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A new design for a heat sink within a convex-parabolic microchannel filled with hybrid nanofluid for cooling Core I7 CPU

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Abstract

CPU computes several complex algorithms at billions of cycles per second. It is acceptable to generate some heat while working at such great speed. In order to reduce the problem of high temperature, which slows down the performance of tasks, a new heat sink with convex-parabolic fins was designed to study the best heat dissipation methods to reach the cooling efficiency of the processor so that it performs all tasks without any problems. On the other hand, the new heat sink was cooled by the hybrid nanofluid, and all the equations governing the phenomenon were solved by the finite volume method, and the results were reported at Reynolds numbers and fin numbers. From the results, the cooling efficiency was improved by 74% when a large number of fins were used. Besides that, the maximum temperature of the heat sink decreases by increasing the number of convex-parabolic fins, giving the processor a cool surface to perform tasks without having to fear the problem of overheating. The results of this study can be used for the initial design of the heat sink and the improvement in the efficiency of cooling the Core I7 CPU.

Keywords Overheating · CPU · Cooling efficiency · The heat sink · Convex-parabolic · Numerical simulation

List of symbols

Cp	Heat capacity specific (J K^{-1})
D_h	Diameter hydraulic (m)
f	Friction factor (–)
H	Height (m)
L	Channel length (m)
k	Thermal conductivity (W m^{-1} K^{-1})
Nu	Number of Nusselt (–)
p	Pressure (N m^{-2})
P	Dimensionless pressure (–)
T	Temperature (K)
Pr	Number of Prandtl, ϑ_f/α_f (–)
R	Thermal resistance (K W^{-1})
Re	Number of Reynolds (–)
S, A	Surface (m^2)
U, V	Velocity component dimensionless (–)
u, v	Velocity components/(m s^{-1}) (–)
X, Y	Dimensionles Cartesian coordinates/(m) (–)
x, y	Coordinates of Cartesians/(m) (–)

Greek symbols

ϕ	Volume fraction of nanofluid (–)
μ	Viscosity dynamic (Pa s)
ϑ	Viscosity kinematics (m^2 s^{-1})
ρ	Density (Kg m^{-3})
θ	Dimensionless temperature (–)
α	Diffusivity of heat (m^2 s^{-1})

Indices

f	Fluid (–)
avg	Average (–)
NF	Nanofluid (–)

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Introduction

The various industrial revolutions that the world witnessed led to a significant development from the first industrial revolution to the fourth, as the latter led to the integration of many technologies that, in turn, removed the lines between digital and physical fields, which was characterized by the penetration of technology in many fields. In light of this development, the world needs high-speed and performance electronic devices with robust and small sizes [1–5]. As a result of the rapid development of devices that the world has witnessed, it has created many problems that cannot be overlooked. The most important of these major problems is the generation of high heat, which, in turn, slows performance and reduces the lifespan. It has become essential to remove or reduce heat by employing a variety of different cooling technologies; this is in order to preserve performance and lifespan [6–10]. Where this problem created clear and great competition between manufacturers and researchers to discover the best methods of cooling in various ways, such as the traditional methods of cooling that depend on air and forced and natural convection, where this method is characterized by being inexpensive and easy to use, and when talking about its disadvantages, it is unable to increased heat flow dissipation in the electronic components [11–14]. This made many researchers discover several solutions, most notably the use of single and hybrid nanofluids as cooling fluids [15–22], and they also developed heat sinks used in high-speed electronic components [23, 24]. Among the many proposed ideas were increasing the heat exchange area. Still, this idea created another problem: More space will be used in the devices, and the proposed ideas should be included with new technologies that can be considered a practical solution. The idea of placing long fins in a rectangular shape has gained the attention of many researchers in their numerical and experimental studies. Yu et al. [25] compared the thermal productivity of a heat sink to another whose spaces contain circular pins to increase the heat exchange resistance, as the thermal resistance was lowered by 30% in the new geometry containing circular pins, and Yuan et al. [26] also made another study for the same geometry but for different heat flows. Their results showed that engineering gives lower thermal resistance and a higher pressure drop rate. Li et al. [27] studied another form of the heat sink that contains the fins, where he studied the thermal performance of the heat sink that contains the fins in a Y shape. According to his findings, the straight heat sink performed significantly worse than the one with Y-fins. The increasing need to improve cooling has led to using water and nanofluids as an alternative to air. In the microfluidic channel, Gui-Fu Ding et al. [28], an experimental and numerical study examined the friction and heat transfer of triangular, semi-circular, and rectangular ribs to improve heat exchange. They discovered that the rib's form significantly impacts friction properties and heat exchange. In another study on the shape of the ribs presented by Navaei et al. [29] examine the impact of three forms of ribs (semi-circular, trapezoidal, and rectangular) on the heat transfer inside the heat sink using nanofluids; the results they reached showed that the ribs with a semi-circle shape have a higher Nusselt number. Hongtao et al. [30] studied the effect of three geometry shapes of heat sink channels (triangular cross-sectional, trapezoidal, and rectangular), and the results showed that heat transfer and flow of heat sink are affected by the microchannel shape. Abed Ammar et al. [31] studied four forms of microchannels inside the heat sink (without notches, two notches, four notches, and six notches) and found that the heat transfer coefficient and the Nusselt number were the highest in the two notches channel. A copper heat sink with a rectangular and semi-cylindrical form, low pressure, and heat exchange was studied by Zunaid et al. [32], where the heat sink was cooled by water. The results showed that the semi-cylindrical heat sink has a higher heat exchange. Jadhav et al. [33] studied the effect of fin shapes in a microchannel (circle, square, hexagon, and ellipse), where they found that the number of Nusselt increases with the increase in the height of the fins, and the velocity of entry of the coolant and the best heat exchange was for the square pin. In the same year, Jadhav et al. [34] also presented another study of the microchannel with three schematics of oval-shaped fins and found that heat exchange is better when guiding the worm's tangled fin. In a hexagonal fin fractal channel, the heat sink's thermal performance was studied by Yang et al. [35], they found that the angle of ramification plays an important role in the temperature and that the temperature decreased. Kumar et al. [36] numerically studied the thermal resistance and heat transfer rate in the heat sink containing six circular channels filled with water and nanofluids. They noticed that using nanofluids as a cooling fluid reduced the electronic chip's energy consumption and thermal resistance. In electronic devices with high heat fluxes, many researchers [37–39] have conducted experimental studies in order to improve their cooling, as the results obtained showed that the rate of heat transfer increases, which coincides with a decrease in pressure. Mangalkar et al. [40] also made a review of the cooling of electronic components using nanofluids, where they concluded that with increasing nanoparticles, the rate of heat transmission improves. Kamel Chadi et al. [41] made a numerical investigation of three cases of heat sink with parallel sides and one case without sides with changed the position of the parallel side in the three mentioned cases, and the microchannels were filled with nanofluid, and from the results obtained, it was found that the coefficient of friction decreases with increasing Reynolds number. The computer's central processing unit (CPU) is an indispensable electronic component, especially since it is the computer's brain. From a scientific standpoint, the more influential the processor, the faster the processing of data and the more efficient the system. In this regard, Bayomy et al. [42], an experimental and numerical study was conducted on a processor I7, using water as a coolant. The results were compared with those in the literature that used air for cooling. They found that using water for cooling gives higher heat transfer than air and lower temperature on the surface. Several years later, a numerical study was presented by Wang et al. [43] for three different heat sink designs for the I7 processor, where the hybrid nanofluid was used as a cooling fluid instead of using water and air as cooling fluids. The surface of the diffuser compared to the non-foam design.

