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Improving Cooling System by Analysis the Thermal Performance of Single and Multi-Way Thermal Channels

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Abstract

Single and multi-way thermal channel as a heat pipe is a device that can quickly transfer large amounts of heat with a small temperature difference between a hot source and a cold source and is used in most electronic industries today. In this article, the performance of single and multi-way thermal channels is presented with the aim of improving system cooling. For this purpose, modeling of the channels has been done first, and then the performance of single, two and three-way channels has been compared in different heat fluxes. The simulation results are consistent with the experimental results of the previous researches, with a maximum error of 3%, and it can be understood that the system is significantly improved by increasing the number of cooling channels.

Keywords:
Cooling system, Rectangular Channel, Single and Multi-way Thermal Channels, Thermal Analysis

Introduction

Due to the large application of heat transfer in various fields of science, it is necessary to use large-scale or highlighting levels due to space and physical constraints in electrical systems. The main purpose of using these surfaces is to increase the heat transfer through the increase of the surface (Rothan, 2022; Selimefendigil, 2022). As a result, the best surface (fin or cavity) is that it provides the highest heat transfer, or the maximum temperature difference. The most important point is that, in practice, the fin or cavity should be coincident with the high heat transfer capability, depending on the type and shape of the material, that it has the lowest amount of material to be consumed, and thus the lowest cost possible (Waini et al., 2022; Gürsoy et al., 2022). These two points cannot be easily verified about a Finn or cavity, but it should be found in the optimal situation in which these conditions are simultaneously considered. Finns and cavities of various shapes are used on a variety of heat exchangers.

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In (Lorenzini et al., 2015), in a study in 2015, used structural design to study the numerical geometry of cavities washed by a fluid with constant heat transfer coefficient which can penetrate into a solid cylindrical body. The purpose of this is to minimize the maximum degree of excess heat between a solid body and an environment created by the formation of cavity geometry. In (Gonzales et al., 2015) conducted research in 2015, in which several of the cooling programs (main parameter of SA) and design of the structure were investigated and used to optimize the geometric shape of a homogeneous cavity (Y). Realizing this will affect the penetration of this cavity into a solid wall and will be accompanied by internal heat generation. In previous studies, this figure has been optimized by a comprehensive search and genetic algorithm. This issue has four degrees of freedom (H / L, L1 / L0, T1 / T0, α) and two limitations. In (Lorenzini et al., 2015), used a structured design approach to obtain a configuration that facilitated access to heat flow. This access is through a conductive I-shaped path, so that it is placed in a volumetric medium and will be accompanied by a small thermal conductivity and heat generation. In (Lorenzini et al., 2012) explored a geometric optimization of complex cavities, a T-Y cavity with two external extras in a solid wall. The holes assemblies have been cooled down by a constant convective flow, while the solid body generates uniformity of heat and its external environment is insulated. Two sets of geometric adjustments that have various displacements of lateral cavities are called Design 1 and Design 2 and are numerically investigated. In (Hajmohammadi et al., 2013) stated that due to construction considerations, adding complexity to design may not be desirable for practical purposes. Their main goal was to provide simple cavities consisting of N equal branches. These branches have penetrated into the symmetrical and equal parts of the heat of the rectangular / trapezoid body. In general, it is recommended that, for practical engineering programs, complex holes should be replaced by simpler cavities such as the N-shaped, which is currently being studied in this study.

In (Lorenzini et al., 2013) have been designing the structure to discover the configuration which examines the amount of access to heat. This heat is limited by an X-shaped path in a square-shaped thermal medium and cools this volume of material. The purpose of this is to minimize the maximum temperature of the system, i.e. the hot spots, wherever they are located. In (Zhang et al., 2022) developed an X-shaped model of hot water network, with thermal insulation layers.

In this research the thermal analysis of the single and multi-channels performance in cooling the system compared. Optimization of elemental structure, the first and the highest order of the network by minimizing overall pressure drop and maximizing the overall temperature difference as optimization goals. The results have shown that for each of the high-order orders, the internal radius ratio is always lower than 2.21 than the wet level.

Mathematical Modeling

The governing equations on the cavity surfaces in this research, a two-dimensional object is placed under the heat transfer analysis under the production of internal heat with a rectangular or trapezoidal cross-sectional shape having a cavity N. For a rectangular surface, the size of the object is equal to (H, L) and the trapezoidal cross-sectional shape has an external dimensions (H, H_e, L). As shown in Fig. 3.1, the holes in the object are symmetric and each cavity is rectangular shape and with dimensions (H_0, L_0). As can be seen from the figure, the cavities on the rectangular and trapezoid surfaces create a uniform chap with length $L - L_0$. The total volume of the cavity and the object has been constant, and for the rectangular and trapezoidal cross-sections, the following are obtained:

$$V = HLW = \text{Const.} \tag{1}$$

$$V = \frac{1}{2}(H + H_e)LW = \text{Const.} \tag{2}$$

where W is the thickness of the object, for simplicity, it is assumed that the thickness of the object is very small in relation to other dimensions, and therefore the change in parameters along the thickness line can be neglected. Therefore, the area of the cross-section of a rectangular body is equal to $A = HL$ and for a transverse cross-sectional dimension equal to $A = (H + H_e)L / 2$, which has the same and constant value. In all samples, the volume of the cavity is constant and is obtained from the following equation:

$$V_0 = NH_0L_0W \tag{3}$$

Therefore, using recent relationships, the limitation of the volume constraint for rectangular and trapezoidal cross sections is defined as follows:

$$\phi = \frac{V_0}{V} = \frac{NH_0L_0}{HL} = Const. \tag{4}$$

$$\phi = \frac{V_0}{V} = \frac{2NH_0L_0}{(H + H_e)L} = Const. \tag{5}$$

where ϕ represents the volume fraction dropped by the cavities. The body is considered as isotropic and its conductivity coefficient is constant equal to k, which produces uniform heat with a volume ratio $q'''(\mathrm{Wm^{-3}})$. The outer surface of the heating element is completely insulated. The heat flux dissipated by the cavities is equal to $q''A(1-\phi)$, which is transmitted by the heat transfer of the coefficient h from the cavities. Due to the thermal resistance of the object, the temperature of the object reaches a value greater than the temperature of the fluid into the cavities. The temperature at the corners of the object will be highest and will be shown in Fig. 3-1 with $T_{\max}$. In the design of heat transfer chambers, keeping the maximum temperature in a piece is one of the important parameters of design, and it is optimal to achieve this minimum amount. Hence, in the limiting parameter research is the design of $T_{\max}$ and the main purpose of the design is to minimize this system temperature by using localized heat transfer of $q'''A/(T_{\max} - T_\infty)$. Numerical optimization The geometric parameters of the cavity and the object are performed by calculating the maximum error of the system for a wide range of effective parameters of the system. In order to optimize the system parameters, it is necessary that the governing equations are extracted and analyzed. The differential equation governing the two-dimensional conduction heat conduction is obtained from the following equation under the internal heat production and in the steady state according to the dimensionless parameters:

$$\frac{\partial^2 \tilde{T}}{\partial \tilde{x}^2} + \frac{\partial^2 \tilde{T}}{\partial \tilde{y}^2} + 1 = 0 \tag{6}$$

where the dimensionless parameters are defined as:

$$\tilde{T} = \frac{T - T_\infty}{q''A/k} \tag{7}$$

and

$$(\tilde{x}, \tilde{y}, \tilde{n}, \tilde{H}, \tilde{L}, \tilde{H}_e, \tilde{H}_0, \tilde{L}_0) = \frac{(x, y, n, H, L, H_e, H_0, H_0)}{A^{1/2}} \tag{8}$$

where n is a perpendicular to the inner surface of the cavity, with regard to the dimensionless parameters, the heat transfer in the cavity is obtained as follows:

$$\frac{\partial \tilde{T}}{\partial \tilde{n}}=\frac{a^2}{2}\tilde{T} \tag{9}$$

In which a is a non-dimensional thermal-geometric parameter defined as:

$$a=\left(\frac{2hA^{1/2}}{k}\right)^{1/2} \tag{10}$$

In the present research, the aim of optimization is to minimize the maximum temperature created in the system, which according to the dimensionless parameters is as follows:

$$\tilde{T}_{max}=\frac{T_{\max}-T_{\infty}}{q'''A/k} \tag{11}$$

Solving equations governing on the proposed system

In this research, the differential equation governing the temperature distribution presented in equation (6) is solved using finite element method. For this purpose, the toolbox environment of PDE Toolbox of MATLAB software is used. The geometry of the system is being solved using mesh-shaped triangular elements and the equation for distribution of temperature along with suitable boundary conditions. After examining the independence of the results network, the appropriate size of the elements is determined in such a way that the convergence between the results follows the following relationship:

$$\left|\tilde{T}_{\max}^{j}-\tilde{T}_{\max}^{j+1}\right|<10^{-4} \tag{12}$$

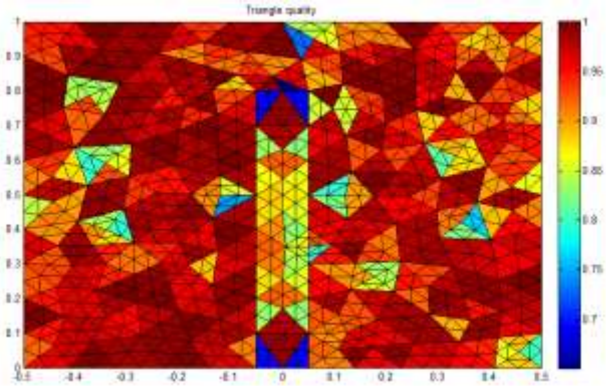
In Figure 1 the toolbox environment of PDE Toolbox is shown in MATLAB software. This toolbox is capable of solving different types of differential equations. To map the geometry of the system, the Draw option is used. Using the Boundary option, different types of boundary conditions can be applied to the system. Then, with the choice of PDE, the type of differential equation is applied along with the numerical values of the coefficients of sentences in different regions. Then, using the Mesh option, we will apply the mesh geometry using triangular elements. Finally, the Solve solution of the governing equations along with the corresponding boundary conditions is solved by choosing and using the Plot option you can pay to view results. In the present study, for repetitive situations, this operation is repeated every time, and the maximum temperature has been recorded in the system and the maximum number of curves has been plotted and studied.

