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RESEARCH ARTICLE

Numerical Investigation of Heat Transfer Characteristics on Differential Square Fin Heat Sinks

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HIGHLIGHTS

- Differential fin geometries were created according to Reynolds numbers of the impinging jets sent on the plane plate.
- Differential fins were shown to have a significant effect on the temperature gradients on the surface.
- The differential fin design enabled 30% saving on the fin material whereas the temperature gradient on the surface was shown to be significantly lower compared to plane plate.

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ABSTRACT

In this study, the temperature distribution on the square fin heat sink with differential fin distribution was numerically investigated. Numerical analysis was performed with ANSYS-Fluent package program and k-Ɛ turbulence model. The heat transfer performance realized on fixed nozzle-heat sink distance (35 mm) and three different Reynolds numbers (4000-8000-12000) on heat sinks with fins and plane surfaces were examined. Air at 20°C was used as the fluid and 1000 W/m2 heat flux applied to the heat sink. In the study, temperature contours showing the temperature distribution on the heat sink and streamline images in which the turbulence formation caused by the fins on the heat sink surface were observed. As a result, it was determined that the differential square fins cause a more homogeneous temperature distribution on the heat sink compared to the plane plate. The heat transfer coefficient from the heat sink surface was determined as h=159,3 W/m2K at the highest Reynolds number. The Nusselt number does not increase much with the increase of the Reynolds number in the differential fins.

Contents

1. Introduction

In recent years, with the development of technology, the dimensions of electromechanical systems have decreased and accordingly the amount of heat load they are exposed to has increased. With the increasing heat flux load, the systems have reached higher temperature levels. Joint temperatures of systems exposed to high heat flux increase, operating performance decreases and their economic life decreases. For this reason, it has become necessary to use thermal control systems in order for electromechanical systems to work efficiently and effectively [1].

Different cooling methods such as impinging air jet [2], liquid jet [3], channel flow [4], micro channels [5], micro pumps [6] and spray cooling [7, 8] are used for thermal

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control of systems exposed to high heat flux. The impingement jet stands out as an advantageous cooling method due to its easy use, high cooling performance and wide area of use [9, 10].

The impingement jets are used in many areas such as cooling gas turbine blades, defrosting aircraft wings, cooling electronic components, glass tempering, paper drying and textiles [11, 12].

In impinging jet cooling, as the fluid sent from the nozzle hits the cooled surface, the boundary layer decreases and the heat and mass transfer from the surface increases. In this way, an effective cooling is achieved in the impact area [9, 13, 14].

In the literature, there are many studies on effective parameters in impinging jet cooling. Yakut et al. [15] investigated the effect of different jet speeds impinged on the heat sink with 100-150-200 mm high heat fins on the heat transfer in their experimental and numerical study. As a result, they determined that the amount of heat transfer increased with the increase in fin length and flow rate. Lee et al. (2014) investigated the variation of the heat transfer on the heat sink by the impinging jet according to the Reynols number and the distance between the nozzle and the heat sink. They determined that the highest Nusselt number occurs at the lowest heat sink-nozzle distance (Z/D=1.5 D) [16].

Caliskan et al. [17] investigated the effect of elliptical and rectangular nozzle geometry jet on heat transfer on the heat sink in their experimental and numerical studies. As a result, they determined that elliptical jets cause more efficient heat transfer than rectangular jets. In addition, they determined that the heat transfer on the heat sink increased in the range of 6,01–16,8% depending on the distance between the heat sink and nozzle of the jet geometry and the Reynolds number.

San et al. [18] investigated the effects of the distance between the nozzles, which they placed equilaterally, on heat transfer, in their study with a quintuple jet. They studied the ratio of the distance between the jets to the diameter of the jet (s/d) in the range of 2-8. They obtained the maximum Nusselt number value at low s/d and h/d (the ratio of the distance between the heat sink and the nozzle to the diameter of the jet) [18]. In his experimental and numerical study, İşman (2011) determined that the use of a single jet with the same air flow provides a more effective heat transfer than the use of double jets [19].

