The Application of Imperialist Competitive Algorithm in Optimizing the Free Convection Heat Transfer in a Vertical Cavity with Flow Diverters

A. Karami, T. Yousefi, D. Ghashghaei, and E. Rezaei

Abstract—**This paper discussed about the application of imperialist competitive algorithm (ICA) to optimize the free convection in a vertical cavity with adiabatic horizontal, isothermally vertical walls and adiabatic diverters. Experiments included diverter angle with respect to horizon ranging from 0° to 150°. Also, the Rayleigh number based on the cavity side length varied from 6×103 to 1.2×104. After data reduction, the regression equation of convective heat flux was obtained as a function of Rayleigh number and diverter angle. Then the cost function was optimized using ICA. One can be sure that the convective heat flux will be optimized due to the optimization of the cost function. Computational results indicate that the proposed optimization algorithm is quite effective and powerful in optimizing the cost function. According to the results, in order to obtain maximum heat transfer, the diverter angle must be at the highest level.**

Index Terms—**Free convection heat transfer; vertical cavity; diverters; optimization; imperialist competitive algorithm (ica).**

I. Introduction

A free convection in a cavity consisting of diverters has been extensively studied using numerical simulations and experiments because of its importance in industrial applications. Some applications are solar collectors, fire research, electronic cooling, aeronautics, chemical apparatus, fenestration systems and construction engineering. Most of the papers in this field are substantially oriented toward the study of natural convection in enclosed squares or rectangular cavities. Tasnim and Collins [1] studied the natural convection in a square cavity with a thin baffle on the hot wall using finite volume method with collocated variable arrangement. They observed that the fin had a blocking effect on the fluid depending on the Rayleigh number, length of the baffle, and its position. Also, a number of recirculating regions were formed above and under the baffle. Frederick [2] has studied numerically natural convection in an air-filled, differentially heated, inclined square cavity, with a single partition attached to its cold wall, at Rayleigh numbers of 10^3–10^5. He showed that the partition leads to the suppression of convection, and reduces the heat transfer by up to 47% in comparison to the empty cavity at the same Rayleigh number. He has used a finite difference over relaxation procedure for the solution of the mass, momentum and energy transfer governing equations. Öztop and Dağtekin [3] studied the natural convection heat transfer and fluid flow of two heated partitions attached to the lower adiabatic wall for Ra numbers of 10^4–10^6. Enclosure is cooled from the left and top walls while the only heat source within the medium is due to the partitions whose length and positions were varied. They showed that the mean Nusselt number increased with the partition length. Karayiannis et al. [4] discussed a detailed analysis on the effects of a central partition, assumed both infinitely thin and isothermal, at the mean temperature of the hot and cold wall temperature on the heat transfer and flow inside the enclosure. Shi and Khodadadi [5] studied the almost perfectly conducting partition on the hot wall. Based on the obtained results, they proposed correlations to calculate Nusselt number as a function of relevant parameters. Acharya and Jetli [6] studied numerically the heat transfer and the fluid flow within a square cavity divided by a single obstacle, attached to the ceiling or to the floor. They considered different positions and heights of the partition. They showed that the heat transfer is strongly influenced by the height of the partition; nevertheless, its position has a rather weak effect on the total heat transfer. Bilgen [7] solved the natural convection problem in cavities with a thin fin on a hot wall. He found that Nusselt number increased with the increase in Rayleigh number, and decreased with the increase in fin length and relative conductivity ratio. Shahid and Naylor [8] studied the effects of the presence of a venetian blind on the thermal performance of single and double glazed windows, numerically. The blind was positioned adjacent to the indoor surface of either a single or a double glazed window and the coupled convection and radiation heat transfer problem was solved using a two-dimensional finite volume model. They showed that, the presence of a venetian blind can significantly improve the window energy performance. Also, it was showed that, the blind reduced the overall heat transfer rate through the window by reducing the thermal radiation from the indoor glazing. In a similar investigation, Avedissian and Naylor [9] studied free convective heat transfer in an enclosure with an internal louvered blind, numerically. Their study focused on the effects of Rayleigh number, enclosure aspect ratio, and blind geometry on the convective heat transfer. They presented their results for average Nusselt number by a correlation validated against experimental measurements. They also showed that this correlation can be combined with a simple one-dimensional model to closely predict the enclosure U-value. Almost, in all the above investigations a correlation has been obtained for

Manuscript received August 15, 2011, revised October 28, 2011.