Figure 1. The toolbox environment of the PDE Toolbox of MATLAB software

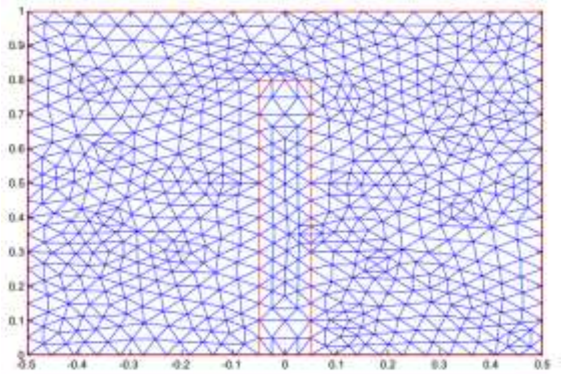
Results

Modeling and networking of the problem has been done in MATLAB software and using the toolbox of PDE Toolbox. In order to accurately determine the geometry made, a proper layout must be made on the geometry. The method of mating in the solution method and the accuracy of the extracted results is very effective, so that if the appropriate layout is not used in the problem, in addition to slowing the solution process or even the divergence of the results, the extracted results will also have a huge error. In this research, for the precise lattice of the network and due to the complexity of the boundaries in the corners, triangular elements are used. As we see in Fig. 2, the meshes are smaller in the areas around the inner structures and the meshes are shifted to the environment so that the computational cost do not go up too much. This grid-ranking was considered as the worst Equiangle skew, and it was seen that this value is greater than 0.7 for all elements, which is a very good value. It should be noted that in the software guide, for high accuracy results, this value should be greater than 0.5.

Investigating the autonomy of the network results are usually carried out using several studies for the size of different networks and numerical results are considered for different mesh size values and should not be seen from a number of networks. There is little change in the results. Considering the aim of the present study is to minimize the maximum temperature generated in the system, therefore, the maximum temperature generated in the system is chosen as a criterion for choosing the appropriate networking. Based on the study of the dependence of the maximum temperature on the number of meshes, the higher the number of meshes, and the greater the accuracy of the results. In this study, changing the number of meshes from 5,000 to 50,000, the maximum temperature was not significantly changed from 10,000 mesh to the top and increasing the number of meshes over this amount only increases the time of the calculation. Accordingly, in the present study, 10000 mesh criteria were considered.



(A)



(B)

Figure 2. (A) - An example of a system mesh, 3 (B) - Review the worst Equiangle skew criterion

Validation of the results

In this study, the research done by (Feng et al., 2015; Bhanja et al., 2011) was used to validate the results. In their study, they presented a report on the geometric optimization of the T-shaped finite set shown in Figure 3. They were dedicated to optimizing the proposed system in order to maximize the overall thermal conductivity of the set with the limit of total volume and materials used in Finn. Their investigation shows that the optimization of Finn's set compared to the change of some parameters, such as the length of the two crowned ends in Taoist Finns, is almost ineffective. Given the geometric characteristics shown in their research, the dimensionless parameters are considered as follows:

$$\phi_0 = \frac{A_{p0}}{A_0} = \frac{D_0 B_0}{H_0 L_0}, \quad \tilde{T} = \frac{T - T(L_0, 0)}{q''' A_0 / k_0}, \quad \tilde{k} = \frac{k_0}{k_p} \tag{13}$$

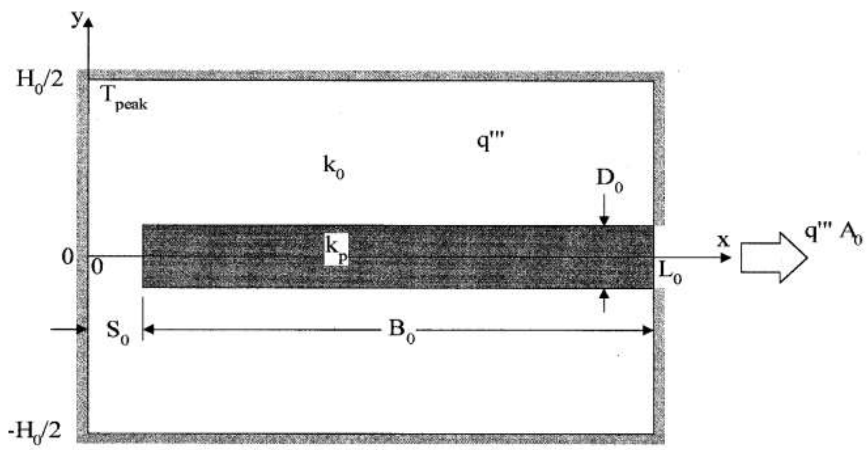
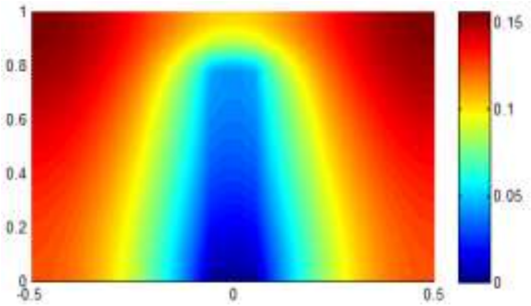


Figure 3. Geometry under investigation in the research presented in the reference

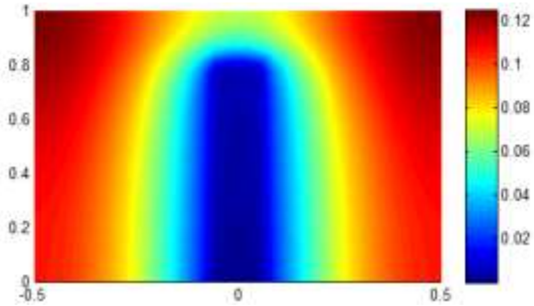
With regard to the dimensionless variables presented in relation (13), the comparison of the results between the modeling of the present research with the results of the research is given in Table 1 for the different values of the coefficient of thermal conductivity of the material. As can be seen, there is a very satisfactory agreement between the results presented with the reference results [13]. Based on the results, the maximum error obtained is about 3%. In Fig. 4, the distribution of temperature inside the reference blade (Bhanja et al., 2011) for $\phi_0 = 0.1$, $H_0/L_0 = 1$ and $D_0/B_0 = 0.15$ obtained using the present modeling is shown.