The process of high temperature of electronic components due to its use for extended periods leads to slow use and damage to its components, especially the central processing unit (CPU), which generates heat during operation, where the high temperature in the absence of cooling leads to the accumulation of excessive heat and thus reduce both efficiency and performance. Traditional cooling methods, such as fans, create additional thermal resistance and consume energy, which may hinder heat dissipation and raise temperatures for other components. Therefore, it is not excluded that their results will be counterproductive; this made many researchers interested in quick ways to dissipate heat from these components.

Although there are various researches on increasing the heat transfer rate with the help of different heat sink configurations and technologies, the effect of convex-parabolic fins and hybrid nanoparticles on the cooling performance of I7 CPU has not yet been studied. Consequently, this study focuses on enhancing the Core I7 CPU's cooling efficiency by using a new design of convex-parabolic fins and multi-walled carbon nanotube–Fe_3O_4/water. To achieve the aim of the study, the new heat sink was designed and considered the effect of convex-parabolic; it was proposed to enhance heat exchange and cooling efficiency in Core I7 CPU. Several parameters will be discovered, such as Reynolds number, the efficiency of the hybrid nanofluids on cooling, and the number of fins.

Describing the model and modeling

Based on the traditional heat sink used in the CPU I7, the new heat sink was designed and placed on the same processor in order to improve the heat dissipation generated by the processor. Figure 1a shows the heat sink that was studied, and the study was conducted taking into account the four models of the shape of the heat sink channels, where the convex-parabolic fins of the microchannels are observed in Fig. 1b. The heat sink and processor were cooled based on the hybrid nanofluids (multi-wall carbon nanotube–Fe_3O_4). The thermal properties of the nanofluid were taken from the reference [44]. Processing unit (CPU) Core I7 size, 37.5 mm × 37.5 mm, was chosen as the heater's dimensions; the microchannel dimensions for all its forms were 10 mm × 37.5 mm, and the thickness of the solid layer of the dispersant and the microchannel is 0.5 mm. This research employs many physical equations, including the energy equation, the continuity equation, and the momentum equation.

The equations governing 3D steady-state laminar convection may be written in dimensionless form after ignoring viscous dissipation, thermal conduction, and radiation [45].

$$\nabla(\rho\overrightarrow{V}) = 0 \tag{1}$$

Momentum equations:

$$\rho_{\mathrm{nf}}(\nabla\overrightarrow{V})\overrightarrow{V} = -\nabla P + \mu_{\mathrm{nf}}\nabla^2\overrightarrow{V} \tag{2}$$

Energy equation:

$$\overrightarrow{V}\nabla T = \alpha_{\mathrm{nf}}\nabla^2 T \tag{3}$$

where $\alpha_{\mathrm{nf}} = k_{\mathrm{nf}}/\left(\rho C_p\right)_{\mathrm{nf}}$.