In order to increase the heat transfer performance with the impinging jet, besides the effects of the above parameters, the geometry of the heat sink is also of great importance. Thanks to its simple application, low cost and high heat removal capacity, heat sinks of different geometries have a great effect on the heat transfer development process [20]. Many numerical and experimental studies have been carried out on the design of the heat sink.

Yang et al. [21] numerically investigated the cooling performance with pulsed jet in a heat sink with variable fin height. As a result of their work with 15000 and 20000 Reynolds numbers and 12 heat sinks with variable fin height, they stated that the base temperature can be reduced by increasing the fin height in the center of the heat sink. They also stated that there is optimization potential for non-standard wing height.

Ravanji et al. [10], in their numerical study, performed heat transfer analysis in heat sinks with square rectangular, circular and elliptical fin geometries with impinging jet. As a result, they stated that the elliptical fin geometry greatly reduces the local temperatures in the stall region and the wall jet region. They stated that there is an increase of 47-54% compared to the plane surface due to the increase in the Reynolds number in elliptical fin heat sinks [10]. Froissart et al. [22] performed heat transfer analysis in heat sinks with convex and concave geometry with impinging jet. As a result, they obtained the most efficient heat transfer in the round-end convex heat sink.

Özdilli et al. [23] carried out a numerical study to determine the heat transfer performance by impinging jet in 5 different heat sink geometries: cylindrical, cylindrical-concave, cylindrical-convex, cylindrical-wave and cylindrical-channel. As a result, they determined that the best performance was achieved in the cylindrical-concave heat sink, and the worst performance was achieved in the cylindrical-convex heat sink. Khalaji et al. [4], numerically and experimentally investigated the effect of finned heat sink geometry on heat transfer in a vertical air duct. The analyzes were carried out for the plane plate, cylindrical fin heat sink and rectangular fin heat sink with narrowing-expanding geometry. They determined that the most efficient heat transfer takes place in the heat sink with a narrowing-expanding geometry [24].

When the studies on heat sinks, which are passive cooling methods, are examined in the literature, there are studies on different fin geometries, heights and designs. However, a study in which the fin heights are determined according to the temperature distribution formed at the base of the heat sink has not been found in the literature. In the numerical study, it is aimed to provide a homogeneous temperature distribution at the heat sink base with square geometry differential fins placed according to the temperature gradient formed by the impinging jet on the plane heat sink surface where a constant heat flux is applied. A curved surface was created with the temperature distributions obtained for the plane plate heat sinks, and differential fin geometries were created separately for each Reynolds number. It was determined that the obtained differential fin geometries exhibited a homogeneous surface temperature distribution by creating a lower temperature gradient compared to the plane surface heat sink.

2. Material and Method

A numerical study was carried out to examine the effect of square fins designed according to the temperature gradients formed on the plane plate by the impinging air jet on the temperature distribution on the heat sink. The analysis was carried out at air velocities corresponding to Re=4000-8000-12000 values, 1000 W/m^2 heat flux and 293,15 K air temperature. 50x50x5 mm aluminum heat sink was used as a heat sink. The nozzle diameter of the impinging air jet is

10 mm. The image of the control volume used in CFD analysis is as in Figure 1.

