer surface of the heat sinks and the flow rate of cold fluid that moves across its extended surface area. A heat sink is a kind of passive-type cooler. Generally, air or a liquid is used as a coolant in heat sinks, where the heat is absorbed away from the CPU, thereby allowing regulation of the CPU's temperature.

Microprocessors, one of the most important inventions of high technology, are used in almost every electronic device, including desktop computers, and industrial applications[1, 2]. A CPU is somewhat the brain of the computer system that controls many electronic and electromechanical systems. New-generation CPUs have higher processing speeds and data processing capabilities and can perform millions of operations per second. Therefore, the electrical current value passing over them is getting enhanced as the data processing rates are getting increased more and more. In addition, their dimensions are getting smaller, and their effectiveness is getting enhanced more and more compared to conventional CPU coolers in line with technological developments.

Nowadays, the heat thrown into the air by the CPU of a desktop computer available is between 50 and 150 joules per second, and normal operating temperatures range between 55 and 85°C[1, 2]. However, the operating temperature of CPUs should be kept at a temperature lower than the upper limit of 85°C, not to be passed the upper limit because of sudden temperature increases[2, 3, 4]. The main challenge in cooling CPUs is to distribute a greater amount of heat than produced while maintaining the CPU temperature below the determined value of 85°C[3]. It is known that CPUs are very susceptible to a temperature increment above the limit value that can burn the CPUs[5]. It is known that power density of the new-generation CPUs under normal operating conditions is 150 W/cm^2 and this value also reaches a peak value of 300 W/cm^2 in some cases[6]. This generated heat must be removed with a higher heat flux (such as 1200 W/cm^2) in order for CPUs to operate in a safe temperature range. The cooling of new generation CPUs will also be solved not by the conventional heat sinks, but by the production of new generation heat sinks that are compact and highly effective, which can electronically control the cooling rate. To satisfy the cooling needs of the new-generation CPUs needs new-generation heat sinks using new cooling techniques, which are swirl flows, improved heat transfer fluids like nanofluids, and the heat fins produced from minichannels.

Heat sinks with minichannel-fins for cooling CPUs have been studied by lots of researchers using single-phase or double-phase coolant fluids and laminar or turbulent flows in the cooling system. In the literature, Yuki and Suzuki concluded that a single-phase cooler using liquid-coolant and absorbing a large amount of heat energy has many advantages, such as any movement, any phase change, and lack of corrosion on the heat transfer surface[6]. Heat sinks with minichannels can absorb and dissipate heat from any surface to surrounding air using extended surfaces[7, 8, 9]. In the classification which is made by Kandlikar and Grande as to minichannels' hydraulic diameters, it was stated that the hydraulic diameters of minichannels are changing between 200 μm and 3 mm.

For a few years, the attention of researchers, whose research area is heat transfer, has been focused on the heat sink with minichannels. Although minichannels have a smaller heat transfer surface than microchannels, they give low-pressure drop versus microchannels, and thus permit a higher mass flow rate. It is stated in the literature that heat sinks with minichannels provide a greater heat transfer rate than those of microchannels[3, 10]. Yuki and Suzuki reported that the heat transfer surface area of the heat sink could be increased by using fins to enhance the heat transfer rate using a single-phase cooler. In this case, it is possible to take advantage of the great heat transfer rate of the undeveloped heat boundary layer in the heat sink[6].

A heat sink, in which a single-phase flow in minichannels exists, was developed by Gayatri. In the research, the cooling performance of ethylene glycol (EG) and water was compared with each other, separately. The best results were achieved with water[11]. A few researchers produced a heat sink with minichannels using water as a coolant. In their study, they determined CPU performance for liquid coolant with nanoparticles and without nanoparticles. They found that Nu numbers for coolant with nanoparticles were greater than that without nanoparticles. Besides, they concluded that Nu numbers increased depending on increment of the mass flow rate of the coolant[3].

The different ways of increasing the mass or heat transfer rate by producing the swirl flow both by active and passive methods have been reported in the literature. It is known that swirl flows are favorable active techniques used to increase mass-heat transfer rates[12]. If it is necessary to increase the convective heat transfer rates on the surface, where simultaneously both a heat transfer and a fluid flow occur, it is highly recommended to use swirl flow on the surface. Arzutug et al recorded that at the bottom surface of the swirl jet flow cell, the increasing swirl intensity has an increasing effect on mass transfer, and the uniformity of mass transfer coefficients enhanced with increasing swirl intensity. Swirl flows produce macro-sized vortices on the heat transfer surface and thus disrupt the heat transfer boundary layer, reducing thermal resistance on the heat transfer surface. So, the convective heat transfer can be increased between the surface and the fluid flowing on the surface[13]. Some researchers explained the increment of heat transfer on a surface originates from "the swirl flow brings the different layers of the liquid refrigerant in contact with the heat transfer surface depending on time"[14]. Vortex cooling tubes have been developed and used in the aviation industry. Besides, the vortex chambers have been used for cooling the solutions and the electrolytes, and good results have been obtained[15, 16].

Complementary of the swirl flow and the minichannel-fins usage use a nanofluid, consisted of a composite of water, nanoparticles, and ethylene glycol as a high-performance heat transfer fluid. Nanofluid usage as a heat transfer carrier in heat exchangers is one of the heat transfer increment techniques. In the state of using nanofluids, nanoparticles produce micro-sized vortices within the boundary layer and it causes mixing within the boundary layer. As a result, the vortices improve heat transfer between the nanofluid and the surface by reducing thermal resistance[13, 17, 18].

Generally, water is used as a base fluid in the preparation of the nanofluids because of its higher density and specific heat than the other base solutions. Carr et al. have stated that the heat-absorbing capability of water due to the temperature increment across the cooler is approximately 3500 times than that of air[10]. In the literature, the effective thermal conductivity of nanofluids depends on the following properties of the nanofluids: the heat conductivity of the nanoparticles, the kind of base solution, nanoparticles volume fraction, particle size, and the shape of nanoparticles, the thickness of nanolayer, and the heat conductivity of nanolayer. Some researchers have declared that the increment ratio of the heat conductivness in the nanofluids has been calculated by using the ratio of the heat conductivity of the nanofluids to that of the base fluid[15, 19]. According to some researchers, in the case of using nanofluids as heat carrier fluid, the increment of heat transfer rate depends on the enhancement of interactions and fluctuations of nanoparticles, the chaotic movement of the nano-sized particles, and the heat conductivity of the base fluid[20, 21]. Besides, the addition of nanoparticles to a liquid fluid affects the mass transfer rate positively. The effective mechanisms of the mass transfer rate are hydrodynamics, diffusion, and blockage of the active surface with nanoparticles. The researchers recorded that the first two mechanisms enhance the mass transfer rate. However, the third mechanism affects it negatively[16, 22].