Table 1. Comparison of the maximum temperature obtained from the results of the modeling of the present research and the results of [13] for the different values of the ratio of thermal conductivity coefficient ($\phi_0 = 0.1$, $H_0/L_0 = 1$ and $D_0/B_0 = 0.15$)

$\tilde{k}$	$\tilde{T}_{\max}$		
	Reference [14]	Present Results	Error (%)
1000	0.1282	0.1244	3.05
300	0.1359	0.1331	2.10
100	0.1572	0.1563	0.58
30	0.2248	0.2287	1.70
10	0.3749	0.3827	2.04



(A)



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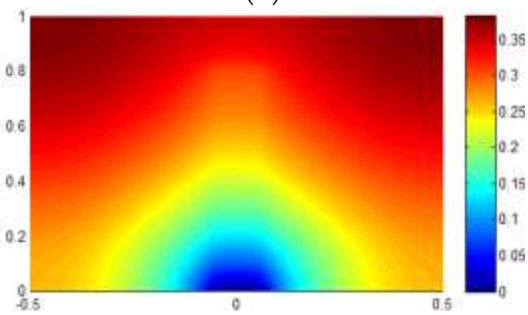


(C)

Figure 4. In-line temperature distribution of the reference model [14] for $\phi_0 = 0.1$, $H_0/L_0 = 1$ and $D_0/B_0 = 0.15$ obtained using the present modeling (A) $\tilde{k} = 1000$, (B) $\tilde{k} = 100$ and (C) $\tilde{k} = 10$

Investigating the effect of optimal parameters and results of a rectangular convex

In this section, the effect of different parameters on the maximum heat created in a cube with its geometric dimensions is shown in Fig. 5 is being examined.

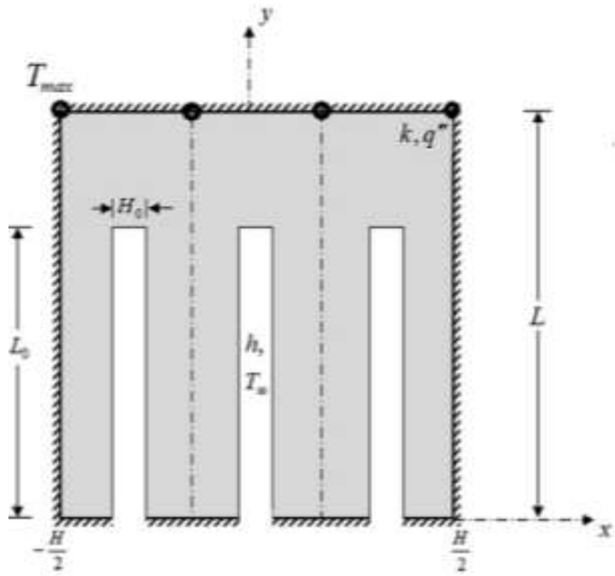


Figure 5. Geometric characteristics of cubic heat production with N cavity inside

In Fig. 6, the combined effect of the dimensionless parameter of the cavity H_0/L_0 is shown on the maximum temperature generated in a heat production disk with a constant $H/L=1$ ratio. This form is presented for a cube with a cavity (N = 1) for different values of the particle size fraction ϕ and it is assumed that the inner surface of the cavity has constant temperature boundary conditions. As can be seen, for the different values of parameter ϕ, the maximum created temperature reaches its minimum value, with the cavity volume being approximately equal to the volume of the cube, in the sense of $L_{0,opt} \approx L$. According to the results, it is observed that narrow holes (H_0 less) and longer lengths (L_0 larger) have the least effect on the reduction of the maximum temperature of the object, and against the cavities with larger dimensions they have the greatest effect on reducing the maximum temperature created in the body. In Figure 7, the contour of the body temperature distribution is represented by the internal heat generation for three modes $\phi = 0.05$, $H_0/L_0 = 0.5$ and $\phi = 0.05, H_0/L_0 = 0.1$ and also $\phi = 0.15$, $H_0/L_0 = 0.4$. As it can be seen, in this case most of the temperature of the object occurs at its corners, and the internal surface temperature of the cavity has a minimum temperature. And its amount is the same on all internal surfaces. In addition, it is observed that the performance of two cavities with the same characteristics $\phi = 0.05$, $H_0/L_0 = 0.1$ and also $\phi = 0.15$, $H_0/L_0 = 0.4$ is the same. Therefore, based on need, it is possible to determine the optimal design that does not change the overall system performance and does not affect the geometric features of the system.