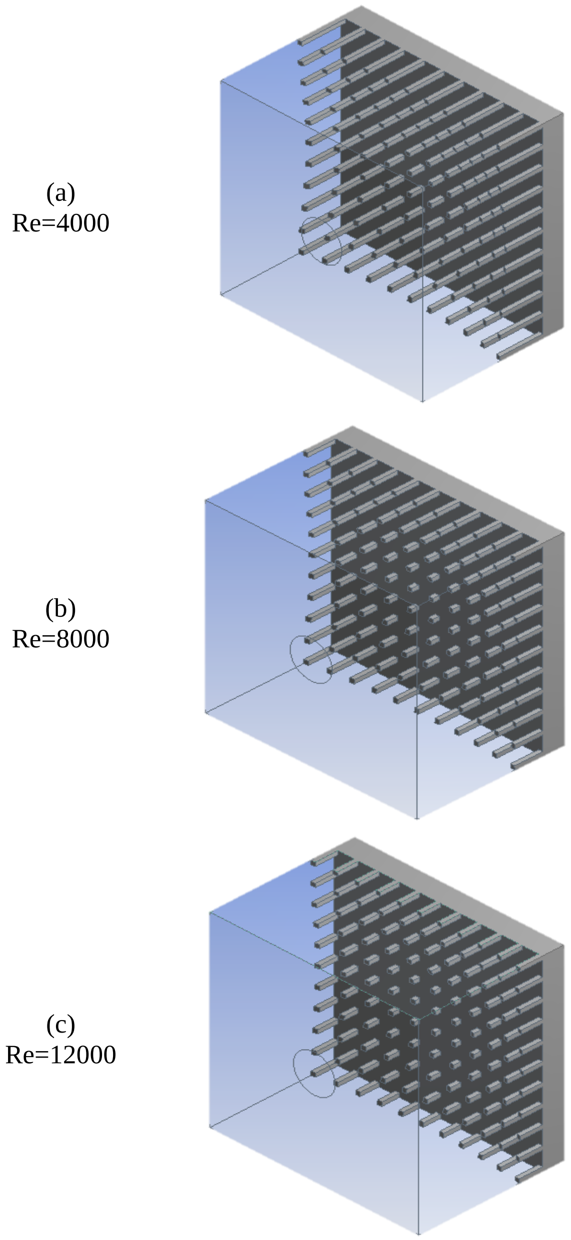

Figure 1 Control volume used in CFD analysis

Numerical analyzes were made with Ansys-Fluent package program. In the study, “k-Ɛ RNG” turbulence model and “Enhanced Wall Functions” conditions were used as turbulence model. Numerical analyzes were carried out under the following boundary conditions:

- the fluid used in numerical analysis is incompressible air in the gas phase,
- the thermodynamic properties of air do not change with time and location.
- the air flow in the control volume does not change with time,
- the control volume is considered stable,
- effects of gravity are neglected.

Considering the boundary conditions, the following conservation equations were used in the analysis. Conservation of mass equation;

$$\frac{\partial \rho}{\partial t} + \frac{\partial \rho u}{\partial x} + \frac{\partial \rho v}{\partial y} + \frac{\partial \rho w}{\partial z} = 0 \quad (1)$$

Momentum equation;

$$\frac{\partial \rho}{\partial t} + \vec{\nabla}.(\rho\vec{V}) = \frac{\partial \rho}{\partial t} + \vec{V}.\vec{\nabla}\rho + \rho\vec{\nabla}.\vec{V} = 0 \quad (2)$$

Equation of conservation of energy;

$$\rho c_v \frac{dT}{dt} = k\nabla^2 T + \Phi \quad (3)$$

can be expressed as.

In addition, the transport equations used by the ANSYS-Fluent program for the k-ε turbulence model are as follows.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu}{\sigma_k}\right)\frac{\partial_k}{\partial x_f}\right) + G_k + G_b + \rho\varepsilon + Y_M + S_k \quad (4)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j}\left(\left(\mu + \frac{\mu_t}{\sigma_e}\right)\frac{\partial_e}{\partial x_j}\right)$$
$$+ C_{1\epsilon}\frac{\varepsilon}{k}(Gk + C_{3\epsilon}Gb) + C_{2\epsilon}\rho_\epsilon\frac{\varepsilon^2}{k} + S_e \quad (5)$$

Mesh tests for the created control volume started from approximately 200.000 mesh numbers and the "Orthogonal Quality" was between 90% and 94% in the mesh number of 875.000 (Figure 2), and it was seen that the mesh number did not affect the results in increases after this mesh value (Figure 3).