The heat conduction through the solid wall can be written as follows:

$$\nabla^2 T = 0 \tag{4}$$

Furthermore, the number of Reynolds (Re), Prandtl numbers (Pr), and diameter hydraulic are expressed as follows:

$$\mathrm{Re} = \frac{U_0 D_{\mathrm{h}}}{\vartheta_{\mathrm{f}}}, \mathrm{Pr} = \frac{\mu C_{\mathrm{p}}}{k}, D_{\mathrm{h}} = \frac{4S}{p} \tag{5}$$

where U_0, ϑ_f, S, p are the inlet velocity, kinematic viscosity, surface of section, and perimeter, respectively. The following equation is used to determine the average Nusselt number, which describes the nanofluid flow:

$$\mathrm{Nu}_{\mathrm{avg}} = \frac{h_{\mathrm{avg}} \cdot D_{\mathrm{h}}}{k} \tag{6}$$

$$h_{\mathrm{avg}} = \frac{q_{\mathrm{w}}}{(T_{\mathrm{w}} - T_{\mathrm{nf}})} \tag{7}$$

where h_{avg}, T_{w}, and T_{nf} are the heat transfer coefficient, surface, and nanofluid average temperatures, respectively.

To evaluate the cooling efficiency with another parameter, the thermal resistance can be calculated [46]:

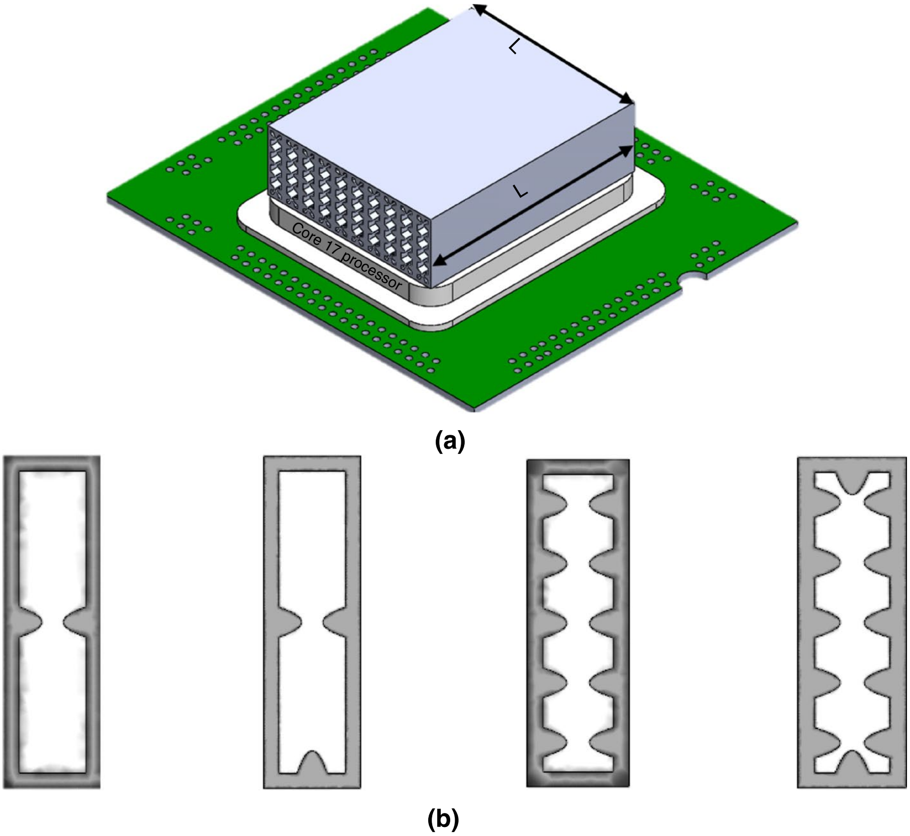

Fig. 1 A schematic view of **a** the heat sink and **b** the different types of convex-parabolic fins

$$R = \frac{T_{\max} - T_{\mathrm{in}}}{q_{\mathrm{w}} A_{\mathrm{w}}} \tag{8}$$

where $T_{\max}, T_{\mathrm{in}}, A$ are the maximal, inlet temperatures, and area, respectively. To give information regarding the required pressure drop in the heat exchanger, the dimensionless number fanning friction factor (f) is as follows [47]:

$$f = \frac{\Delta P \cdot D_{\mathrm{h}}}{2\rho_{\mathrm{nf}} U_0^2 L} \tag{9}$$

The following items were the boundary conditions as considered for numerical simulation:

- The inlet, the used coolant, enters at a constant velocity and temperature of 293.15 K.
- For the outer wall, the boundary condition was applied as a no-slip wall.
- The heat produced by the CPU is continuously emitted into the bottom side of the microchannel at a rate of 138 kW m^{-2}.
- The pressure outlet was taken into account in the output section.
- The sidewall symmetry condition was used.

