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# Optimization of heat transfer in an air cooler equipped with classic twisted tape inserts using imperialist competitive algorithm

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ABSTRACT

In this paper a novel optimization algorithm based on Imperialist Competitive Algorithm (ICA) is used to optimize the heat transfer in an air cooled heat exchanger equipped with the classic twisted tape inserts. This algorithm has some advantages such as simplicity, accuracy, and time saving. Experiments included the twist ratio ranging from 1.76 to 3.53. Also, the Reynolds number varied from 4021 to 16,118. After data reduction, the regression equation of average Nusselt number was obtained as a function of Reynolds number and the twist ratio. Then the cost function was optimized by the use of ICA. One can be sure that the Nusselt number 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 twist ratio must be at the lowest level.



## 1. Introduction

It has been commonly known that the heat transfer rate of heat exchangers especially for single-phase flows can be improved through many enhancement techniques. In general, heat transfer enhancement (HTE) techniques can be divided into two categories: (1) active techniques which need external power source and (2) passive techniques which do not need to external power source. Some examples of passive HTE methods include: insertion of twisted stripes and tapes [1,2], insertion of coil wire and helical wire coil [3,4] and mounting of turbulent decaying swirl flow devices [5,6]. Despite of the high pressure drop caused by insert in embedded tubes, the use of tube insert in heat exchangers has received a lot of attention during the last two decades [2,7]. The increase in turbulence intensity and swirling flow may be the main reasons for HTE induced by tube inserts. An experimental study was carried out on heat transfer in a round tube equipped with propeller type swirl generators by Eiamsa-ard et al. [8]. The effects of the blade angle, pitch ratio and number of blades on Nusselt number and pressure loss were also studied. Chang et al. [9,10] studied the heat transfer enhancement in a tube fitted with the serrated twisted tapes and broken twisted tapes. Shabanian et al. [11] studied the heat transfer enhancement in an air cooler equipped with different tube inserts. It was observed that using different tube inserts (butterfly, jagged and classic twisted tape inserts), increase the heat transfer from the air cooler. Also, observations showed that by using the butterfly insert with an inclined angle of 90°, maximum heat transfer is obtained. Also, results have revealed that the difference between the heat transfer rates obtained by employing the classic and jagged inserts reduces by decreasing twist ratio.

The main focus of the present study is based on the experimental data obtained by Shabanian et al. [11] for optimizing heat transfer from the air cooler equipped with the classic twisted tape inserts using Imperialist Competitive Algorithm (ICA). 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.

## 2. Experimental apparatus

A schematic view of the experimental rig is shown in Fig. 1a [11]. The rig consists of two fans and a set of copper tubes. The set of tubes has three sections including calming section, bent tube and outlet section. The fluid enters the calming section having a length of 2 m in order to eliminate the entrance effect. The temperature and pressure are measured at the end of this section at the inlet of bent tube section. Then, the fluid passes through nine bends in the 6.5 m length of the bent tube and reaches to the outlet section. The pressure and the temperature are measured at the outlet

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**Nomenclature**

| | |
|---|---|
| $A$ | heat transfer area ($m^2$) |
| $Q$ | heat transfer rate (W) |
| $C_p$ | specific heat capacity (kJ/kg K) |
| $D$ | diameter of the smooth tube (m) |
| $D_h$ | hydraulic diameter (m) |
| $h$ | heat transfer coefficient (W/$m^2$ K) |
| $K$ | thermal conductivity (W/m K) |
| $m$ | mass flow rate (kg/s) |
| $Nu$ | Nusselt number |
| $Pi$ | axial distance of twist pitch (m) |
| $P$ | static pressure (Pa) |
| $R$ | twist ratio $R = Pi/D$ |
| $Re$ | Reynolds number |
| $T$ | temperature (K) |
| $U$ | mean velocity (m/s) |