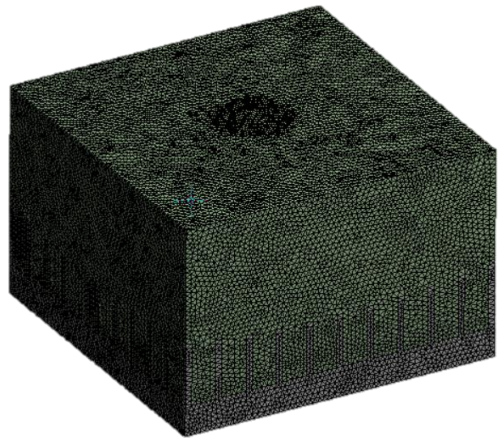

Figure 2 Mesh image used for the control volume

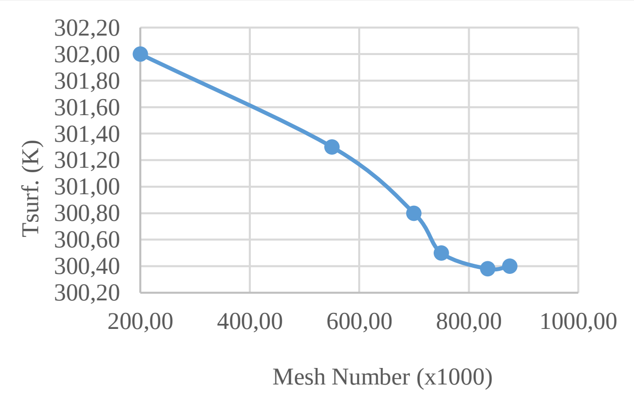

Figure 3 Mesh independence of the solution for the control volume

3. Results and Discussion

In this study, the effects of differential fins obtained by accepting the plane surface heat sink as reference, on the temperature homogenization on the surface were investigated numerically. In numerical analysis, the temperature distributions on the surfaces were determined at different Reynolds numbers and different heat sink geometries. Differential fin geometries were determined with the data obtained from the temperature distribution on the plane surface heat sink, the image of which is given in Figure 4.

(a)
Re=4000

(b)
Re=8000

(c)
Re=12000

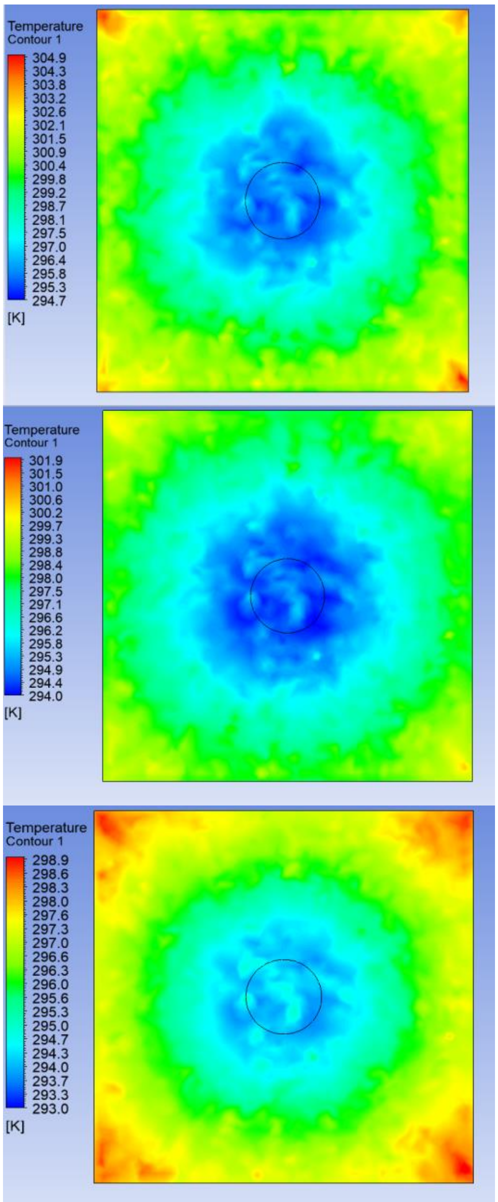

Figure 4 Temperature gradient in the plane surface heat sink.