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the Nusselt number. Recently, Yousefi et al. [10] have studied free convection heat transfer in a vertical cavity consisting of diverters. The aim of that study was to investigate the effect of confined diverters on free convection heat transfer in the vertical cavity. They found that, the maximum heat transfer occurs at the diverter angle of 150° and Rayleigh number of 12000. The main focus of the present study is to utilize imperialist competitive algorithm (ICA), to obtain the optimum free convection heat transfer in a vertical cavity consisting of diverters. ICA is a new evolutionary algorithm in the evolutionary computation field based on the human's socio-political evolution. The proposed method for the optimization was developed using MATLAB functions. This method has some advantages, such as simplicity, accuracy, and time saving. The experiments have been carried out using a Mach–Zehnder interferometer. A schematic representation of the problem is shown in figure 1. The diverter length L, diverter width H, thickness of each diverter t, pitch of the diverter p, cavity side length W, diverter angles θ, and also the boundary conditions are represented in this figure.

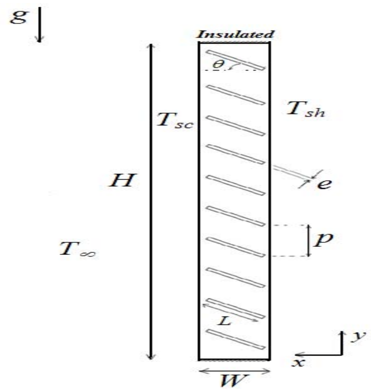

Fig. 1. Schematic of the problem

II. Experimental Setup

A. Interferometer

The experimental study was carried out using Mach–Zehnder interferometry (MZI) technique [10]. The interferometer consisted of a light source, a micro lens, a pinhole, two doublets, three mirrors and two beam splitters. Figure 2 shows the interferometer setup. Beam splitters BS_1 and BS2, along with plane mirrors M_1 and M_2 constituted the basic MZI. The laser beam gets expanded after passing through spatial filter and the doublet1. The expanded beam was splited into two equal beams by BS_1. One beam passes through the test section and the other through the undisturbed field. These two beams, again, recombine at BS_2. If the four optical plates, M_1, M_2, BS_1, and BS_2 are parallel, then an infinite fringe interferograms will be formed. Further information about MZI can be found in [11–13]. The used light source was a 10 mW Helium–Neon laser with a 632.8 nm wavelength. All the interferograms were digitized with a ‘‘ARTCAM-320P’’ 1/2″ CCD camera with 3.2 M pixels. To acquire the interferograms a camera was connected to a PC. Figure 3 shows some of the interferograms which were recorded by the CCD camera.

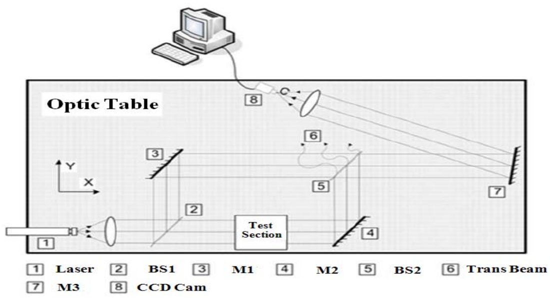

Fig .2. Schematic of (MZI) setup

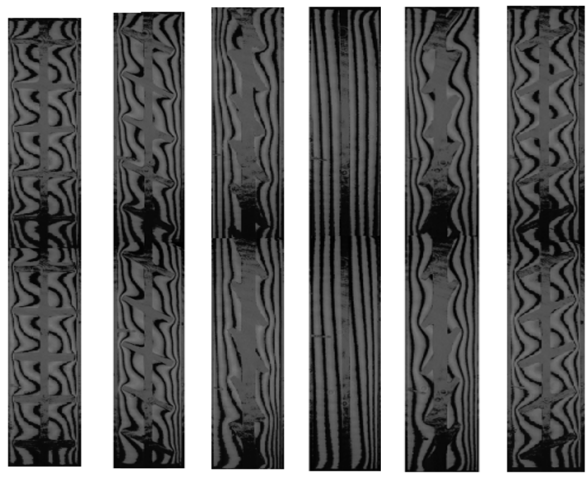
(a) (b) (c) (d) (e) (f)