*Greek symbols*

| | |
|---|---|
| $v$ | kinematic viscosity ($m^2$/s) |

*Subscripts*

| | |
|---|---|
| *col* | referrers to the colony |
| *imp* | referrers to the imperialist |
| *pop* | referrers to the population |

section. The 50 W fans with 1400 rpm rotation speed are placed in at a 20 cm distance beneath the bent tube and entire assembly is enclosed in a 60 × 100 × 50 cm cubic channel [11]. Hot water from a 100 l reservoir equipped with heaters enters the bent tube after passing through rotameter with 58 °C temperature. Water volumetric flow rate varies from 100 l/h to 400 l/h, corresponding to Reynolds numbers from 4021 to 16,118. The tube inlet and outlet water pressure and temperature are measured through two

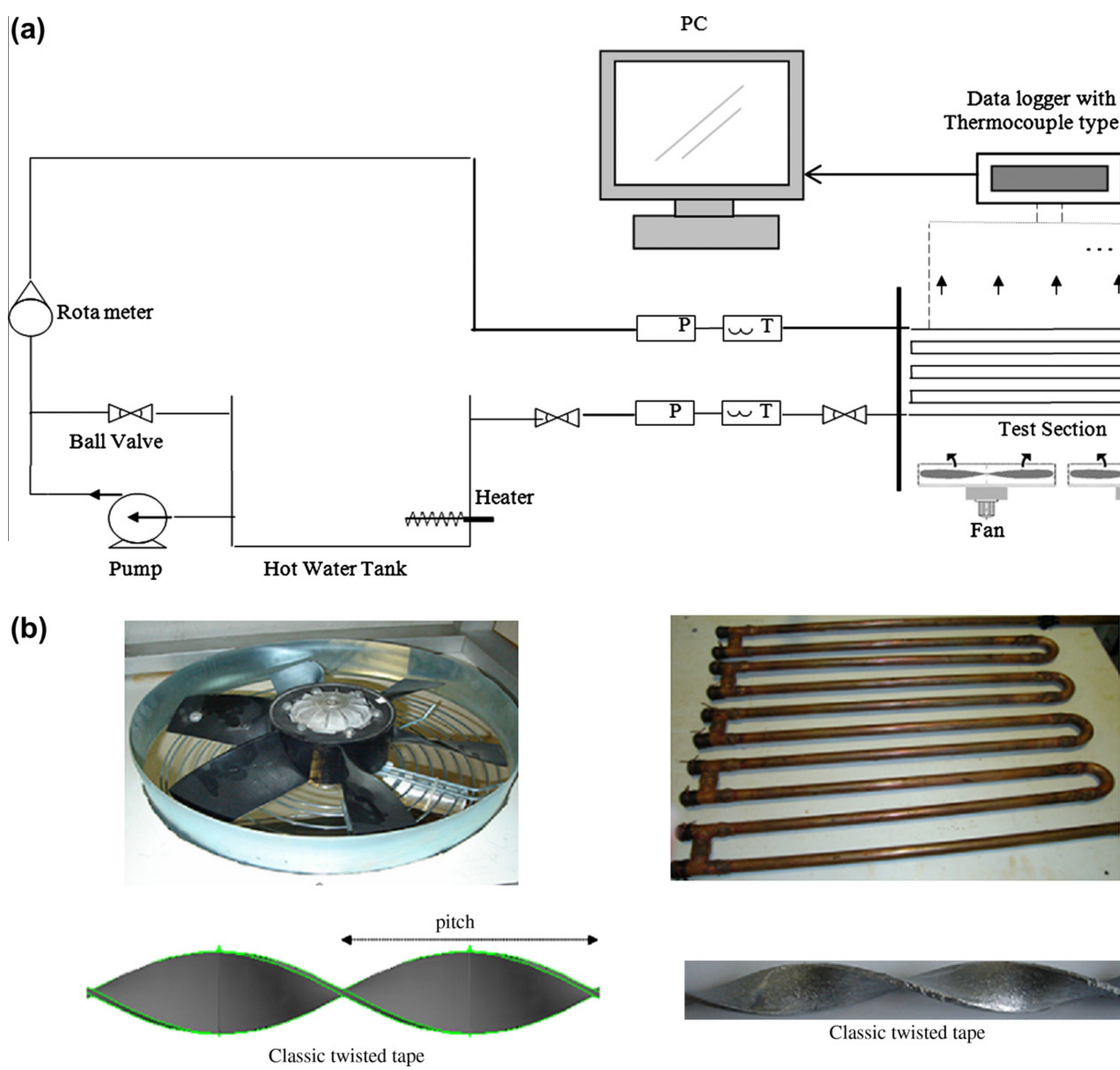


**Fig. 1.** (a) Schematic diagram of the experimental rig and (b) the used tools in the experiment [10].

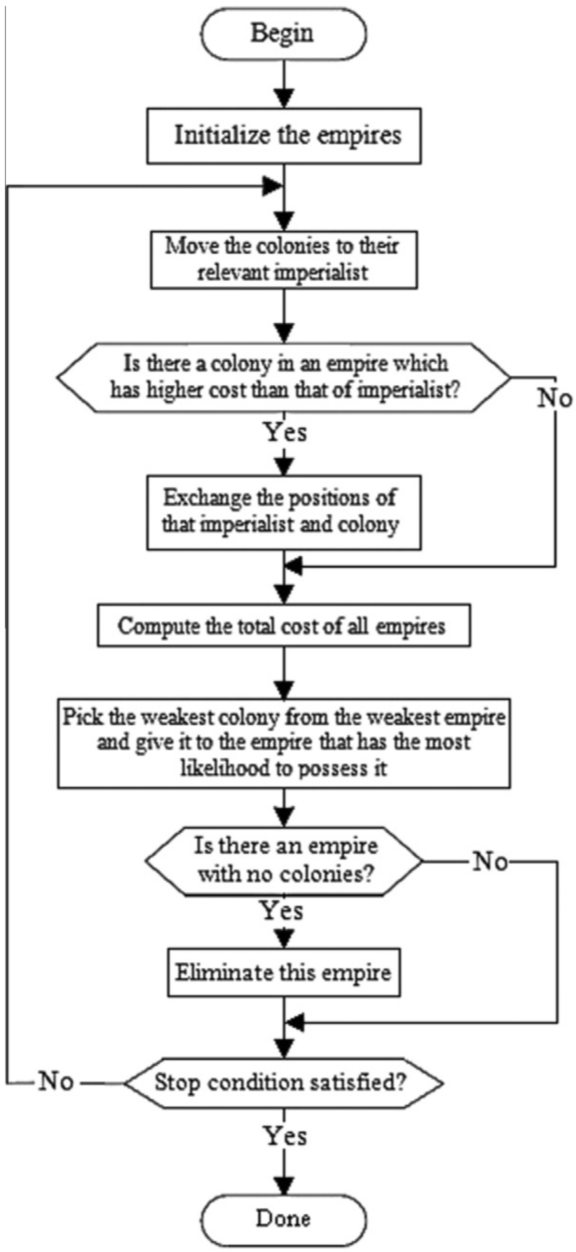


**Fig. 2.** Generating the initial empires: the more colonies an imperialist possess, the bigger its relevant ★ mark [28].

pressure transmitters and a copper-constantan thermocouple [11]. Moreover, in order to determine the average Nusselt number, the temperatures at 20 different positions on the outer surface of the tube are measured. All 20 temperature sensing probes are connected to a data logger set. In the experiments, the classic inserts are placed in the bent tube. Fig. 1b shows the bent tube, fan and tube inserts used in the experiment. The tube applied here has 17 mm of inner diameter and 1 mm thickness. The classic twisted tape inserts having 15 mm width and 1 mm thickness with four twist ratio, defined as the ratio of the axial distance of twist pitch to the tube diameter such as 1.76, 2.35, 2.94 and 3.53.