Numerical approach

To evaluate the performance of the suggested heat sink, a numerical analysis was performed using the CFD code ANSYS FLUENT, which contains convex-parabolic fins, on cooling the processor. All the physical equations (continuity, energy, and momentum) governing the phenomenon have been solved by the finite volume method. The semi-implicit schemes for pressure-connected equations (SIMPLE) connect the continuity and momentum equations. The convection terms are spatially discretized using nonlinear upstream interpolation convection dynamics (the second-order upwind approach). The grid mesh was examined for the study at several elements, with tests conducted at Reynolds values $\mathrm{Re} = 1000$ and for convex-parabolic fins $n = 2$. In order to determine the average Nusselt number, four cases with different element numbers were considered, as shown in Table 1. The highest number of elements was selected to perform the numerical simulation of all convex-parabolic fins of microchannels used in this study in order to give accurate values for all physical variables. Figure 2 shows that the grid mesh G4 was calculated with 6,287,154 triangular elements used in this study, where Fig. 2a shows the solid zone, and Fig. 2b shows the fluid zone.

Table 1 The grid independence test for configuration

Grid type	Nu_{avg}	Error/%
G1(706,328)	41.3998	2.9373
G2(735,199)	43.8015	2.6934
G3(1,529,426)	44.5228	4.3845
G4(6,287,154)	42.65267	–

In order to verify the validity of the proposed numerical study of the best heat dissipation methods and the best performance of the processor, and according to several studies, the experimental and numerical studies by Tawk et al. [48], the validation was done by comparing the maximal temperature for different heat fluxes on the length of the channel illustrated in Fig. 3a.

Another validation was made with another numerical study conducted by Wang et al. [43] illustrated in Fig. 3a. According to the results obtained and after comparing them with those in the literature, there is a good agreement between the results.

Results and discussion

In this study, in order to cool the CPU I7 and improve the efficiency of the finned heat sink, the microchannels were filled with the multi-wall carbon nanotube–Fe3O4 hybrid nanofluid. The heat sink was exposed to a constant heat flow of 138 kW m^{-2}. The used fins were placed in several models and numbers in order to study the effect of adding them on the thermal efficiency and cooling of the processor. The results were reported for several parameters, such as Reynolds number (250–1000) and numbers of fins (2–12). The problem of high CPU temperature and reaching its maximum value is one of the most critical problems faced by the user because it negatively and significantly affects the performance and speed of the processor; that is, the higher the processing power of tasks, the higher the temperature of each core in the processor, and in order to reduce it and not damage the processor and stop it. In work, the value of electrical energy decreases, as this decrease leads to poor performance and therefore a longer time to perform tasks, as manufacturers have developed processors in light of technological development so that processors have higher performance in tasks, but the purchase cost is expensive. When a suitable cooling system is created, the less cheap CPUs may attain optimum processing efficiency.

From it, Fig. 4 shows the change in temperature for all four cases at the Reynolds number 1000, as they were considered at equal positions; it can be seen that the change in temperature at the largest number of fins (ε = 12) is less than the minimum number of fins (ε = 2).

The number of fins from $\varepsilon = 2$ to $\varepsilon = 12$ plays an important and useful role in dissipating heat on the processor's surface. This gives an increase in processing tasks and

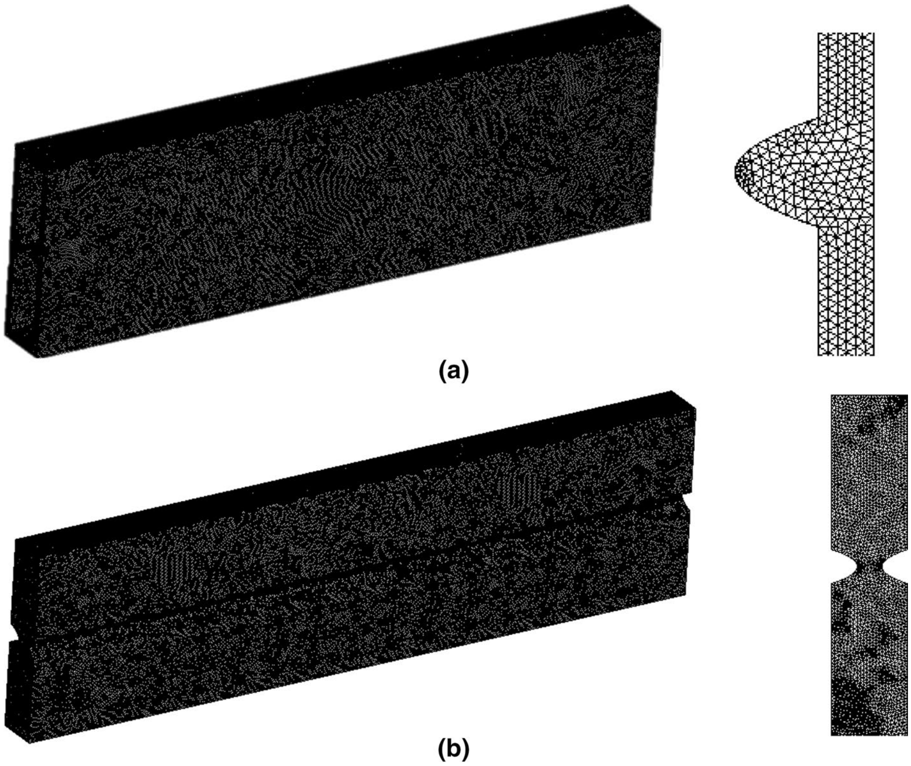

Fig. 2 Grid distribution (**a**) solid zone and (**b**)fluid zone

processing efficiency and also shows the lines of temperature change in all cases a marked decrease compared to the study conducted by Wang et al. [43], where the decrease in temperature at $\varepsilon = 2$ was about degrees 10°, while at $\varepsilon = 12$, the value of the decrease was 15°.