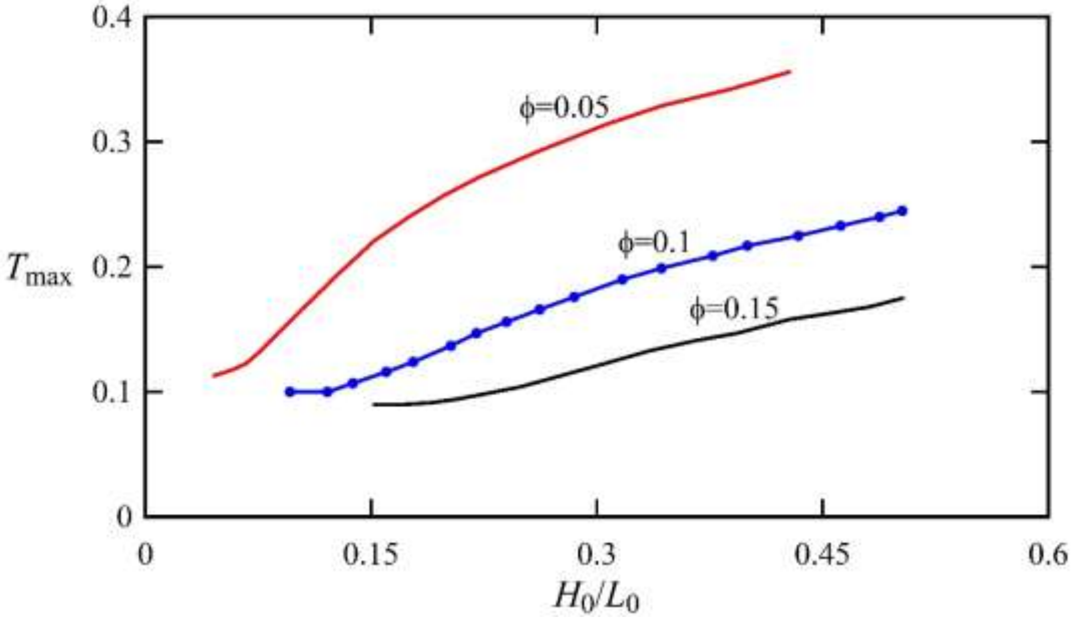


Figure 6. The combined effect of the dimensionless parameter of the cavity H_0/L_0 , on the maximum temperature produced in a heat production disk with a constant $H/L = 1$ and $N = 1$ ratio

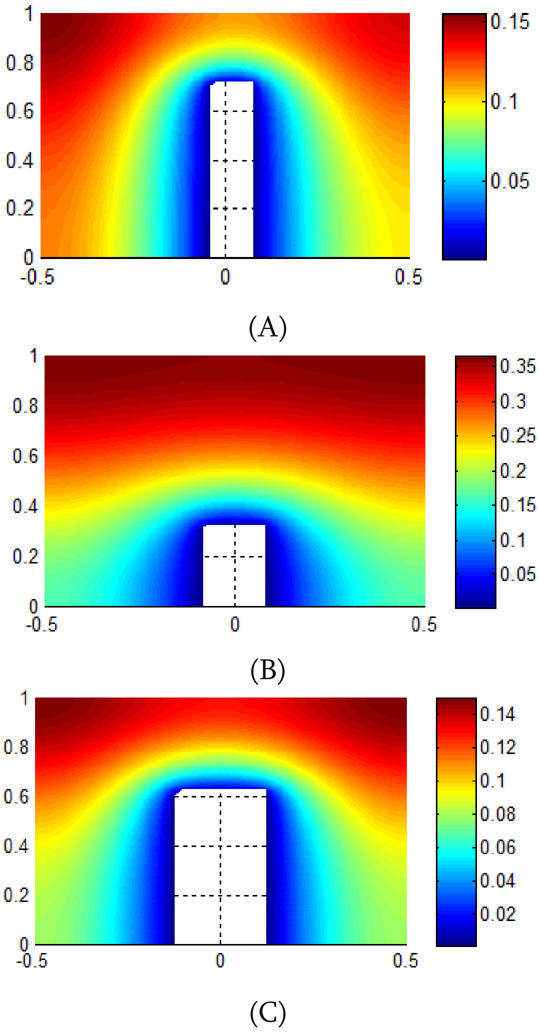


Figure 7. Contour of body temperature distribution with internal heat generation for three modes (A) $\phi = 0.05$ $H_0/L_0 = 0.4$ ، $\phi = 0.15$, and (C) $H_0/L_0 = 0.1$ ، $\phi = 0.05$, (B) $H_0/L_0 = 0.1$ ،

The steps taken in Fig. 7 are presented taking into account the transfer heat transfer inside the cavity with the dimensionless displacement heat transfer coefficient. The results of Fig. 8 show that in the presence of a heat transfer from the inside of the cavity, in order to reduce the maximum temperature of the object, the dimensions of the cavity geometry are optimal, which should be determined in order to increase the system performance and reduce the body temperature. It should be noted that the changes in the maximum temperature of the system around the optimum points are very tangible. As the results show, with increasing ϕ, the cavity performance increases in the maximum temperature of the system. For a given value of the volume fraction parameter, H_0/L_0 ratio has an optimal value for which the maximum system temperature has the lowest reduction. For example, for $\phi = 0.4$, $\phi = 0.2$, and $\phi = 0.1$, the best system performance is obtained for H_0/L_0, respectively, at 0.408, 0.201, and 0.099. In Fig. 9, the temperature contour is shown along with the flow and temperature lines for optimal $\phi = 0.4$ and $H_0/L_0 = 0.408$. In this case, the cavity is located in the center of the body and has a heat transfer with $\alpha = 0.1$ dimensionless coefficient. As can be seen, homogeneous lines inside the chamber are symmetric in the chamber due to the dominant effect of the heat transfer and the symmetry of the conductor and the conduction heat transfer relative to the central vertical axis of the chamber. As can be seen from the figure, the maximum temperature created in the enclosure is 49.32 ° C.

