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Minimization of Rate of Heat Transfer from Rectangular Cavities with Free Convection in Various Aspect Ratios for Finding Characteristics of an Array of Adiabatic Thin Fins by PSO Algorithm

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ABSTRACT: In the present paper, the calculation of the optimum characteristics of thin fins attached to the hot wall in closed cavities with different aspect ratios has been investigated. Free convection is predominant in the cavity. The equations of continuity, momentum, and energy are discretized by means of finite volume method and the equations will be solved by a SIMPLER algorithm. The fins are connected to the hot wall and Particle Swarm algorithm is used to optimize the location and the length of fins. In order to model fins with high heat transfer, the dimensionless diffusion coefficients of momentum and energy equations are set equal to infinity and for the modeling of insulator fins, these coefficients are considered infinite and very small, respectively. The aim is to find the optimum characteristics of the array of fins attached to the hot wall in the rectangular cavities in such a way that the heat transfer from the cold wall is minimized. The results of particle swarm optimization algorithm are compared with the reference amounts. Results show that the particle swarm optimization algorithm is capable to find the optimum characteristics of an array of fins that is not calculated by the other methods, until now. The obtained results showed that with the increase of aspect ratio, the increase of the number of fins (increase in the number of variables), the particle swarm optimization algorithm might not have the needed ability to find the general optimum. This issue was studied by some numerical tests. Therefore, it was concluded that by decreasing the number of variables (Fixed location) and finding only the length of each fin, and also by increasing the number of particles in the sample space, the accuracy of the algorithm can be increased.

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1- Introduction

The study of cavities both with free convection and active vertical walls is one of the attractive subjects for the researchers of thermal science in the recent decades. This importance is because of the wide application of these cavities in the technology. In many cases of the heat transfer, free convection of cavities must be reduced such as the distance between two glasses of double glazed windows, or between the glass cover and absorber plate in the solar collectors.

Many studies have been done in the field of the improvement of heat transfer in the closed cavities with different aspect ratios, and in most of them the vane is attached to the hot wall. Lakhal et al. [1] investigated the heat transfer of free convection in the inclined rectangular cavities with high heat transfer fins attached to the hot wall. They concluded that heat transfer in the cavity is influenced by the fins and in low Rayleigh numbers, heat conduction is dominated. Some works have been also done in the field of the optimization of cavities with free convection. Azimifar and Payan [2] obtained the optimum shape of two-dimensional cavities with free convection by using similar blocks and by means of Particle Swarm Optimization (PSO) algorithm in different boundary conditions.

By doing a wide range of search in the references, it was observed that no optimization algorithm is implemented for calculating the location and length of the fins installed on the hot wall of a closed rectangular cavity with free convection in different aspect ratios. Therefore, presented in this paper is a solution which could be an appropriate replacement for a try-and-error based solution in such problems, in order to reduce heat transfer in the closed cavities with a free convection.

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2- Methodology

Fig. 1 illustrates a two dimensional cavity.

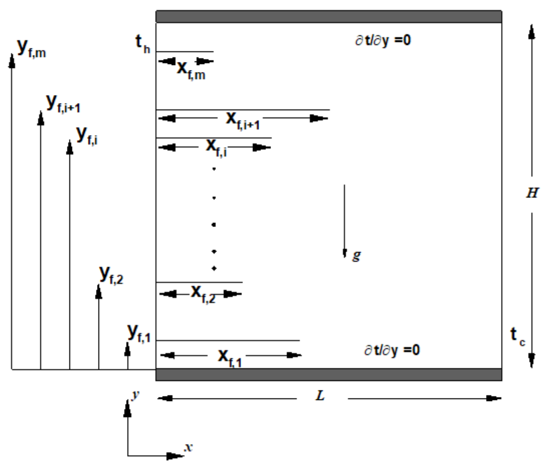

Figure 1. Schematic of a rectangular cavity with optimal characteristics of fins

The cavity includes an incompressible fluid. The heat transfer of the free convection is predominant in the cavity and Boussinesq approximation is used in it. The aim is to find the optimum characteristics of an array of thin fins attached to the hot wall so that the amount of heat transfer from the cold wall is minimized.