A few researchers discovered that the nanoparticles up to a volume ratio of 2% don't affect the viscosity of the nanofluid. However, as the solid-liquid ratio increases in the nanofluid, the viscosity value of the nanofluid enhances compared with the base solution[19]. The new-generation coolants or heat transfer fluids are composed of a mixture of a low-volume fraction of nano-sized particles with any carrier liquid or base liquid[19]. Lots of researchers as Kakaç et al.[15], Masuda [23], and Lee et al.[24] have recorded that the nanofluids with low concentrations (1–5 vol%), which consist of such as Al_2O_3, CuO, Cu, SiO, TiO nanoparticles, have enhanced the effectual heat conductivity and the convective heat transfer coefficient of heat transfer solutions more than 20%. It has been recorded by Lee et al.[24] and Wang et al.[25] that the heat conductivity ratio has increased by 50% by using nanofluids consisting of ethylene glycol with 15% CuO nano-sized particles. In a review study, Marcelino et al stated the usage of a CuO-water nanofluid as a heat transfer carrier has provided reasonable stability and particle dispersion. Afshari et al conducted an exhaustive numerical study to determine the heat performance of block heat sinks for cooling CPU by using nanofluid Fe_3O_4/water with a volume concentration of 0.2%. They used two different block heat sink configurations, including mini channels, for testing under various working conditions[26].

Some researchers stated that using a nanofluid as a coolant enhanced the heat performance of minichannels compared with pure water. In a study conducted by Naranjani[27], the thermal performance of the small heat sink with corrugated channels and nanofluids was investigated. The researchers stated the heat transfer performance of the heat sink increased by using modified channels instead of straight ones by 24–36% in the heat sinks. Besides, they concluded that when the water-based nanofluids containing nano-sized Al_2O_3 particles with different volume fractions of less than 3% is used as a coolant, the total performance of the heat sink increased by 22–40% compared to the situation using water. Additionally, they informed that the total performance of the heat sink was increased by enhancing nano-sized particle volume fraction and reducing the mean size of nano-sized particles in water–Al_2O_3 nanofluids. Ebrahimi et al. examined conjugated heat transfer thermo-hydraulic performance for nanofluid flow numerically in rectangular microchannel CPU cooler with longitudinal vortex producers using a finite-volume technique at different ranges of Reynolds numbers. They have used CuO and Al_2O_3 nanofluid as heat transfer carriers in numerical study. The researchers have concluded from the heat analysis that the heat transfer increased by 2.29–30.63% and 9.44%–53.06% for water-Al_2O_3 and water-CuO nanofluids, respectively[28].

In the study, the conical-geometry pin fins with five different conical size ratios (Hcp/d) have been taken into account, and the performances of conical-geometry fins have been compared to those of cylindrical fins by researchers. Researchers have determined the temperature distribution and Nusselt number distribution in different Re numbers. Besides the heat resistance, pressure drop in the CPU heat remover, and hydro-thermal performance of the CPU heat remover have been calculated. The results showed that the heat resistance decreased with enhanced Re and Hcp/d ratio[29]. In the study about heat sinks by Bencherif et al., the heat dissipation rate was tried to be increased, while the occupied volume and mass values of the CPU coolers, and the heat transfer surface area was tried to be decreased[30]. Some theoretical and practical studies have been executed to find the hydrothermal performance of a CPU cooler with hemispherical pin fins and the optimum hemispherical pin fins configuration by Sahel et al. Experimental results have showed that the perforations lead to new vortex structures allowing a better mix of the fluid bulk and increased heat transfer as expected. Besides, it is concluded that heat transfer rate was increased with increasing Re number and hole diameter[31].

The major factors affecting the heat performance of CPU coolers are air velocity, choice of material, and fin design[10]. The solution of a simple CPU cooling problem is accomplished by using a conventional heat sink, in which generated heat is transferred by a conduction mechanism through the solid fins and dissipated from the surface of the solid fins to air. Besides, in the heat sinks recirculating liquid-coolant, the generated heat is transferred by liquid coolant to a radiator and exhausted from the fins of the radiator to air. However, the design of the heat sink or the fins used in the present study is too different from the models existing in the literature. In the present study, there are minichannels inside the used fins. Most of the heat produced by the CPU is transferred (convection mechanism) to the minichannels by fluid flow. And then, the heat is transferred by convection from the outer surface of the fins to the cold air.

It has been demonstrated that in Figure 1, the fin temperature is at a maximum value of T_b at the base of the fin and decreases towards the tip of the fin in the axial direction in the heat sinks with conventional-type fins[32]. Thus, the amount of heat transferred out of the fin by convection gradually decreases. Since the fin cross-sectional area is too small, the temperature can be assumed as uniform across the blade section. In this situation, the temperature difference of $[T(z) - T\infty]$ between the fin surface and the bulk fluid outside of the fin decreases towards the tip of the conventional fin, as shown in Figure 1.

In the present study, the minichannel-fins have been used to keep this temperature difference at higher values, that is, to increase the fin efficiency. Since a fluid flow occurred in used minichannel-fins, the temperature gradient between the fin surface with the nanofluid is higher than that of conventional type fin. In this configuration, the $[T(z) - T\infty]$ temperature difference has been kept at a high value along the fin, resulting in a more efficient heat transfer from inside the fin to the cold fluid outside.

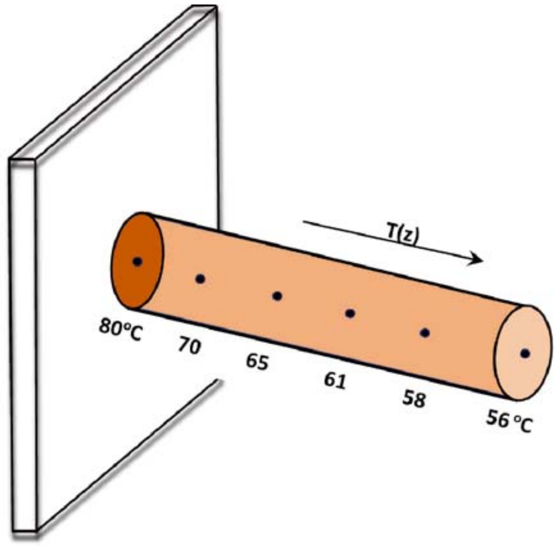

Figure 1. The temperature distribution along a metal-rod fin[32]

Reviewing the relevant heat transfer literature shows that heat sink studies focus on different nanofluids, mini-micro channels and channel geometry, and flow types inside of minichannels or out of minichannels. In the literature, there are many studies on heat sinks, including double combinations of factors affecting heat transfer[33]. However, there are no heat sink studies involving swirl flow, nanofluid, and minichannel trio, in the literature. The present study puts forward a novel heat sink design with high cooling performance that contains three effective properties on the heat transfer together in this heat sink. Besides, the cost of the heat sink in the present research is less than that of a dual-phase heat sink because of using a single-phase heat transfer fluid, and it is not needed to use complex systems as used in dual-phase heat sinks. Heat sinks using dual-phase fluids require a lot of power because they have a pump, a condenser surge valve, and a radiator. The present study helps to understand that, unlike the transferred heat by conduction throughout the fins of a conventional heat sink, the heat transfer by convective mechanism in the minichannel-fins of the heat sink can be developed. The present study shows the effects of the nanofluids with different CuO volume fractions used as a coolant and the swirl flow and Reynolds number of this liquid on the cooling rate. In addition, the present study also includes the temperature change depending on the time at the contact surface of the aluminum block heater with the heat sink. Besides, the measurement step of the heat absorption performance of the developed heat sink and the determination step of the heat flux values at specified nanofluid Reynolds numbers and CuO% volume fractions in case of constant air flow conditions are included in this study also.