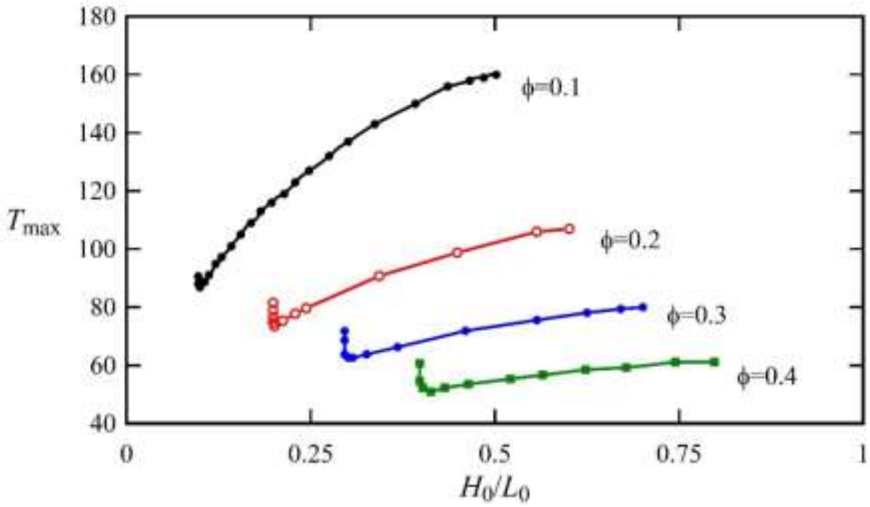


Figure 8. The effect of parameter H_0/L_0 on the reduction of the maximum cube temperature with the internal cavity, taking into account the heat transfer in the cavity with the $\alpha = 0.1$ dimensionless displacement heat transfer coefficient for $N = 1$ and $H/L = 1$

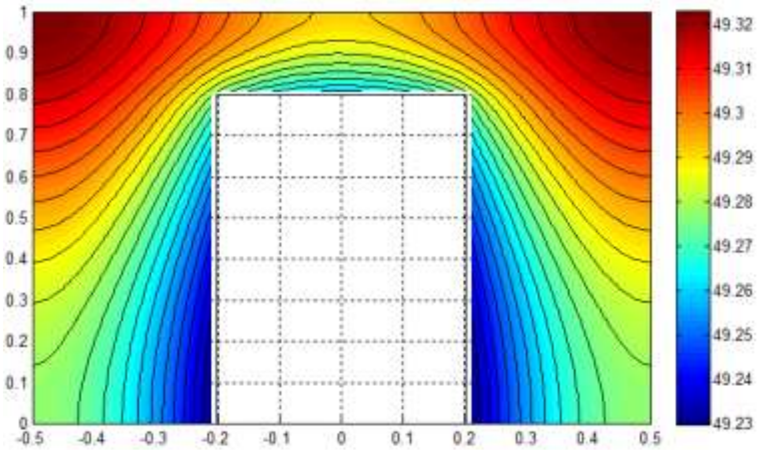
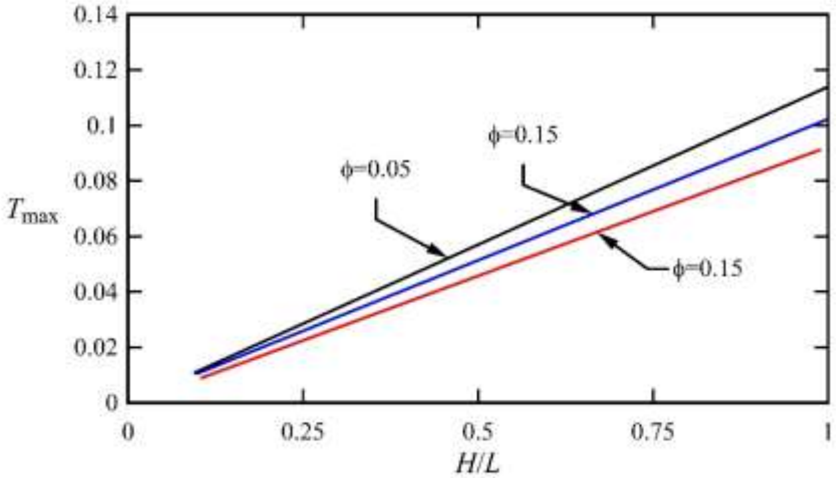


Figure 9. Contour of temperature along with flow and temperature lines for optimum conditions $\phi = 0.4$ and $H_0/L_0 = 0.408$ and heat transfer displacement of the cavity with dimensionless $\alpha = 0.1$ coefficient

In the next step, the optimization of cavity geometry is similar to the calculation process used to derive the results presented in Figures 6 and 8, in order to examine the effect of parameter H/L , in Figures 10-12, the maximum temperature of the compartment in two modes of insulating the cavity and in the presence of heat transfer $\alpha = 0.1$ displacement with intensity H/L is presented in terms of dimensionless H/L parameter. Given the geometric symmetry in the rectangular chamber of the figure (Fig. 2), the results shown in Figures 10 and 11 provide the effect of the number of holes, N, on minimizing the maximum temperature of the chamber for a chamber with a ratio of A and the number of n cavities $H/L = 1$. For example, if the maximum temperature in the compartment with a ratio $H/L = 0.5$ is equal to $2 \times T_{\max}$, then the maximum temperature created in a chamber with a ratio of $H/L = 1$ and having two cavities is equal to $T_{\max}$. According to the results of these shapes, with the increase in the number of holes, the maximum temperature created in the system can be significantly reduced.