## 3. Data reduction

In order to express the experimental results in a more efficient way, the measured data are reduced using the following procedure [11]:

The heat transfer rate resulted from the hot fluid in the tubes is expressed as:

$$Q = mC_p(T_o - T_i) \tag{1}$$

On the other hand, the heat transfer rate to the air surrounded the tube is approximated by:

$$Q = hA(\overline{T}_w - T_b) \tag{2}$$

where

$$T_b = (T_o + T_i)/2 \quad \text{and} \quad \overline{T}_w = \left(\sum T_w\right)/20 \tag{3}$$

$T_w$ is the local wall temperature and is measured at the outer wall surface of the tubes. Also, $T_o$ and $T_i$ are the outlet and inlet temperatures of the fluid, respectively and $T_b$ is the average temperature of the outlet and inlet temperatures. The relations used in calculation of the average heat transfer coefficient and the average Nusselt number are as follows:

$$h = mC_p(T_o - T_i)/A(\overline{T}_w - T_b) \tag{4}$$

$$Nu = hD_h/K \tag{5}$$

In addition, the Reynolds number is obtained according to the following equation:

$$\mathrm{Re} = UD_h/\upsilon \tag{6}$$

In the present work, the uncertainties of experimental measurements are determined based on ANSI/ASME [11,12]. The maximum uncertainties for Nu and Re are estimated at 7% and 5.2%, respectively.

## 4. 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. 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). Therefore, an array of variable values to be optimized is formed. In Genetic Algorithm terminology, this array is called "chromosome", but here the term "country" is used for this array. In an $N_{\text{var}}$ -dimensional

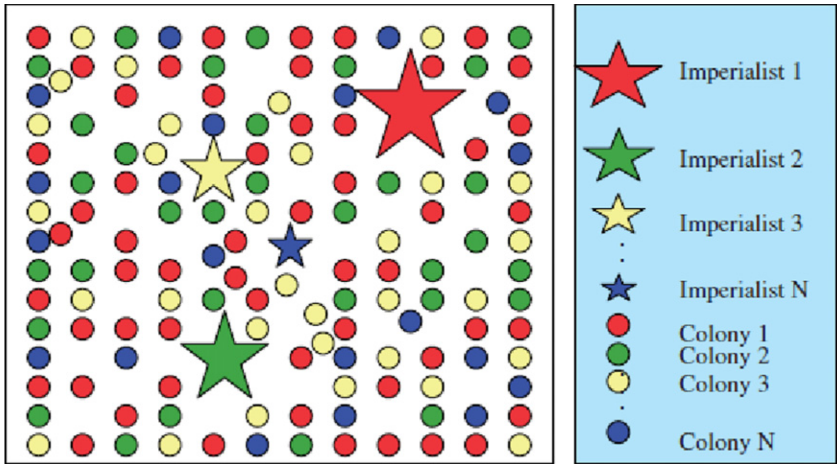


**Fig. 3.** Moving colonies toward their relevant imperialists [28].

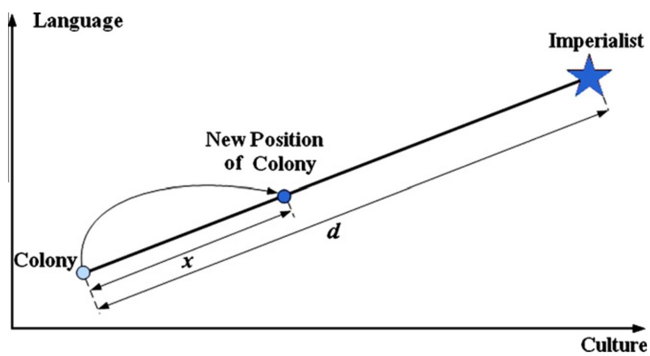


**Fig. 4.** Moving colonies toward their relevant imperialist in a randomly deviated direction [28].

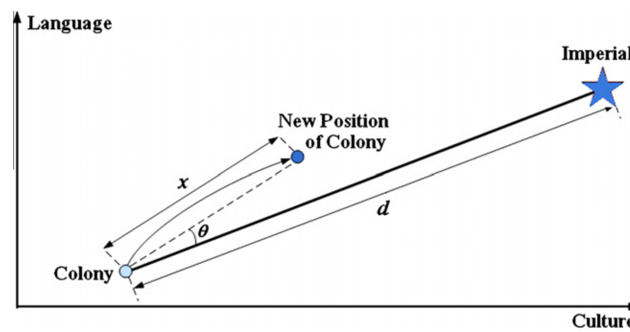


**Fig. 5.** Procedure of the proposed algorithm [28].

optimization problem, a country is an $1 \times N_{\text{var}}$ array. This array is defined by:

$$\text{country} = [p_1, p_2, p_3, \ldots, p_{N_{\text{var}}}] \tag{7}$$

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 $(p_1, p_2, p_3, \ldots, p_{N_{\text{var}}})$ [28]. Then *cost*

$$= f(\text{country}) = f(p_1, p_2, p_3, \ldots, p_{N_{\text{var}}}) \tag{8}$$

The flowchart of the ICA algorithm is shown in Fig. 2. To start the optimization algorithm the initial population of size $N_{pop}$ is generated. The $N_{imp}$ of the most powerful countries to form the empires is selected. The remaining $N_{col}$ of the population will be the colonies each of which belongs to an empire. Now, there are two types of countries; imperialist and colony. To form the initial empires, the colonies are then divided among imperialists, based on their powers. That is the initial number of colonies of an empire should be directly proportionate to its power. To divide the colonies among imperialists proportionally, the normalized cost of an imperialist are defined by $C_n = c_n - \max\{c_i\}$, where $c_n$ is the cost of $n$th 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]

$$p_n = \left| C_n \middle/ \sum_{i=1}^{N_{imp}} C_i \right| \tag{9}$$

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

$$N.C._n = round\{p_n.N_{col}\} \tag{10}$$

where $N.C._n$, is the initial number of colonies of $n$th empire and $N_{col}$ is the number of all colonies. To divide the colonies for each imperialist, $N.C._n$ of the colonies is chosen randomly and is given them to it. These colonies along with the imperialist will form $n$th empire. A schematic representation of the initial population of each empire can be observed in Fig. 3. 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. This fact has been modeled by moving up all the colonies toward the imperialist. This movement is shown in Fig. 4, 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 $x$

$$x \sim U(0, \beta \times d) \tag{11}$$

where $\beta$ 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.

To search different points around the imperialist a random amount of deviation was added to the direction of movement. Fig. 5 shows the new direction. In this figure, $\theta$ is a random number with uniform or any proper profile. Then

$$\theta \sim U(-\gamma, \gamma) \tag{12}$$

where $\gamma$ is a parameter that adjusts the deviation from the original direction. Nevertheless, the values of $\beta$ and $\gamma$ are arbitrary, in most of our implementation a value of about 2 for $\beta$ and about $\pi/4$ (Rad)

**Table 1**
Optimization variables in heat transfer and their levels.

| | Notation | Coding | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Optimization Variables | | −3 | −2 | −1 | 0 | +1 | +2 | +3 |
| Reynolds number | Re | 4021 | 6037 | 8053 | 10,076 | 12,085 | 14,101 | 16,118 |
| Twist ratio | R | 1.76 | – | 2.35 | – | 2.94 | – | 3.53 |