EXPERIMENTAL

The heat sink designed in this research consists of three parts in Figure 2. The first part is called the swirl flow chamber which is located at the bottom section of the heat sink and is made of aluminum. As a result, the heat sink contacts with the CPU's upper surface and absorbs heat from the CPU. In this part, the swirl flow generated by 2 tangential inlets at the swirl cell, carries the heat absorbed from the bottom surface of the cell upward in a vertical pipe (Fig. 2). And then it is distributed to the minichannel-fins. In the second part where there are mini-channels positioned laterally, liquid flow in the vertical pipe is poured into an annular flow channel by passing through the minichannels. The minichannels made of copper pipes are used as the heat fins in the heat sink, where there exist 264 pieces of copper pipe in 800 μm hydraulic diameter and 25 mm length. The heat transfer fluid, which is taken into the annular geometry chamber, is then collected in a storage tank, where it is suctioned by a centrifugal pump and pumped back to the swirl flow chamber. In the third part, an air turbine (16,000 rpm) existing at the top of the cooler ensures airflow over the mini-channels used as heat fins. Thus, the transferred heat by the flow of copper oxide (CuO) nanofluid is exhausted into the air by convection from the outer surface of 264 pieces of 25 mm long and 800 μm inner diameter mini-channels. Both the liquid pump and air turbine are controlled by an electronic control card.

In the present study, an aluminum block heater as CPU simulator is used with 50.6 W in power and a size of 4 cm x 4 cm x 1 cm. This aluminum heater supplies a constant heat flux from only the surface that touches the heat sink. In this configuration, since the lateral surfaces of the aluminum block heater are insulated with glass wool materials against heat loss, the heat is transferred vertically. Electric energy is transformed into heat energy with 100% efficiency. So, the produced heat in the aluminum heater is transferred to the heat sink completely. According to the design, the contact surface of the CPU with the heat sink is 4 cm x 4 cm in size. So, the absorbed heat from this surface of 16 cm^2 has been discharged into the atmosphere from a 35 times bigger surface than the heat-absorbing surface. In this design, absorbed heat from the CPU is exhausted to the air by way of mini channel fins. In addition, the heat carried by the fluid flow in the fins is thrown into the air by convection. The photograph of the prototype of the heat sink and showing the structure of the minichannels are displayed in Figure 3a and Figure 3b, respectively.

In the study, the nanofluids with four different compositions are used as heat carrier fluids. These are the mixtures of CuO, water and EG. Ethylene glycol (EG) is used as a base fluid in the nanofluids. The heat transfer fluid is not subject to phase change as the heat sink is a closed system. In addition, EG is used to increase the boiling point of the coolant by a few degrees Celsius and helps decrease corrosion in the heating systems and decrease the freezing point of the heat transfer solution. The first nanofluid is composed of 3% EG and water (no nanoparticle), and the other three nanofluids are composed of three different volume concentrations of CuO nanoparticles with a 3% EG-water solution. These nanofluids are prepared by using the ultrasonic bath for 24 hours. The nanofluids provide reasonable stability and nanoparticle dispersion. The mixture of EG-water keeps the CuO nanoparticles loose and free. In this way, the nanofluid flows inside the minichannels and other parts of the heat sink without coagulation. The used CuO nanoparticles in the research were provided by the Nanoamor Company. According to the producer, the geometrical structure of the nanoparticles can be accepted as spherical, and the mean diameter of nanoparticles is 30–50 nm with a density of 6300 kg/m^3. A powerful pump is used to overcome pressure drops, and to attain fluid flow in the system. Logically, a swirl flow chamber was used to increase the heat transfer rate at the bottom surface of the heat sink, first. Secondly, thanks to the swirl flow generated at the bottom, the nanoparticles in the nanofluid are prevented from precipitating at the bottom. So, the swirl flow formed on the base surface of the swirl cell not only creates a uniform nanofluid concentration by carrying the nanoparticles up but also prevents blocking the base surface of the swirl cell. By means of an electronic control card mounted on the system, the speed of the pumps and fans can be controlled, and thus it is aimed to provide energy efficiency and reduce the noise level.

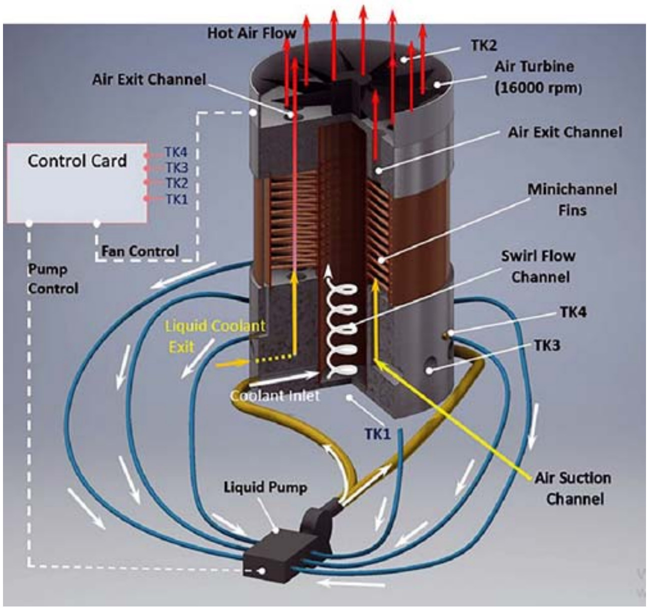

Figure 2. The schematic representation of the heat sink

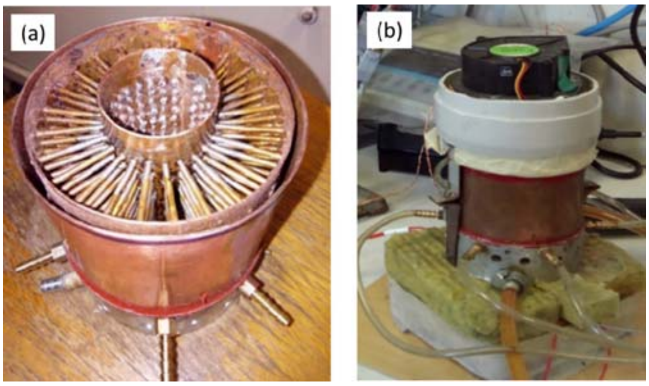

Figure 3. a) The structure of the minichannel-fins in the heat sink. b) The photograph of the prototype heat sink

Reynolds number of the coolant (nanofluid) and CuO% volume fraction parameters were chosen as parameters in the research (Table 1). In the experiments, the effect of Re number of the coolant (nanofluid), CuO% volume fraction in nanofluid were investigated on the heat flux withdrawn by heat sink (cooling rate of the heat remover) and on the decrement in the CPU temperature.

Table 1. The values of the parameters used in the research

Reynolds Number	108	211	262	286
CuO Nanoparticle % Volume fraction	0.0	0.08	0.16	0.24

Test Banch and Measurment Technique

Heat sink performance has been tested by using the system in Figure 4. In this system, an aluminum block of 2 cm in height and 4 cm x 4 cm in size has been placed between the heat sink and the aluminum block heater, and heat enhancing paste has been applied to the contact surfaces to reduce the heat contact resistance. The lateral surfaces of the aluminum block and heater are insulated with rock wool heat insulation material. Thus, the generated heat is only transferred to the heat absorber. By applying a constant electric current at 1.5 A to the resistors, constant heat flux conditions are provided. And then the obtained heat is conveyed to the heat remover through the aluminum block. After steady state conditions are met, temperature measurement is made using 2 thermocouples placed at T_1 and T_2 points shown in Figure 4.