Figure 5 shows the velocity field along the microchannel for the four cases; it is clear from the figure that the greater the number of fins, the greater the velocity value. The value of the flow within the channel contrasts what we observe at $\varepsilon = 2$ and $\varepsilon = 3$. So that the fluid movement for $\varepsilon = 10$ and $\varepsilon = 12$ is slower compared to $\varepsilon = 2$ and $\varepsilon = 3$.

Figure 6 shows the thermal performance of the heat sink for the different Reynolds numbers and the numbers of fins. It can be seen that with the increase in the number of fins, the average Nusselt number and the Reynolds number increase. It can be seen from the figure that the maximum value of the average Nusselt number was at $\varepsilon = 12$, and when compared with the standard case (without porous) by Wang et al. [43], the percentage of increase in the average number of Nusselt was 45%, while the percentage at $\varepsilon = 2$ was 6%.

Figure 7 shows the thermal resistance of the heat sink with convex-parabolic fins, for the different Reynolds numbers and the numbers of fins. It is clear from the figure that the higher the Reynolds number, the lower the thermal resistance, and this is due to the velocity of the hybrid nanofluid flowing inside the microchannels. On the other hand, it is clear that the greater the number of fins, the lower the thermal resistance. Besides, the cooling efficiency and processor performance improved by 74% at the number of 12 fins; this improvement was significant compared to the cooling efficiency of the heat sink studied by

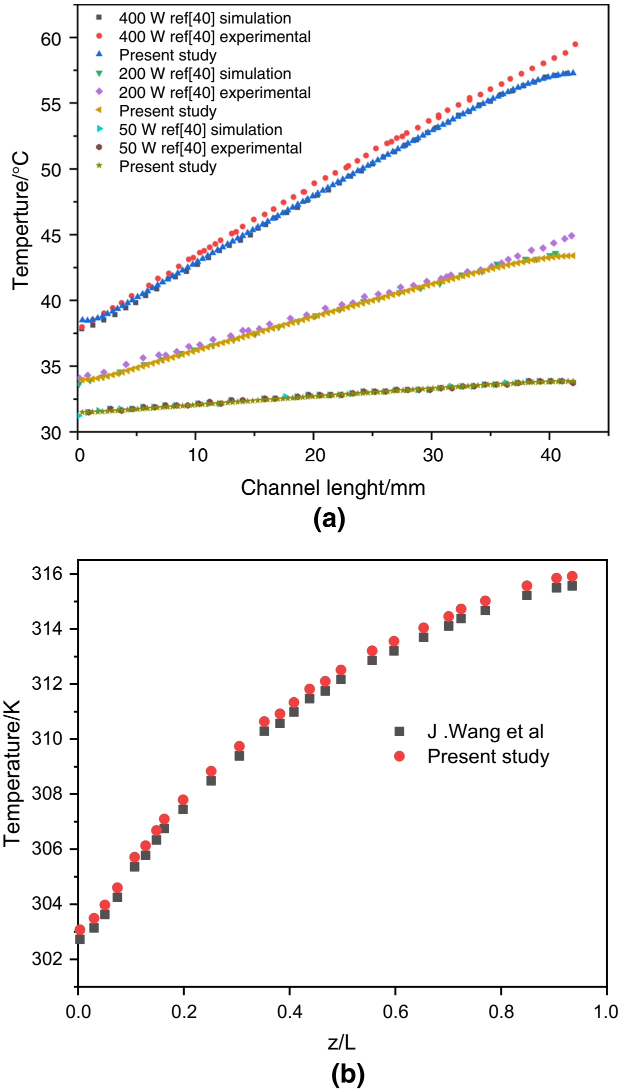

Fig. 3 Validation of numerical study for the present study with results (**a**) experimental and numerical study by Tawk et al. [48] and (**b**) numerical study by Wang et al. [43]