When Figure 4 is examined, it is seen that there is a distinct temperature gradient between the stagnation zone where the jet hits and the heat sink edges. The aim of this study is to obtain a more homogeneous temperature distribution on the surface by reducing this gradient, which appears in Figure 4, as much as possible. For this reason, square-section fins with increasing heights from the center to the edges and corners were placed on the heat sink in parallel with the increase in the temperature distribution.

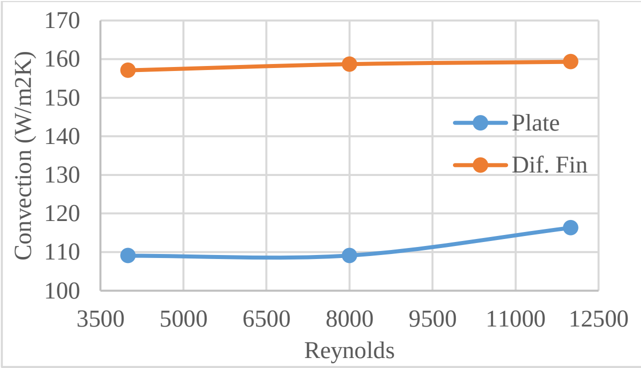

Figure 5 Nusselt versus Reynolds for differential fins and smooth plates.

When Figure 5 is examined, the Nusselt number does not increase much with the increase of the Reynolds number in the differential fins designed with the temperature data taken according to different Reynolds values in the case without fins.

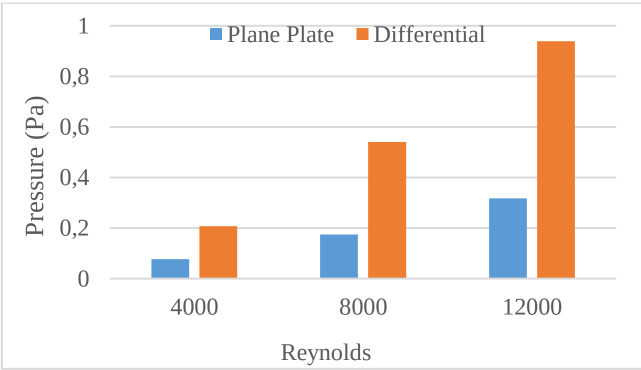

Figure 6 Nozzle outlet pressures for plane plate and differential geometry.

Figure 6 shows the nozzle outlet pressures as a result of placing the differential fins on the plate. The reason why the pressures are relatively low in the absence of fin placement on the plate is that the flow can reach the plate more easily.

When Figure 7 is examined, it is seen that there are significant differences in the temperature distributions of heat sinks with and without differential fins according to different Reynolds numbers. When the temperature gradients (a) and (b) in Figure 7 are examined, there is a temperature gradient of about 10,2 °C on the surface in the case of Re=4000 without fins, while this difference appears to be about 8 °C when differential fins are used. This situation reveals that the differential fins create a more homogeneous temperature distribution on the surface. Similarly, for Re=8000 and 12000, the difference in temperature gradient in the finned and finless cases was approximately 2°C and 1.8°C.

The highest Nusselt numbers obtained in the study were determined as 159.3 W/m^2K and 116.3 W/m^2K for finned and finless cases at 12000 Reynolds value, respectively. This shows that the use of fins significantly increases the heat transfer. In addition, it has been determined that there is a maximum difference of 2% in the result by using equal height fins instead of differential fins in the study.