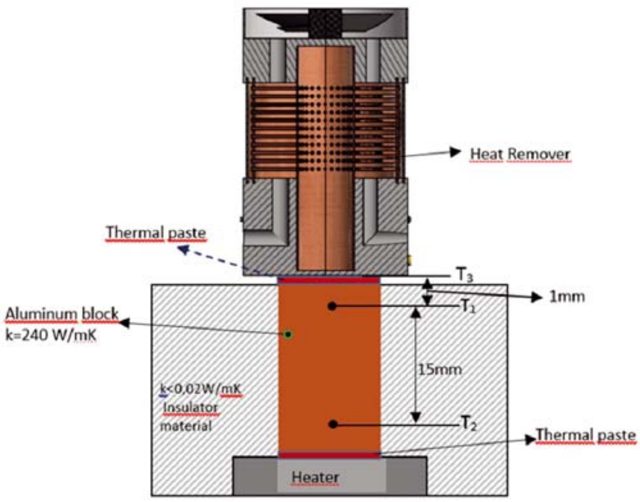

Figure 4. The performance test system used for the heat sink[2]

Aluminum material heat conduction coefficient (k) is 240 W/mK as obtained from the literature. The product of the heater's current output value gives the value of heat produced. In the formula of Fourier's law, the value of k, the difference between T_1 and T_2 temperatures, and the distance between the two temperature measurement points (15 mm) are replaced to find the thermal flow rate (J/s).

Ni-CrNi thermocouples, which are used in the performance test system, were calibrated before cooling performance tests of the heat sink, by referring to a higher accurate thermocouple. And then, a thermocouple calibration curve has been graphed using calibration data and used in heat transfer performance calculations.

The thermophysical properties of CuO nanofluid are figured out using the following equations: Firstly, the effective density of the nanofluid is figured out by using Equation-I[16].

$$\rho_{eff} = \rho_o + \emptyset(\rho_p - \rho_o) \quad \text{(I)}$$

Where, ρ_o is the density of base fluid, ρ_p is the density of CuO nanoparticle, $\emptyset$ is the volume % fraction of CuO nanoparticles. It is reported by a few researchers that nanoparticle additives up to volume ratio of 2% don't affect heat transfer solution viscosity[19]. For this reason, the used viscosity values of nanofluids in this research were taken as the same with base fluid which consists of EG 3% and distilled water. The effective heat conductivity of the nanofluids has been figured out using Equation-II, suggested by Koo and Kleinstreuer[34, 35].

$$k_{eff-nf} = k_{static} + k_{Brownian} \quad \text{(II)}$$

Where, k_{eff-nf} is the effective heat conductivity of the nanofluid. Thermophysical properties of ethylene gylicol (average temperature of CPU at 71°C), pure water and CuO nanoparticles used in the present work is given in Table 2.

The geometrical structure of the nanoparticles can be accepted as spherical, and the mean diameter of nanoparticles is 30–50 nm with a density of 6300 kg/m^3.

In this equation, the static term is only a function of the conductivity of the base fluids and the volume concentration of the nano-sized particles. The effective heat conductivity of the nanofluids (k_{eff-nf}) has been calculated considering both static and Brownian effects. The effective conductivity values have been used in other calculations. In the present study, since the value of the volume fraction of the CuO nanoparticle in the nanofluid is less than 1%, in calculating the effective heat conductivity of the nanofluid according to the heat conductivity models, the static conductivity due to the intermolecular energetic potential and the thermal conductivity according to the Brownian motion should be calculated. In this study, in laminar flow through minichannels, the Nusselt numbers Nu are obtained from the Sieder and Tate correlation (Equation-III)[34, 35]:

$$Nu = \frac{hD}{k} = 1.86\,(Re * Pr * \frac{D}{L})^{\frac{1}{3}}\,(\frac{\mu_b}{\mu_o})^{0.14} \quad \text{(III)}$$

Some researchers discovered that up to a volume ratio of 2%, the solid particles do not affect the viscosity of the nanofluids. However, as the nanoparticle amount in the nanofluid has increased, the viscosity of the nanofluid increases compared to the base fluid[19]. Dynamic viscosity values of CuO nanofluid used in this correlation, deve-

Table 2. Thermophysical properties of ethylene gylicol, pure water and CuO nanoparticles used in the present work

Property	Ethylene Gylicol (50% by volume) 71°C [36]	Water [27]	CuO [Nanoamor]	Unit
Density, ρ	1025.9	1000	6300	kg/m^3
Specific heat capacity, C_p	866.3	4180	–	J /kg °C
Thermal Conductivity, k	0.258	0.6 x (1 + 4.167 x 10^{-5}.T)	–	W/m K
Viscosity, μ	0.95 x 10^{-3}	2.761 x 10^{-6} x exp(1713 / T)	–	kg /m s

loped by Kulkarni et al for CuO-water nanofluid, are calculated using the following Equation-IV[34, 37]:

$$\log(\mu_{nf}) = Ae^{-BT} \quad \text{(IV)}$$

where, μ_{nf} is dynamic viscosity of nanofluid (mPa · s), A and B are parameters in the equation of the volume fraction of CuO nanoparticles, R^2 is the correlation coefficient. A and B have been calculated by using the equations as follows[34].

$$A = 1.8375\emptyset^2 - 29.643\emptyset + 165.56 \quad (with\ R^2 = 0.9873) \quad \text{(V)}$$

$$B = 4.10^{-6}\emptyset^2 - 0.001\emptyset + 0.0186 \quad (with\ R^2 = 0.988) \quad \text{(VI)}$$

Uncertainty Analysis

The error analysis of the experimental measurements for the present study is realized using a sensitive method called uncertainty analysis, defined by Kline and McClintoc, at a 95% confidence level[38, 39, 40]. Errors have been determined using by lowest counts and sensitivities of the measuring apparatuses used in the present study. The detailed error analysis for the present study is given in Table 3. For the given experimental conditions, the maximum uncertainty (W_{Re}) is calculated at 1.5% in the Reynolds number, in the heat flux (W_q) 2.1%, and for Reynolds numbers less than 300, in the Nusselt number as (W_{Nu}) 11%.

Table 3. The average possible error for the experimental parameters

S. no.		Uncertainty equation	Uncertainty %
1	$Re = \frac{D_h V \rho}{\mu}$	$W_{Re} = \sqrt{[\left(\frac{W_D}{D}\right)^2 + \left(\frac{W_m}{m}\right)^2]}$	1.5
2	$Nu = (h_c D_h)/k$	$W_{Nu} = \sqrt{[\left(\frac{W_{h_c}}{h_c}\right)^2 + \left(\frac{W_{D_h}}{D_h}\right)^2]}$	11
3	$q = \frac{Q}{A} = k\frac{\Delta T}{\Delta z}$	$W_q = \sqrt{[\left(\frac{W_T}{T}\right)^2 + \left(\frac{W_z}{z}\right)^2]}$	2.1

RESULTS AND DISCUSSION

Within the scope of this experimental study, a new heat sink, including parts: minichannel-fins, nanofluid, and swirl flow chamber, having positive effects on cooling, has been designed and the heat removing capability has been tested at the room temperature of 25°C.