Fig. 3. Interferograms of the cavity consisting of diverters for Ra= 12000 for (a) θ=0° (b) θ=30° (c) θ=60° (d) θ=90° (e) θ=120° (f) θ=150°

B. Experimental Test Section

The details of the vertical cavity used in the experiments [10] are shown schematically in figure 4. The length of each isothermal wall was chosen as 140 mm which caused the induced flow to be two-dimensional. Also, the wooden end caps with thermal conductivity of 0.05 W/m K [14] were installed on each aluminum plate bases to minimize the end effects. By passing electricity through the heater that was placed at the back of the aluminum plate and considering relatively thick-walled (16mm) aluminum plate, we achieved constant surface temperature. The uniformity of each plate surface temperature was experimentally validated by measuring it at 3 different locations. The differences in temperature readings for each aluminum plate surface were about 0.1˚C. The local surface temperatures of the heated aluminum plate were recorded via three type-K thermocouples, embedded vertically in the aluminum plate wall, as it is shown in figure 4. Two other thermocouples of the same type were used to measure the ambient and the reference temperatures for data reduction. All the temperatures were monitored continuously in a PC by a selector switch and a ‘‘TESTO 177 T4’’ four channel data logger. The laboratory pressure was recorded during all the experiments. The maximum uncertainties of temperature and pressure measurement for the present test condition were ±0.1˚C and ±100 Pa, respectively. In all of the experiments the heater voltage and current were recorded. In order to ascertain the accuracy of the measurements, the energy balance calculation for many cases was done by calculating free convection heat transfer from the fringe patterns of the

Mach–Zehnder interferometer and measuring electrical power input to the heaters. A compression between the heat transfer coefficients obtained by two methods shows a complete agreement. Four sets of ten-diverters of dimensions 167 m × 14 m × 1.5 m, with thermal conductivity of 0.05 W/m K with angle of 0°, 30°, 60°,90°,120° and 150° with respect to horizon were built to use in the cavity for each experiment with its associated angle. In each set, the diverters were glued to a thin rod. Two windows were used on both sides of the cavity for the prevention of external air to enter to the cavity. In order to eliminate the effect of any air disturbances on the experimental test section, the entire interferometer table was located within a top open transparent plastic enclosure of dimensions 3 m × 1.5 m × 1.5 m.

III. Imperialist Competitive Algorithm

The optimization problem can be easily described as to find an argument x whose relevant cost $f(x)$ is optimum, and it has been extensively used in many different situations such as industrial planning, resource allocation, scheduling, pattern recognition and so on. Different methods have been proposed to solve the optimization problem. Evolutionary algorithms, such as genetic algorithm [13,14], particle swarm optimization [15,16], taboo search [17-19], ant colony optimization [20-22], bees algorithm [23-25] and simulated annealing [26,27] are a set of algorithms that are introduced and suggested in the past decades for solving optimization problems in different science and engineering fields. Imperialist Competitive Algorithm (ICA) is an algorithm introduced for the first time in 2007 by Atashpaz-Gargari and Lucas [28] and used for optimizing inspired by the imperialistic competition and has a considerable relevance to several engineering applications [29-35]. Like other evolutionary ones, the proposed algorithm starts with an initial population. Population individuals called country are in two types: colonies and imperialists that all together form some empires. Imperialistic competition among these empires forms the basis of the proposed evolutionary algorithm. During this competition, weak empires collapse and powerful ones take possession of their colonies. Imperialistic competition hopefully converges to a state in which there exists only one empire and its colonies are in the same position and have the same cost as the imperialist [28]. Using this algorithm, one can find the optimum condition of the most functions. In this connection, the proposed model based on regression analysis is then embedded into the ICA to optimize the objective function. The goal of optimization algorithms is to find an optimal solution in terms of the variables of the problem (optimization variables). We form an array of variable values to be optimized. In Genetic Algorithm terminology, this array is called "chromosome", but here the term "country" is used for this array. In an N_{var} -dimensional optimization problem, a country is a $1 \times N_{\text{var}}$ array. This array is defined by:

$$country = [p_1, p_2, p_3, ..., p_{N_{\text{var}}}] \tag{1}$$

The variable values in the country are represented as floating point numbers. The cost of a country is found by evaluating the cost function f at the variables $(p_1, p_2, p_3, ..., p_{N_{\text{var}}})$ [28].

Then

$$cost = f(country) = f(p_1, p_2, p_3, ..., p_{N_{\text{var}}}) \tag{2}$$

The flowchart of the ICA algorithm is shown in figure 4. To start the optimization algorithm we generate the initial population of size N_{pop} . We select N_{imp} of the most powerful countries to form the empires. The remaining N_{col} of the population will be the colonies each of which belongs to an empire. Then we have two types of countries; imperialist and colony. To form the initial empires, we divide the colonies among imperialists based on their power. That is the initial number of colonies of an empire should be directly proportionate to its power. To divide the colonies among imperialists proportionally, we define the normalized cost of an imperialist by $C_n = c_n - \max\{c_i\}$, where c_n is the cost of nth imperialist and C_n is its normalized cost. Having the normalized cost of all imperialists, the normalized power of each imperialist is defined by [28]

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \tag{3}$$

From another point of view, the normalized power of an imperialist is the portion of colonies that should be possessed by that imperialist. Then the initial number of colonies of an empire will be

$$N.C._n = round\{p_n . N_{col}\} \tag{4}$$

where $N.C._n$, is the initial number of colonies of nth empire and N_{col} is the number of all colonies. To divide the colonies, for each imperialist we randomly choose $N.C._n$ of the colonies and give them to it. These colonies along with the imperialist will form nth empire. A schematic representation of the initial population of each empire can be observed in figure 5. As shown in this figure, bigger (powerful) empires have more number of colonies while smaller (weaker) ones have less [28]. As mentioned, imperialist countries started to improve their colonies. We have modeled this fact by moving all the colonies toward the imperialist. This movement is shown in figure 6, where the colony moves toward the imperialist by x units. The new position of colony is shown in a darker color. The direction of the movement is the vector from colony toward imperialist. In this figure x is a random variable with uniform or any proper profile [28]. Then for x we have

$$x \sim U(0, \beta \times d) \tag{5}$$

where β is a number greater than 1 and d is the distance between colony and imperialist. A $\beta > 1$, causes the colonies to get closer to the imperialist state from both sides.

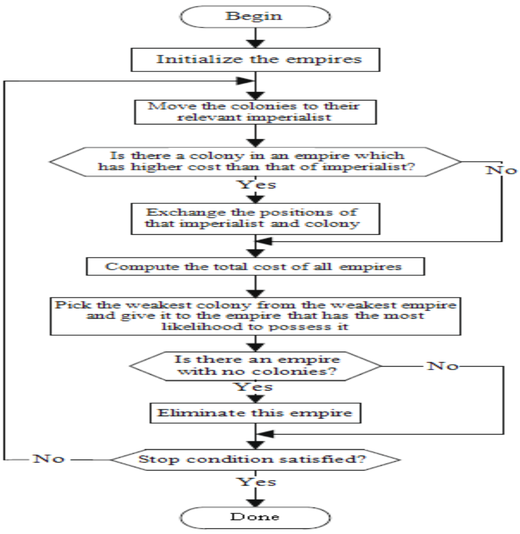

Fig. 4. The procedure of the proposed algorithm [28]

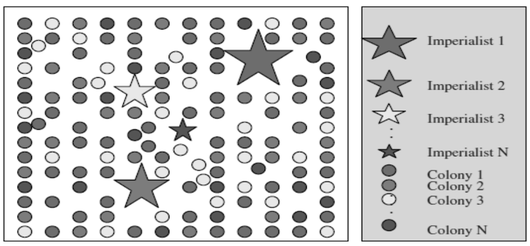

Fig. 5. Generating the initial empires: the more colonies an imperialist possess, the bigger its relevant ★ mark [28]