Figures 10. Maximum temperature of the compartment in the case of insulating the cavity in accordance with the dimensionless dimension H/L

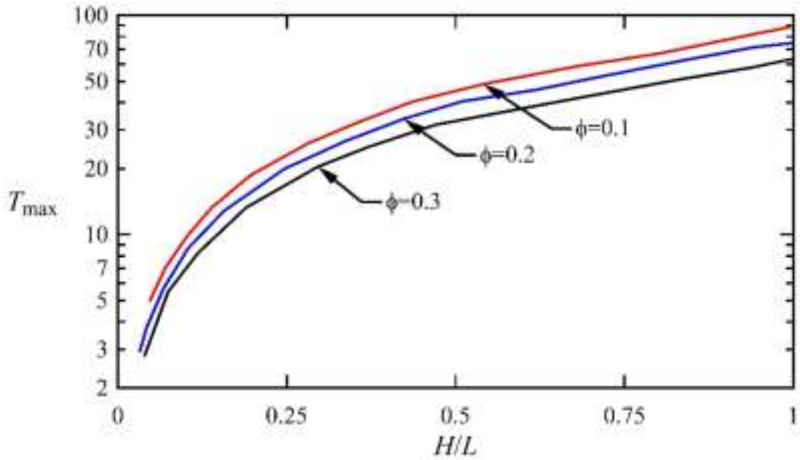
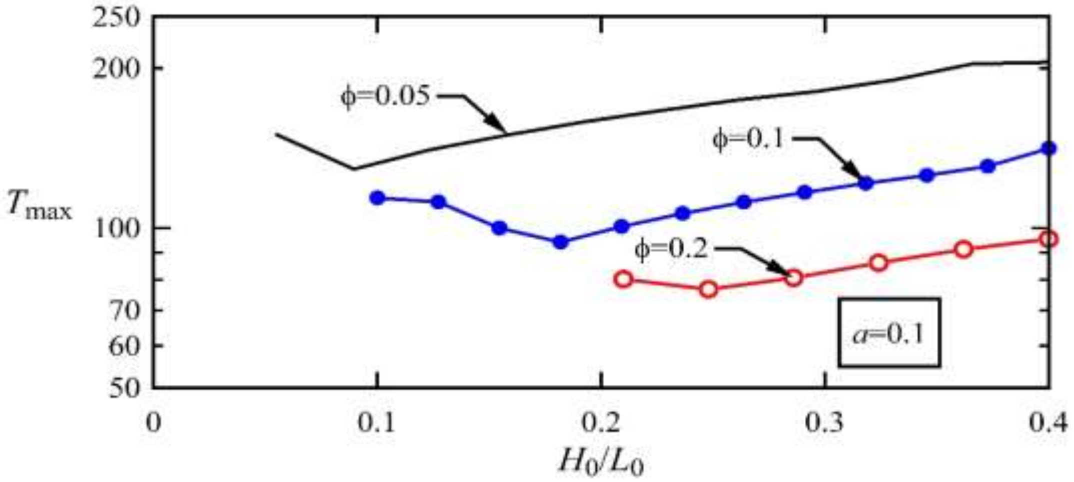
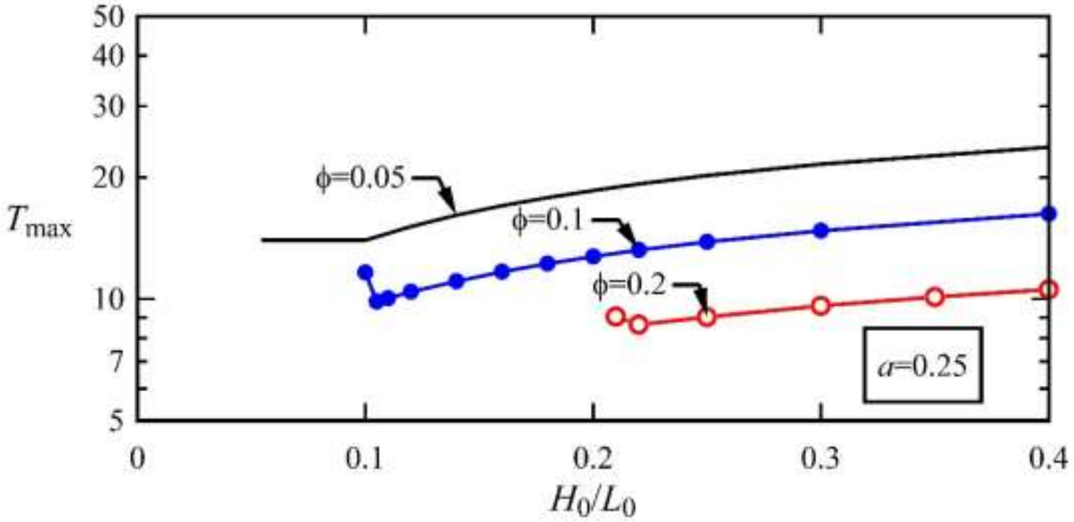