The experimental procedure consists of two steps:

In the first step, the heat of 50.6 W has been produced by using an aluminum block heater, which is used as a CPU simulator at constant heat flux conditions. An aluminum heat bridge has been located on an aluminum block heater to measure temperatures and compute the cooling flux of heat sink. After a ten minute electric current has been applied to resistors, a required maximum CPU temperature value of 135°C has been achieved. In the second step, the heat sink is located on an aluminum heat bridge, and a centrifugal liquid pump is started immediately. And then, a nanofluid flow has been supplied at a determined liquid rate in heat sink. Simultaneously, a timer has been started with the starting of the pump. To determine the heat flux rate of heat sink, temperature measurements are taken by using two Ni-CrNi thermocouples, located inside two

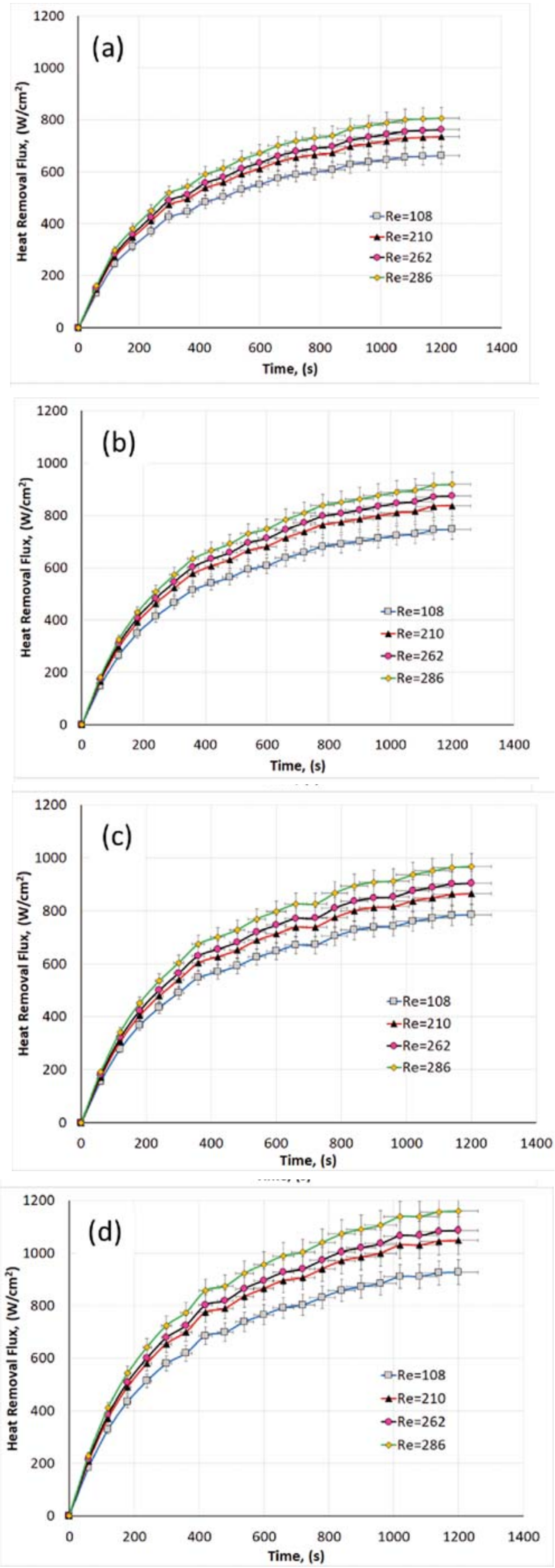

Figure 5. The cooling performances of the heat sink for different coolant mixtures: (a) Coolant with 3% EG-water; (b) Nanofluid-coolant containing water, 3% EG, and 0.08% CuO nanoparticle; (c) Nanofluid-coolant containing water, 3% EG, and 0.16% CuO nanoparticle; (d) Nanofluid-coolant containing water, 3% EG, and 0.24% CuO nanoparticle

holes laterally on the aluminum bridge. The aluminum bridge and aluminum block heater have been covered with insulating material, called stone wool. Consequently, throughout the cooling process, temperature values versus time have been measured and saved.

By using the temperature data measured at different times, the computed heat flux values (W/cm^2) of the heat sink have been calculated and graphed versus time in Figure 5(a–d). According to these graphs, it has been seen that the heat removal flux with increasing time increased dramatically in five minutes. However, after 5 minutes, the heat removal flux values have increased together with the tangential decreasing. After 20 minutes, it has become steady state. Besides, heat flux values increased depending on the increase of Reynolds number values.

It is seen from Fig. 5(a–d) that the heat flux values have increased exponentially for studied Re numbers depending on the volume fraction of CuO. For example, at the 20th minute for Re of 286, the heat flux value is 808 W/cm^2 for no nanoparticle, water with 3% EG. However, in nanofluids containing 0.08 CuO, 0.16 CuO, and 0.24, the heat flux values are 920, 967, and 1160 W/cm^2, respectively.

The variation of heat flux withdrawn through minichannel-fins versus pressure drops in different time intervals, for different cooling fluids, is shown in Figure 6(a–c). As cooling fluids, 3% EG-water mixture is used firstly, and also CuO-EG-water nanofluids with different three CuO% volume fractions are used. It can be seen from Figure 6(a–c) that as the pressure drop throughout the minichannel-fins has increased, the heat flux values withdrawn from the CPU have also increased. Besides, it is shown in Figure 6(a–c) that as CuO load is increased in CuO nanofluids, the heat flux withdrawn from the CPU is enhanced. According to the graphs in Figure 6(a–c), at 472 Pa conditions, if CuO load in the nanofluid is increased from 0.0 to 0.24%, the heat flux withdrawn increases respectively 1.40, 1.41, and 1.42 times.

Figure 7 shows that, as the Reynolds number enhances inside of the minichannel-fins depending on fluid flow rate, it is observed that the pressure drops through the minichannel-fins increases dramatically. The pressure drop difference, for the CuO-EG-water nanofluids with different CuO% volume fractions is too low at the value of Re equals 108. It is observed from Figure 7 that, the difference among curves showing pressure drop for nanofluids with different CuO% volume fractions, is getting increased as the Reynolds number enhances.

It is seen from Figure 8(a–d) that the junction temperature has changed depending on the time, on the heat transfer surface between the heat sink and the aluminum block heater. According to these graphs, it can be observed that the junction temperatures dropped exponentially in 20 minutes and remained constant after 20 minutes.

In Figure 8–a, the temperature values reached 76°C at the 20th minute, for Re is 286, and water with 3% EG. Besides, at 20th second and Re is 286, the temperature values were measured as 67.9°C, 61.7°C, and 58°C for nanofluids containing 0.08 CuO, 0.16 CuO, and 0.24 respectively, from Figure 8(b–d).