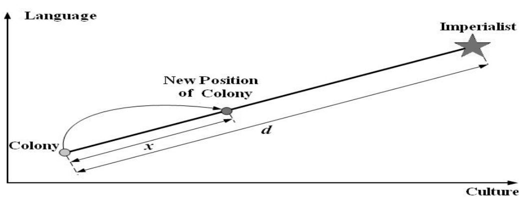

Fig. 6. Moving colonies toward their relevant imperialists [28]

To search different points around the imperialist we added a random amount of deviation to the direction of movement. Figure 7 shows the new direction. In this figure, θ is a random number with uniform or any proper profile. Then

$$\theta \sim U(-\gamma, \gamma) \tag{6}$$

where γ is a parameter that adjusts the deviation from the original direction. Nevertheless, the values of β and γ are arbitrary, in most of our implementation a value of about 2 for β and about $\pi/4$ (Rad) for γ, have resulted in good convergence of countries to the global minimum.

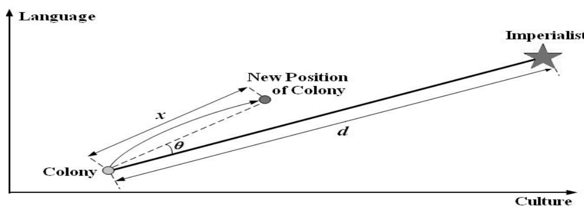

Fig. 7. Moving colonies toward their relevant Imperialist in a randomly deviated direction [28]

IV. ICA Optimization Results and Discussion

In order to use ICA, the optimization (input) and output variables with their levels must be determined. As it can be seen from table1, Rayleigh number (Ra) in four levels ranging from 6×10^3 to 1.2×10^4, diverter angle in six levels from 0° to 150° as optimization variables, and average heat flux (q″) as output variable. Then the experiments were carried out based on general full factorial design. After data reduction, the values of average heat flux for twenty four different tests were determined.

The values of heat flux are shown in table2. Then, a correlation for heat flux in terms of Rayleigh number and diverter angle in the coded form was developed as given below:

$$q'' = 128 + 23.6\,Ra + 19.1\sqrt[3]{\theta} + 8.58\,\theta^2 - 2.10\,\theta^3 - 0.291\,\theta^4 + 0.0811\,\theta^5 + 0.0122\,\theta^4\,Ra$$

The adjusted R squared of the above correlation is 92%. After that, the regression equation was embedded into the ICA to be optimized. The main parameters used in ICA model are brought in table3. Also, the results of optimization are shown in table4. Figure 8 shows the minimum and mean cost of all imperialists. As it can be understood from these results, the minimum value (heat transfer) of the objective function (q″) occurs at the diverter angle of 75°. Because in this angle, the warm air near to the warm wall prevents the falling down of cold air. This restriction leads to the decrease in the heat transfer enormously. Again, according to table4, the maximum value (heat transfer) of the objective function (q″) occurs at the diverter angle of 150°, because in this angle, the fluid motion is easier, therefore the fluid velocity will be increased and consequently heat transfer increases.

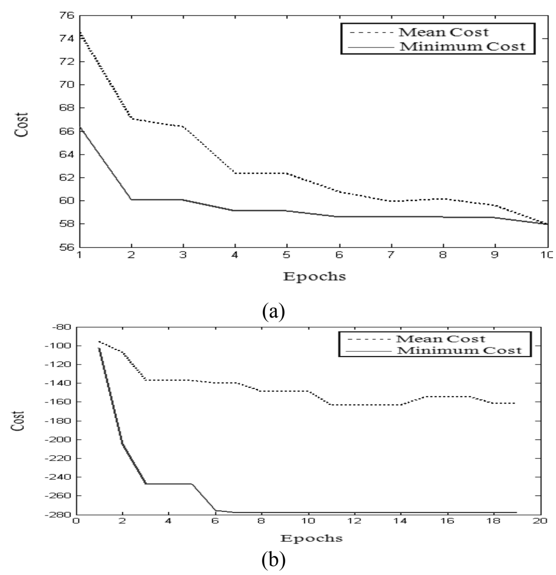

Fig. 8. Mean and minimum cost of all imperialists versus epochs for (a) minimum heat transfer, (b) maximum heat transfer