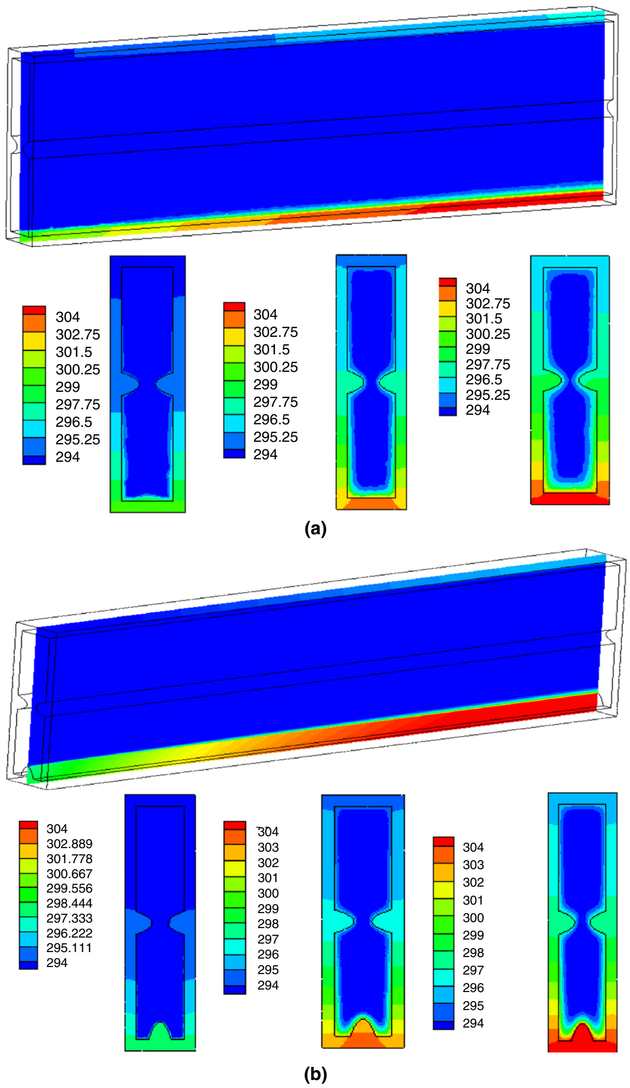

Fig. 4 Temperature contours for Re=10^3 **a** $\varepsilon = 2$, **b** $\varepsilon = 3$, **c** $\varepsilon = 10$, and **d** $\varepsilon = 12$

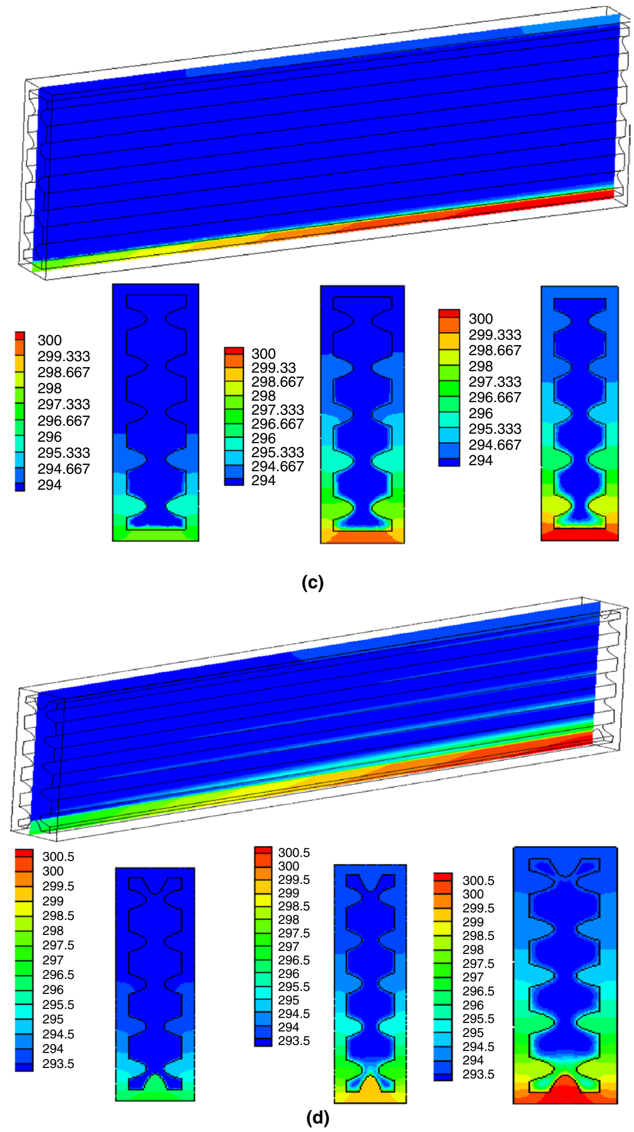

Fig. 4 (continued)

Wang et al. [43], and from here, it can be said that the heat sink with convex-parabolic fins is much better in terms of cooling efficiency and performance.

The friction coefficient of the hybrid nanofluid is shown in Fig. 8 for different numbers of fins and Reynolds numbers. The friction coefficient of the hybrid nanofluid within the microchannels of the heat sink decreases with the increase in the number of Reynolds and the number of fins.

Besides, the relationship between the coefficient of friction and the Reynolds number is inverse, and due to the increase in the flow velocity of the hybrid nanofluid as a result of enhancing the Reynolds number, the value of the friction coefficient decreases.

Figure 9 shows the maximum temperature of the heat sink with convex-parabolic fins. The effect of the presence of the fins on the heat reduction is quite clear; the increase in the number of fins increases the average Nusselt number and thus increases the heat transfer on the surface of the processor,