A comparative presentation of the present study results with the literature data[41] showing the effect of Reynolds

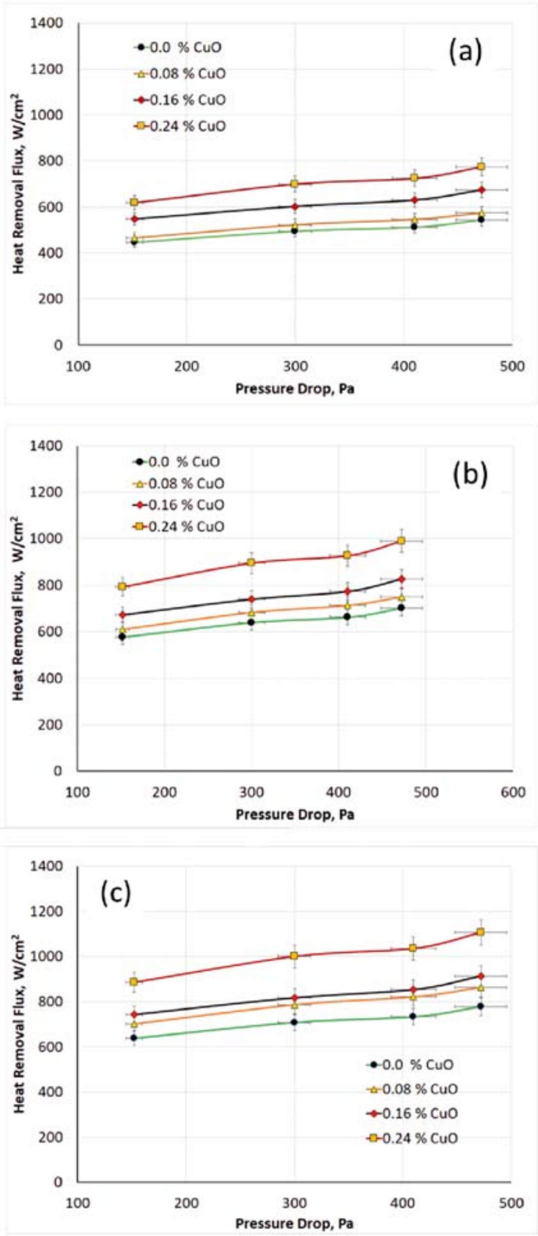

Figure 6. The relationship between pressure drop in the minichannel-fins and heat flux withdrawn from CPU in the different time intervals for nanofluid-coolants composed of water with 3% EG and different CuO% volume fractions: (a) for 5 minutes; (b) for 10 minutes and (c) for 15 minutes

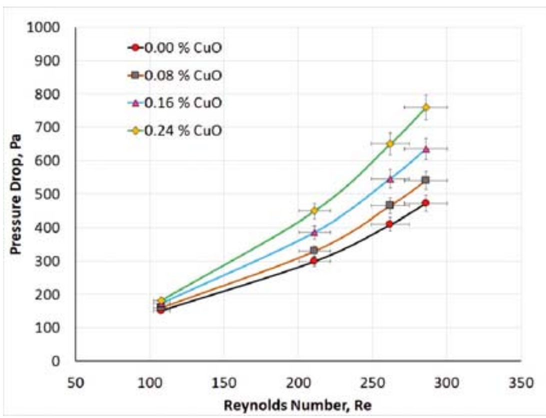

Figure 7. The relationship between pressures drop in the minichannel-fins and Reynolds Number, for nanofluid-coolants composed of water with 3% EG and different CuO% volume fractions

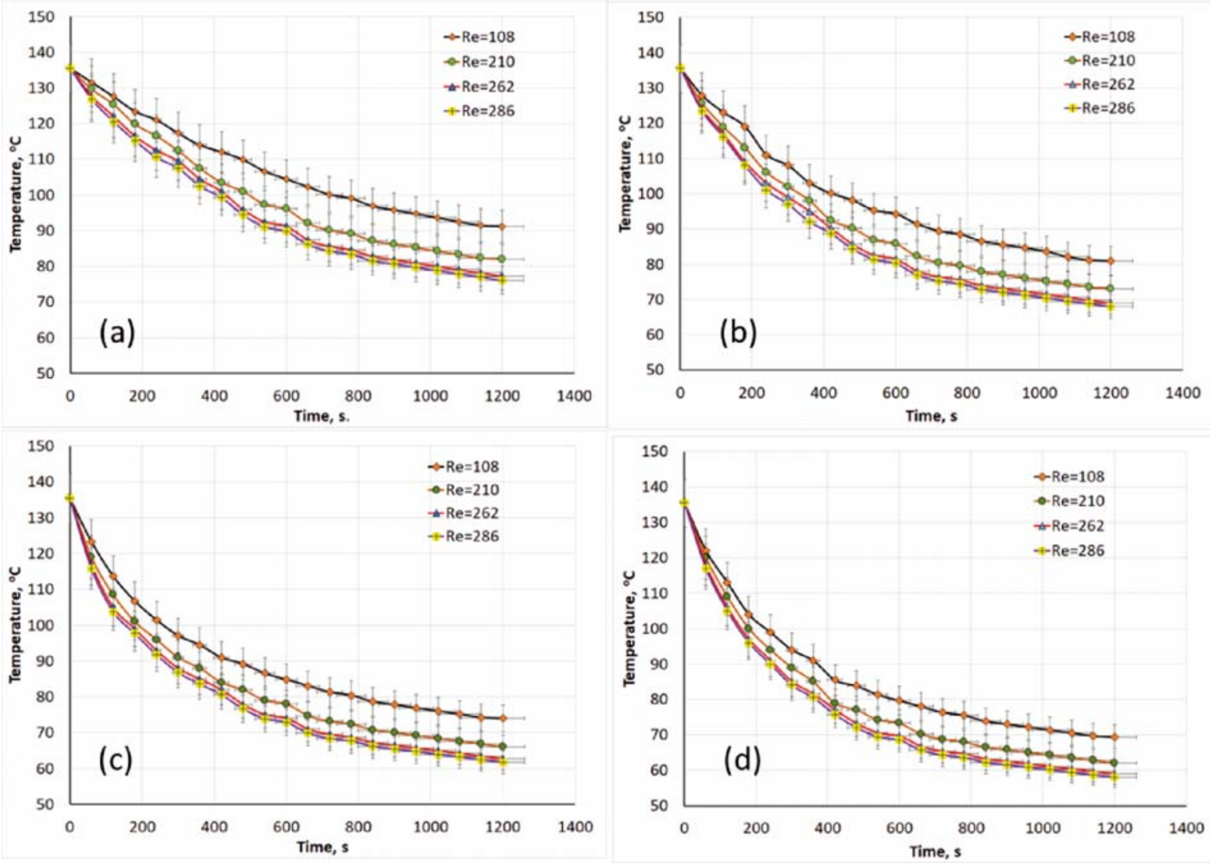

Figure 8. The changing of temperature at the contact surface of the aluminum block heater with the heat sink versus time for different coolant mixtures: (a) Coolant containing 3% EG and water; (b) Nanofluid-coolant containing water, 3% EG, and 0.08% CuO nanoparticle; (c) Nanofluid-coolant containing water, 3% EG, and 0.16% CuO nanoparticle; (d) Nanofluid-coolant containing water, 3% EG, and 0.24% CuO nanoparticle

number and CuO % volume fraction on contact surface temperature between the aluminum block heater and the heat sink is given in Figure 9. According to the graph, the temperature behavior observed in the 100–300 range of Reynolds in the CPU cooling study carried out by Mirry et al[41] with water and nanofluid containing 0.5% Al_2O_3 is similar to the behavior obtained in the present study for nanofluid containing 0.24% and 0.16% CuO in the same Reynolds range, and also that overlap the curves.

In Figure 10, Nusselt numbers distribution versus Reynolds numbers is given at different CuO% volume fractions. In the given graph of Figure 10, Nusselt numbers have increased exponentially depending on the increase of Reynolds numbers. The enhancement of Nu numbers can be explained by the increment of the convective heat transfer rate depending on the increment of Reynolds numbers in the minichannel-fins has increased[42].