2- 1- Direct problem

The equations governing free convection include a series of partial differential equation including continuity, momentum, and energy. For the special problem of the free convection, energy equation will be coupled with momentum equation, by the use of Boussinesq approximation. Dimensionless form:

$$\frac{\partial U}{\partial X}+\frac{\partial V}{\partial Y}=0.0 \quad (1)$$

$$U\frac{\partial U}{\partial X}+V\frac{\partial U}{\partial Y}=-\frac{\partial P}{\partial X}+\Gamma\left(\frac{\partial^2 U}{\partial X^2}+\frac{\partial^2 U}{\partial Y^2}\right) \quad (2)$$

$$U\frac{\partial V}{\partial X}+V\frac{\partial V}{\partial Y}=-\frac{\partial P}{\partial Y}+\Gamma\left(\frac{\partial^2 V}{\partial X^2}+\frac{\partial^2 V}{\partial Y^2}\right)+GrT \quad (3)$$

$$U\frac{\partial T}{\partial X}+V\frac{\partial T}{\partial Y}=\frac{R_k}{pr}\left(\frac{\partial^2 T}{\partial X^2}+\frac{\partial^2 T}{\partial Y^2}\right) \quad (4)$$

Where Γ is equal to 1 for the fluid and infinite for solids. In the energy equation, $R_k=k_f/k_{air}$ where, k_f is thermal conductivity coefficient of the fin, and k_{air} is heat conductivity coefficient of the air.
Eqs. (1) to (4) can be solved by finite volume method. Dependent equations of velocity-pressure are solved by the use of the SIMPLER repetitive algorithm.

2- 2- Optimization problem

For the considered optimization problem, the location of fins, $Y_{f,i}$, and the fin's length, $X_{f,i}$, are unknown, and average Nusselt number on the cold wall, $B\overline{Nu}_c$, is available. PSO algorithm [3] based on minimizing the objective function, which is expressed by Eq. (4), has been used.

$$G((X_{f,m},Y_{f,m}))=\left|B\,\overline{Nu_c}-\overline{Nu}_e(X_{f,m},Y_{f,m})\right| \quad (5)$$

Where, $\overline{Nu}_c$ is the average Nusselt number on the cold wall, and B is a constant value that is for reducing heat transfer less than 1, so that $B\overline{Nu}_c$ equals 1.

3- Results and Discussion

The purpose of this section is to solve an optimization problem to find optimum characteristics of an array of fins such that the rate of heat transfer from the cold wall is in its minimum state. The maximum length of the fin is considered equal to 0.5. In the beginning, this investigation was performed for Rayleigh numbers of 10^4 and 10^5, an aspect ratio of 2 and 4, and with 4 fins, thereafter, it has been done for the aspect ratio equal to 10 with 9 fins.
The results of investigating the reduction of heat transfer on the cold wall for different aspect ratios are summarized in Tables 1 and 2. It is noteworthy that the results for an aspect ratio of 10 are obtained for two sample spaces.

Table 1. The rate of heat transfer from the cold wall in aspect ratios 2, 4 for two Rayleigh numbers with 4 fins

A	*Ra*	Nu_e	%decrease	$Nu_{without\,fin}$[4]	Nu_c
2	10^4	1.09	53.59	2.278	2.355
	10^5	2.55	40.90	4.339	4.321
4	10^4	1.60	24.30	1.915	2.116
	10^5	2.94	24.30	3.648	3.879

Table 2. The rate of heat transfer from the cold wall in aspect ratio 10 for two Rayleigh numbers with 9 fins

Ra	X_{fins} - *N*	Nu_e	%decrease	$Nu_{without\,fin}$
10^4	--9	1.44	14.54	1.685
	0.24-1	1.45	13.94	1.685
10^5	--9	2.44	23.77	3.201
	0.34-1	2.46	23.14	3.201

4- Conclusions

1. In the cases that try-and-error method is not able to determine the characteristics of fins for reducing heat transfer, the optimization problem with the same number of fins could be reached to a major reduction of heat transfer.
2. Moreover, it was specified that by increasing the aspect ratio and increasing the number of variables, the precision of algorithm is reduced. The precision was increased with the decrease of variables and decrease of the solution domain.

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