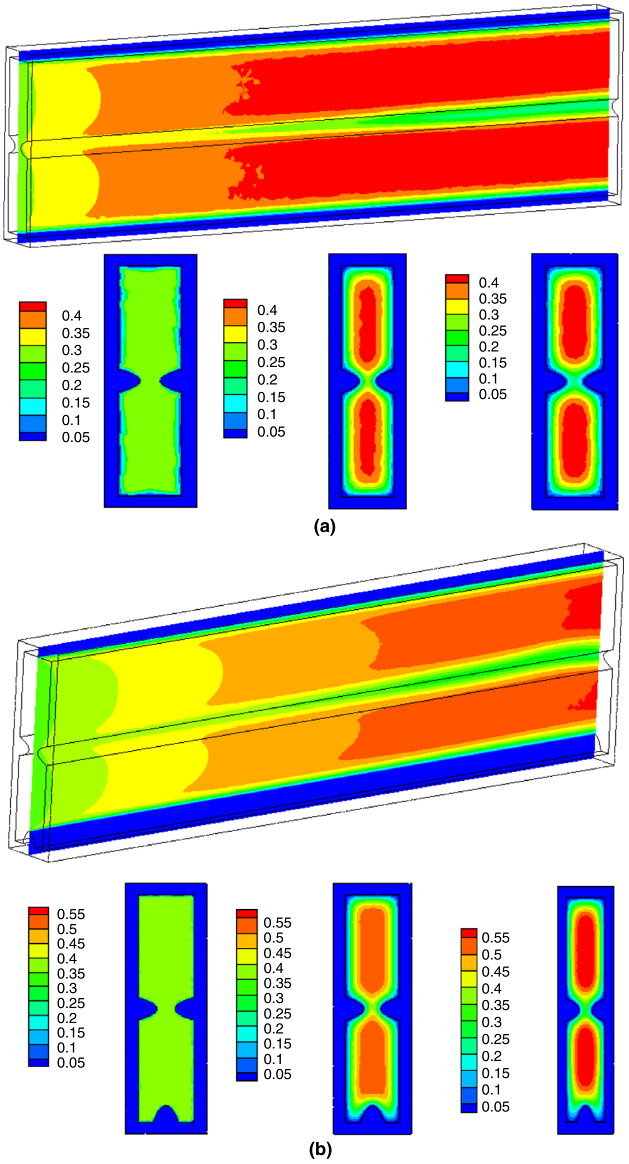

Fig. 5 Velocity contours for Re=10^3 **a** $\varepsilon = 2$, **b** $\varepsilon = 3$, **c** $\varepsilon = 10$, and **d** $\varepsilon = 12$

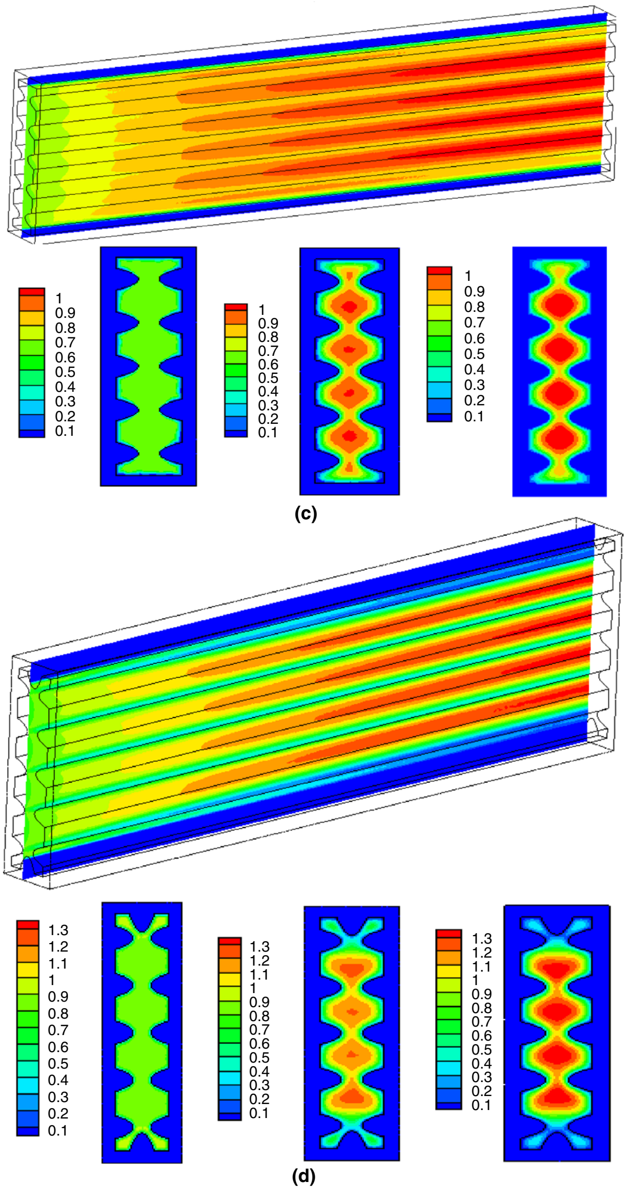

Fig. 5 (continued)

and also, it can be noted that the increase in the number of fins increases cooling efficiency. On the other hand, the heat sink with more fins $\varepsilon = 12$ provides a cooler surface for the processor. According to the rule of thumb, the life expectancy of electronic components is reduced by up to 50% for every 10° increase in temperature. In addition to enhancing CPU performance, reducing the heatsink's base temperature, which increases CPU cooling, extends the CPU's life.