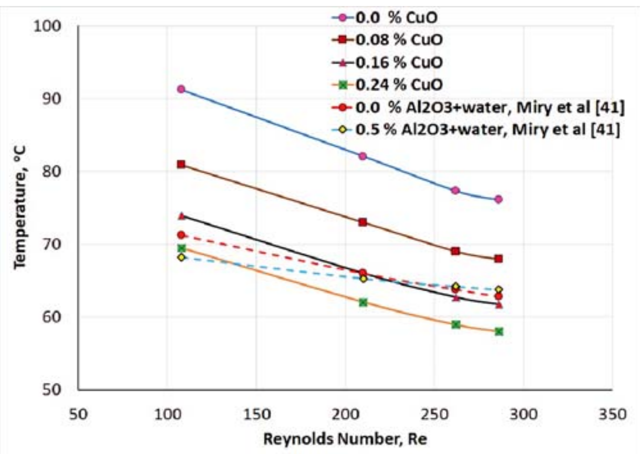

Figure 9. The influence of Reynolds number on the temperature of the contact surface between aluminum block heater and heat sink, for nanofluid-coolants with different nanoparticle % volume fractions (Present study versus Miry et al.[41])

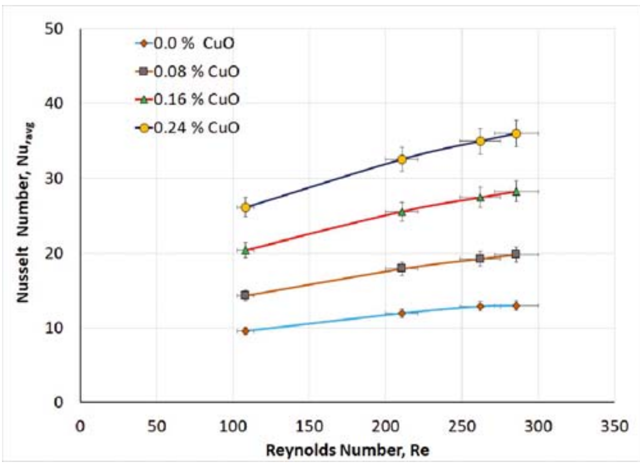

Figure 10. Nusselt number distribution versus Reynolds number for different CuO % volume fractions

In Figure 11, Nusselt numbers distribution versus CuO % volume fraction is given at different Reynolds numbers. The behavior of Nusselt numbers versus CuO% volume fraction has shown that the cooling rate of the situation using the nanofluids is greater than the value obtained using the base fluid. Besides, Nu numbers increase with the increment of CuO% volume fraction. The increment has been explained by Saadoon et al. with the higher thermal efficiency of nanofluids than that of water and an increase in the heat conduction contribution to the total energy. The enhancement of total energy is attributed to the collision rate of the nanoparticles with the increment in CuO nanofluid concentration, which enhances the Brownian motion of the nanoparticles in the nanofluid, and the heat conductivity of the nanofluid[42].

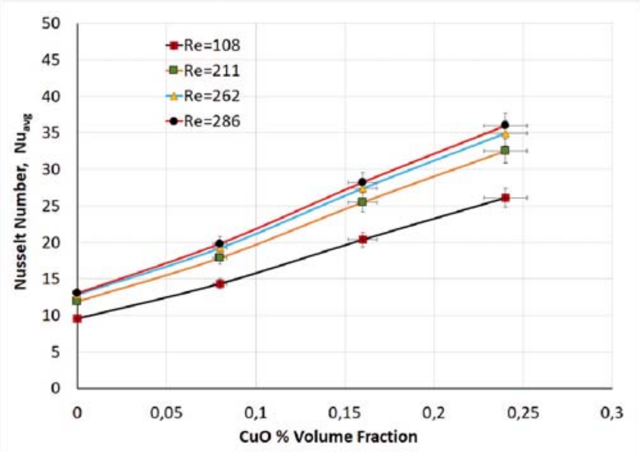

Figure 11. Nu number distribution versus CuO % volume fraction in the nanofluids, for different Reynolds Number

Sadoon et al.[42], in their mini-channel heat sink study, which has minichannels with different wave amplitudes and geometry, determined the effects of wave amplitude and different nanofluid types on the heat sink performance. A detailed comparison of the present study results with the results of the study done by Saadoon showing the effect of CuO % volume fraction on the Nusselt number's distribution is given in Figure 12. According to the graph, the Nusset number distribution observed in the 0.025–0.075 range of CuO % volume fraction in the CPU cooling study carried out by Saadoon et al, is similar to the distribution obtained in the present study for CuO nanofluid and that overlapped with the curves also[42].

The heat energy absorbed by the heat sink versus the energy produced by the CPU for different composition's coolants was graphed by considering the data at the 20th minute, and the Re is 286 in Figure 13(a–d). For the first

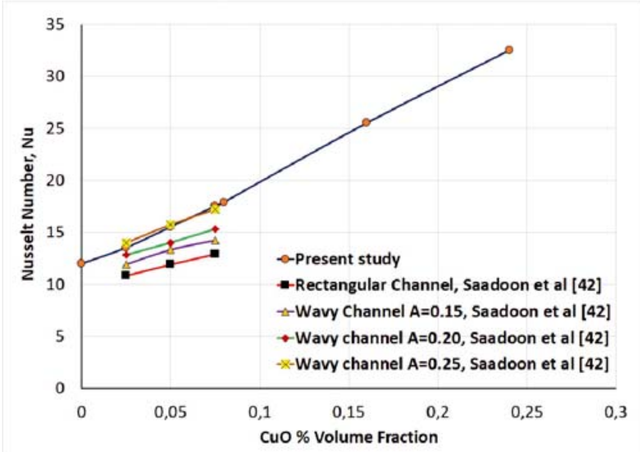

Figure 12. Nu number distribution versus the CuO % volume fraction in the nanofluids, at Reynolds number of 210 (Present study results versus Saadoon et al.[42])