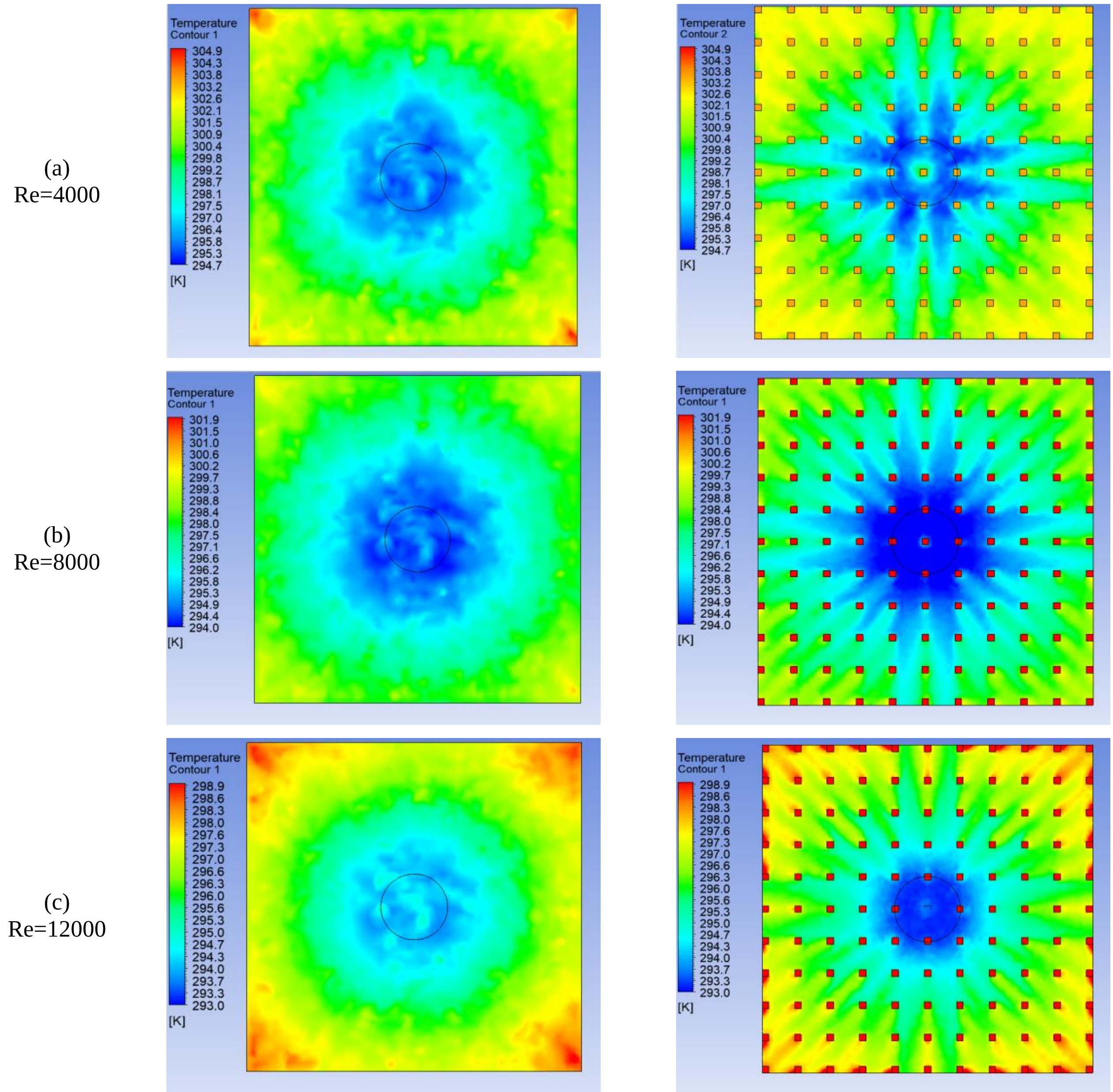

Figure 7 Surface temperature gradients at different Reynolds numbers for heat sinks with and without differential fins

Conclusions

In this study, the effects of differential-height heat sinks designed according to the temperature gradient formed on the plane plate heat sink surface used in heat transfer with the impinging jet, on the temperature homogenization on the surface were investigated. According to the results of the study, it has been revealed that using differential fins instead of using fins of equal height does not provide a noticeable loss in terms of heat transfer. In addition, with the use of differential fins, the temperature gradient on the surface is considerably reduced.

It has been demonstrated that it is possible to achieve the same heat transfer coefficients by saving approximately 30% from the material used. In this respect, due to the expensiveness of aluminum and copper materials used in heat transfer applications, the results presented in this study provide significant added value.

Declaration of Conflict of Interest

Authors declare that they have no conflict of interest with any person, institution, or company.

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