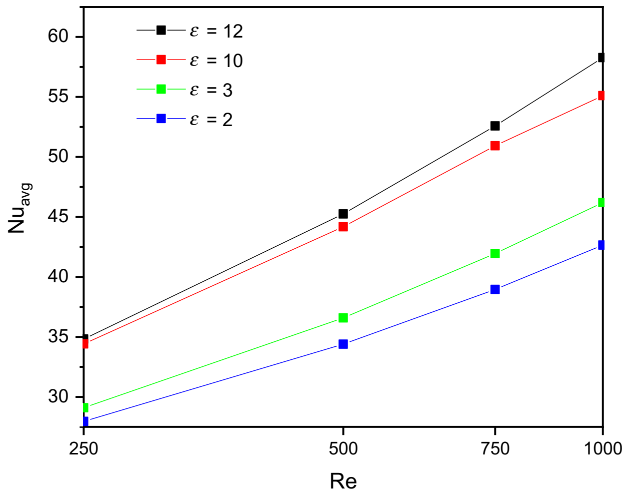

Fig. 6 The average Nusselt number for different Reynolds numbers and the numbers of fins

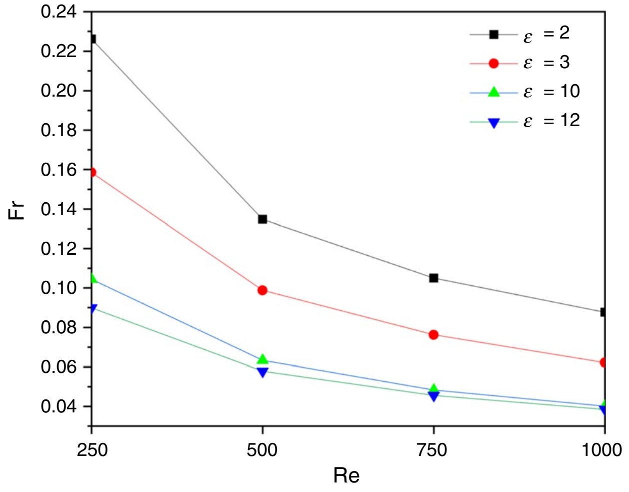

Fig. 8 The friction coefficient for different Reynolds numbers and the numbers of fins

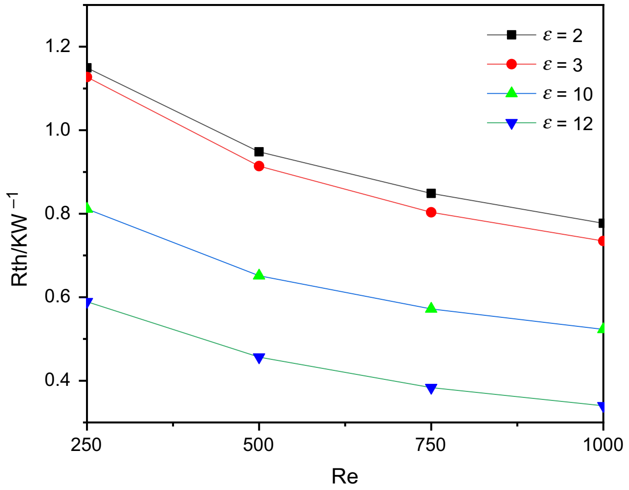

Fig. 7 The thermal resistance for different Reynolds numbers and the numbers of fins

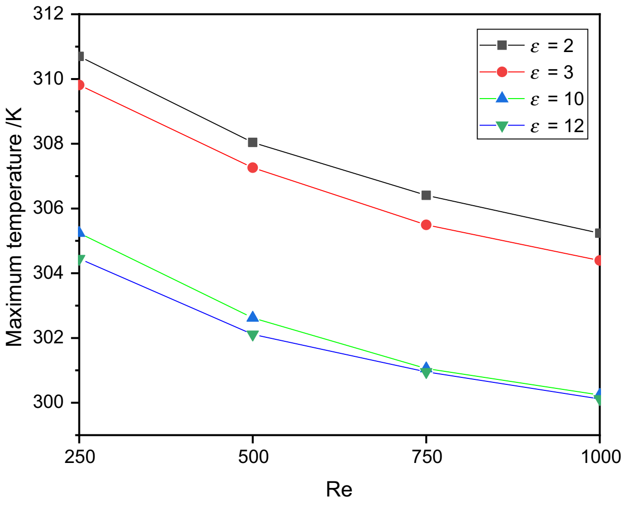

Fig. 9 Maximum temperature for different Reynolds numbers and the numbers of fins

Conclusions

For low-cost processors with high cooling efficiency to perform complex tasks and to reduce the problem of overheating, a 3D simulation of the heat sink with convex-parabolic fins was performed in order to study the cooling efficiency of Core I7 CPU where the heat sink was cooled using a multi-wall carbon nanotube–Fe3O4 hybrid nanofluid, the effect of each of the Reynolds numbers and the number of convex-parabolic fins inside the microchannel of the heat sink were studied, and the study was conducted using the finite volume method.

The most important results can be summarized as follows:

1. The heat sink with fins gives high cooling efficiency compared to the traditional heat sink.
2. The thermal resistance of the heat sink was affected by the number of fins and Reynolds numbers.
3. The coefficient of friction decreases with increasing Reynolds number.
4. The number of Nusselt increased with the number of convex-parabolic fins and the number of Reynolds.
5. The maximum temperature of the heat sink decreases by increasing the number of convex-parabolic fins, giving the processor a cool surface to perform tasks without having to fear the problem of overheating.

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