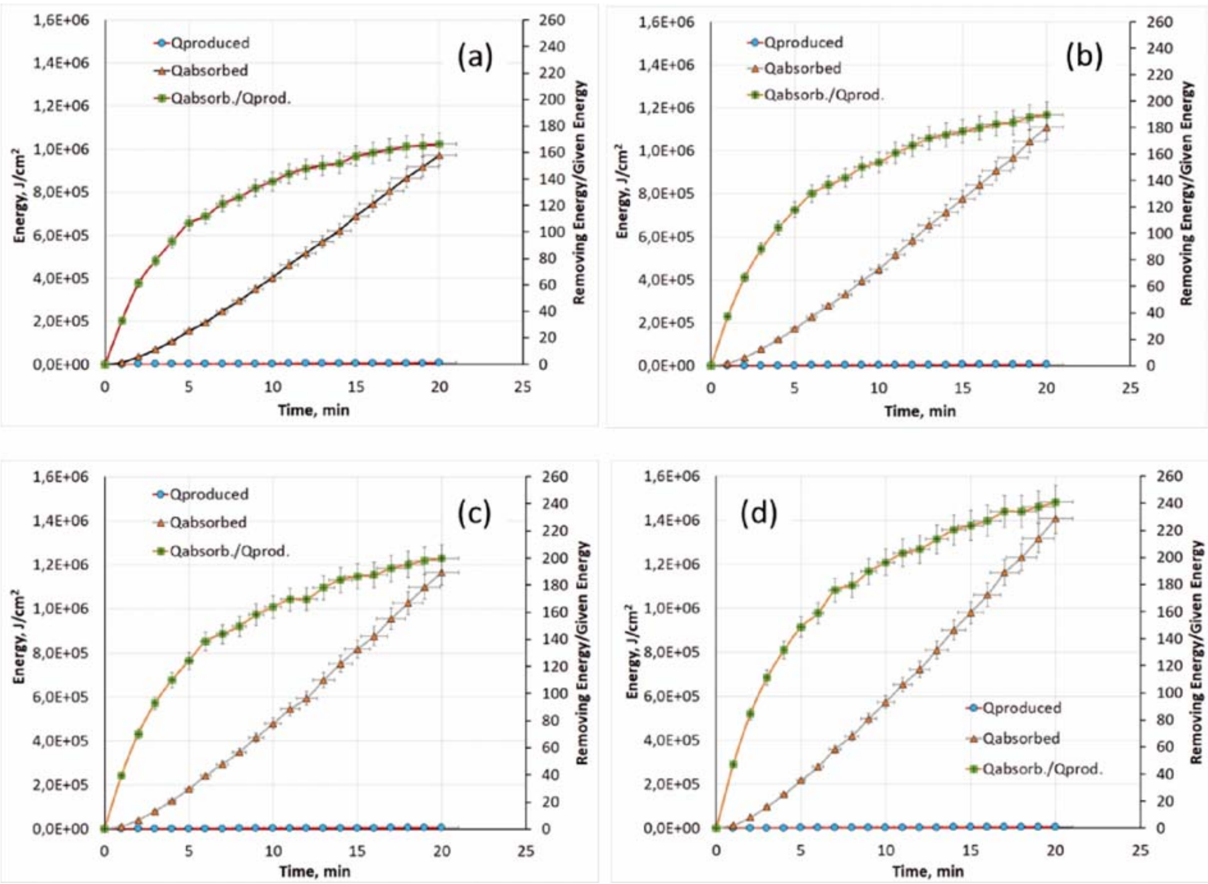

Figure 13. The absorbed heat energy by the heat sink versus the produced energy by the CPU for different coolant mixtures at Re of 286: (a) Coolant with 3% EG with water; (b) Nanofluid-coolant containing water, 3% EG, and 0.08% CuO nanoparticle, (c) Nanofluid-coolant containing water, 3% EG, and 0.16% CuO nanoparticle; (d) Nanofluid-coolant containing water, 3% EG, and 0.24% CuO nanoparticle

coolant composed of 3% EG with water, the absorbed heat is 166 times higher than the produced heat, and heat flux value is 810 W/cm^2. For the second coolant composed of water with 3% EG and 0.08% CuO, this value is 190 times higher, and heat flux value is 925 W/cm^2. That value is 200 times for the third coolant composed of water with 3% EG and 0.16% CuO, and heat flux value is 975 W/cm^2. This value is 241 times for the fourth coolant composed of water with 3% EG and 0.24% CuO, and heat flux value is 1175 W/cm^2.

By considering that the power density of the new-generation CPUs[6] under normal operating conditions is 150 W/cm^2, the heat sink with 810 W/cm^2 heat flux (min. value) at Re 286 is sufficient for cooling the new-generation CPUs (Fig. 13a). However, the power density of the new-generation CPUs under normal operating conditions is 150 W/cm^2, and the cooling flux value of the heat sink (max. value) at Re 286 is 1175 W/cm^2 (Fig. 13d), the developed heat sink has eight times faster cooling capacity.

CONCLUSIONS

In this research, the heat sink with high thermal performance, and the capability to lower the CPU temperature very quickly when needed is tried to be developed. Using this heat sink, it has been tried to test whether heat can be absorbed in high fluxes or not, without having to worry about energy consumption for liquid pumping. According to the results, heat dissipates from the surface of the minichannel-fins, more efficiently than those of conventional fins, allowing for higher cooling rates. Within the scope of the research, after the determined parameters have been tested following conclusions have been reached:

The overall performance of the heat sink increases by enhancing nano-sized particle volume fraction and Reynolds number in the minichannels.

As a result, the produced heat sink in the present research is adequate for heat management of the new-generation CPUs and so, they can operate in a safe temperature range. The cooling performance of the produced heat sink is higher than a lot of heat sinks in the literature aside from impinging jet heat sink.

The heat sink has a large number of fins and thus sufficient heat transfer surface area, and the mass flow rate of coolant in the minichannel-fins is enough. However, because a fast enough cold airflow couldn't be provided across the outer surface of the minichannel-fins in the experiments, the heat removal flux could not exceed the value of 1175 W/cm^2, at Reynolds number of 286 and for coolant containing 3% EG with water and 0.24% CuO nanopowder.

Thanks to the used minichannel-fins, the temperature gradient between the surface of fin and the airflow has been kept at the maximum value along the fins. The CPU temperature decreased from 135 to 76°C for water with 3% EG in 20 minutes at a Reynolds number of 286. For the coolant, which consists of water with 3% EG and 0.24% CuO, the CPU temperature decreased from 135 to 58°C in 20 minutes at a Reynolds number of 286.

It has been found that the heat removal flux of the heat sink has increased from 660 to 810 W/cm^2 depending on the Reynolds number increase from 108 to 286 for water with 3% EG in 20 minutes. The cooling flux of the heat sink has increased from 927 to 1175 W/cm^2 depending on the Reynolds number increase from 108 to 286 for a coolant containing 3% EG with water and 0.24% CuO nanoparticle. At the end of 20 minutes and with the highest Re number value of 286, the heat removing flux of the heat sink has increased from 810 to 1175 W/cm^2 due to the increase in CuO load of the coolant fluid from 0 to 0.24.

Pressure drop in the heat sink has increased depending on the increment of Reynolds number and CuO volume % fraction. Heat flux withdrawn from the CPU for 15 minutes has increased depending on increased pressure drop and reached the value of 1106 W/cm^2 at the pressure drop of 472Pa. At the end of the 20th minute, the heat energy withdrawn from the CPU was found to be 241 times more than that of the produced, for water with 3% EG+ 0.24% CuO at the flow conditions of Reynolds number 286.

In addition, considering that the increase in Re number and CuO volume concentration will increase the pressure drop and accordingly the pump power, the nanofluids with relatively low CuO concentrations were chosen as a coolant and worked at low Re values. These measures are advantageous in terms of the life of the pump.

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NOMENCLATURE

CPU	– Central Processing Unit
EG	– Ethylene glycol
Nu	– Nusselt number
W_{Re}	– the maximum uncertainty in the Re
W_{Nu}	– the maximum uncertainty in the Nu
h	– Heat transfer coefficient (W/m_2K)
Q	– Heat transfer rate from total surface (J/s)
k	– Thermal conductivity (W/mK)
k_{eff-nf}	– Effective thermal conductivity of the nanofluid (W/mK)
D	– Diameter of mini channel (m)
L	– Length of mini channel (m)
T	– Temperature
ρ	– Density (kg/m^3)
ρ_o	– Density of base fluid (kg/m^3)
μ_b	– Dynamic viscosity of fluid at bulk temperature (Pa · s)
P	– Particle properties
o	– Base fluid properties
Re	– Reynolds Number in minichannel
Pr	– Prandtl number
rpm	– Rotational per minute
W_q	– the maximum uncertainty in the q
T_b	– temperature at the base of the fin

q – Heat flux (W/cm^2)
A – Amper (A)
D_h – Hydraulic diameter (m)
K – Kelvin degrees (K)
W – Watt (J/s)
C_p – Heat capacity (J/kg K)
R^2 – Correlation coefficient
∅ – volume % fraction of CuO nanoparticles
μ_0 – Dynamic viscosity of fluid at wall temperature (Pa · s)
η – Fin efficiency
nf – Nanofluid

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