V. Conclusions

In this paper, experiments were carried out using a Mach-Zehnder interferometer based on general full factorial design of experiments for generating data. A correlation was developed to gain relationship between two optimization parameters namely Rayleigh number, the diverter angle and an output variable, and the average heat flux. Then the correlation was embedded into the ICA to be optimized. According to the optimization results, the maximum and minimum values (heat transfer) of the correlation (q″) occur at the diverter angle of 150^o and 75^o, respectively.

TABLE I: OPTIMIZATION VARIABLES IN HEAT TRANSFER AND THEIR LEVELS

	Notation	Coding					
Optimization Variables		-5	-3	-1	+1	+3	+5
Rayleigh number	Ra	-	6000	8000	10000	12000	-
Diverter angle	θ	0	30	60	90	120	150

TABLE II: DESIGN MATRIX

No	Rayleigh number, Ra	Diverter angle, θ	Convective heat flux, q″ (W/m^2)
1	-3	-5	57.3912
2	-3	-3	78.7008
3	-3	-1	83.2129
4	-3	1	64.2982
5	-3	3	108.316
6	-3	5	88.9000
7	-1	-5	103.705
8	-1	-3	167.635
9	-1	-1	103.108
10	-1	1	120.066
11	-1	3	145.800
12	-1	5	149.224
13	1	-5	156.628
14	1	-3	242.654
15	1	-1	128.762
16	1	1	195.753
17	1	3	200.613
18	1	5	210.476
19	3	-5	230.556
20	3	-3	275.276
21	3	-1	161.586
22	3	1	233.241
23	3	3	234.149
24	3	5	288.720

TABLE III: RESULTS OF OPTIMIZATION

Number of total countries	150
Number of initial imperialist countries	11
Number of epochs (decades)	10, 19
Revolution rate	0.3
Assimilation coefficient	2
Assimilation angle	0.5
Cost function	$\pm q''$ [1]

[1]the minus sign refers to maximum heat transfer and the plus one refers to minimum heat transfer.

TABLE IV: THE SELECTED OPTIMAL PARAMETERS OF PROPOSED ICA MODEL

		Ra	θ (degree)	q″(W/m^2)
Maximum heat transfer	Coded value	3.0000	5.0000	277.8980
	Decoded value	12000	150	
Minimum heat transfer	Coded value	-3.0000	0.0000	58.3512
	Decoded value	6000	75	

NOMENCLATURE

e Thickness of each diverter(mm)

g gravitational acceleration (m/s^2)

H Length of the cavity (mm)

L Length of each diverter (mm)

p Pitch of diverters (mm)

q″ Average heat flux (W/m^2)

Ra Rayleigh number based on the cavity side length

T Temperature (K)

W Cavity side length (mm)

x Direction normal to the hot surface

y Direction along the hot surface

Greek symbols

θ Diverter angle

Subscripts

Col referrers to the colony

Imp referrers to the imperialist

Pop referrers to the population

Sc referrers to the cold condition

Sh referrers to the warm condition

∞ Referrers to the ambient condition

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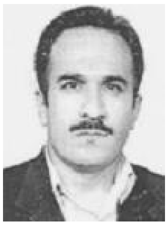

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1. Experimental Study of Natural Convection Heat Transfer From Vertical Array of Isothermal Horizontal Elliptic Cylinders, *Journal of Experimental Thermal and Fluid Science*, vol.32, 240-248, 2007.

2. Effect of Inclination Angle on Free Convection from an Elliptic Tube Confined between Walls, Heat Transfer Research, vol.40, 537-553, 2009.

3. Effects of confining walls on heat transfer from a vertical array of isothermal horizontal elliptic cylinders, Experimental Thermal and Fluid Science vol.33, 983–990, 2009.

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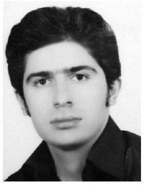

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