Figure 11. Maximum temperature of the enclosure in the presence of a heat transfer of the displacement with intensity $\alpha = 0.1$ of the cavity in accordance with the dimensionless H/L



(A)



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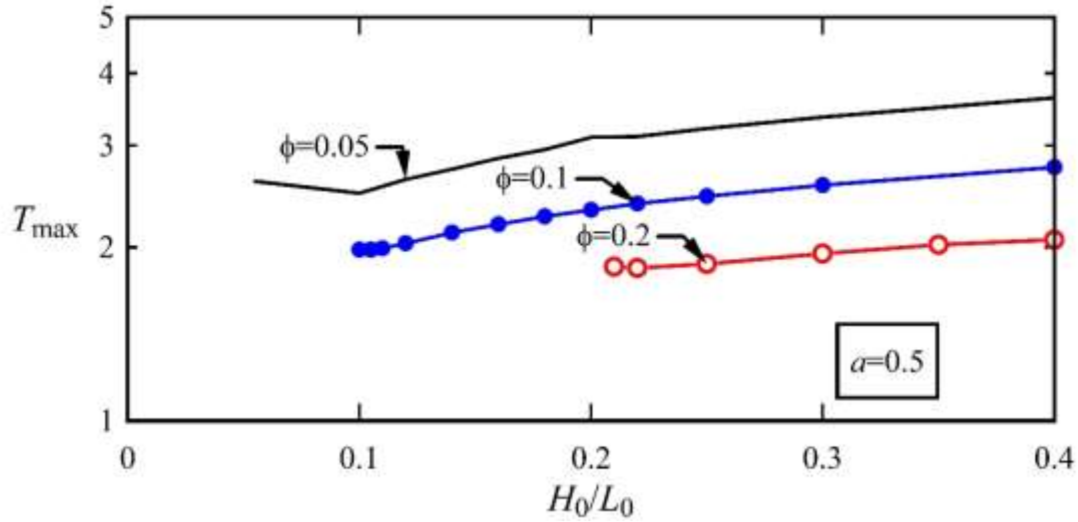

(C)

Figure 12. The effect of heat transfer on the maximum temperature of the system

As shown in Figs. 12, the coefficient of heat transfer from the inner surface of the cavity has a significant effect on the maximum temperature created in the system. In Fig. 12 (A), the maximum temperature variation for the different values of the volume fraction ratio is shown in terms of ratio

H_0/L_0 for the heat transfer ratio $\alpha = 0.1$. As it can be seen, the optimal value system is for the lower values of ϕ, and the optimal position is eliminated by increasing this value. Based on these results, it can be seen that in a specific ϕ, the system temperature converges to a certain value by increasing the H_0/L_0 ratio, and does not change much at the maximum temperature of the system. These results show a significant effect of the heat transfer coefficient on the maximum temperature. For $\alpha = 0.1$, $\alpha = 0.25$ and $\alpha = 0.5$, the maximum system temperature is $205^{o}C$, $20^{o}C$, and $3.8^{o}C$ respectively.

Conclusion

Numerical results from thermal analysis using PDE Toolbox of MATLAB software have been investigated. In the following, the results of this research are presented briefly.

1- Comparison of the results between the modeling of the present study and the results in the - literature for the different values of the coefficient of thermal conductivity of the material indicates that there is a very satisfactory agreement between the results with the existing results. Based on the results, the maximum error obtained is about 3%.

2- The results show that, for different values of parameter ϕ, the maximum created temperature reaches its minimum value, with the resulting cavity volume being approximately equal to the volume of the cube, in the sense of $L_{0,opt} \approx L$. According to the results, it is observed that narrow holes (H_0 less) and longer lengths (L_0 larger) have the least effect on the reduction of the maximum temperature of the object, and against holes having larger dimensions, the greatest effect is on reducing the maximum temperature created in the body.

3- The results show that if there is a heat transfer from the inside of the cavity, in order to reduce the maximum temperature of the object, the dimensions of the cavity geometry will be optimal, which should be determined in order to increase the system performance and reduce the body temperature. It should be noted that the changes in the maximum temperature of the system around the optimum points are very tangible. As the results show, with increasing ϕ, the cavity performance increases in the maximum temperature of the system. For a given value of the volume fraction parameter, the ratio H_0/L_0 has an optimal value for which the maximum system temperature has the lowest reduction. For example, for $\phi = 0.4$, $\phi = 0.2$ and $\phi = 0.1$, the best system performance for H_0/L_0 is 0.408, 0.201 and 0.099, respectively.

4- Based on the results, it is observed that rectangular bodies, in a specific ϕ, converge to a certain value by increasing the H_0/L_0 ratio of the maximum temperature of the system, and little change occurs at the maximum temperature of the system. These results show a significant effect of the heat transfer coefficient on the maximum temperature. For $\alpha = 0.1$, $\alpha = 0.25$ and $\alpha = 0.5$, the maximum system temperature is $205^{o}C$, $20^{o}C$, and $3.8^{o}C$, respectively.

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