**Table 2**
Design matrix.

| No. | Reynolds number, Re | Twist ratio, R | Average Nusselt number, Nu |
|---|---|---|---|
| 1 | −3 | −3 | 49.0730 |
| 2 | −2 | −3 | 69.1300 |
| 3 | −1 | −3 | 85.4150 |
| 4 | 0 | −3 | 101.830 |
| 5 | 1 | −3 | 115.942 |
| 6 | 2 | −3 | 133.120 |
| 7 | 3 | −3 | 149.153 |
| 8 | −3 | −1 | 44.1530 |
| 9 | −2 | −1 | 62.4920 |
| 10 | −1 | −1 | 79.6880 |
| 11 | 0 | −1 | 93.4660 |
| 12 | 1 | −1 | 108.338 |
| 13 | 2 | −1 | 121.757 |
| 14 | 3 | −1 | 135.730 |
| 15 | −3 | 1 | 42.1080 |
| 16 | −2 | 1 | 57.4140 |
| 17 | −1 | 1 | 72.7200 |
| 18 | 0 | 1 | 86.8900 |
| 19 | 1 | 1 | 99.0000 |
| 20 | 2 | 1 | 114.104 |
| 21 | 3 | 1 | 127.140 |
| 22 | −3 | 3 | 37.8910 |
| 23 | −2 | 3 | 50.7500 |
| 24 | −1 | 3 | 65.8460 |
| 25 | 0 | 3 | 79.2650 |
| 26 | 1 | 3 | 91.0060 |
| 27 | 2 | 3 | 104.400 |
| 28 | 3 | 3 | 116.160 |

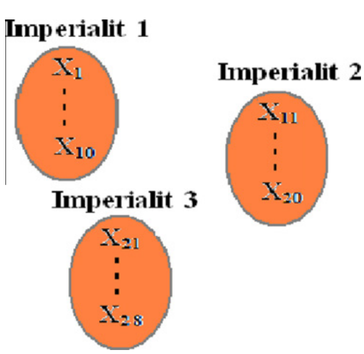


**Fig. 6.** The physical interpretation of ICA in terms of heat transfer parameters.

for $\gamma$, have resulted in good convergence of countries to the global minimum.

## 5. 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 Table 1, Reynolds number (Re) in seven levels, ranging from 4021 to 16,118, twist ratio (R) in four levels from 1.76 to 3.53 as optimization variables, and average Nusselt number (Nu), as output variable. Then the experiments were carried out based on general full factorial design. After data reduction, the values of average Nusselt number for twenty eight different tests were determined [11].

**Table 3**
The selected optimal parameters of proposed ICA model.

| | | Re | R | Nu |
|---|---|---|---|---|
| *Maximum heat transfer* | Coded value | 3.0000 | −3.0000 | 147.827 |
| | Decoded value | 16,118 | 1.76 | |

**Table 4**
Results of optimization.

| | |
|---|---|
| Number of total countries | 150 |
| Number of initial imperialist countries | 12 |
| Number of epochs (decades) | 3 |
| Revolution rate | 0.3 |
| Assimilation coefficient | 2 |
| Assimilation angle | 0.5 |
| Cost function | −Nu |

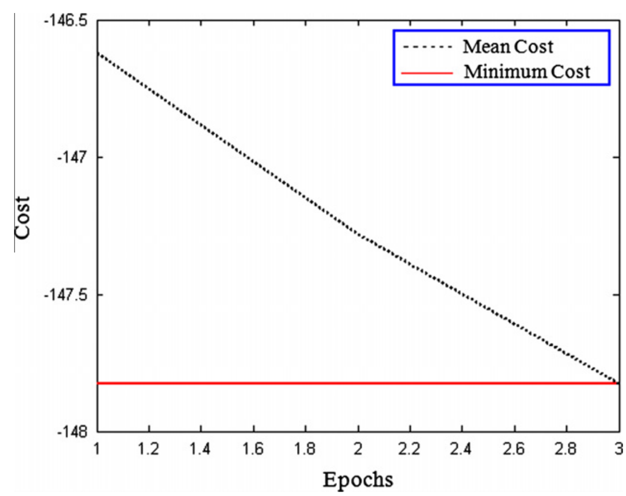


**Fig. 7.** Mean and minimum cost of all imperialists versus epochs for maximum heat transfer.

The values of average Nusselt number are shown in Table 2. Then, a correlation for the Nusselt number in terms of Reynolds number and the twist ratio in the coded form was developed as given below:

$$Nu = 90.2 + 14.7Re - 3.72R - 0.276Re^2 - 0.539Re \times R \quad (13)$$

where the adjusted $R$ square of the correlation is 99.9%. Subsequently, the regression equation was embedded into the ICA to be optimized. In the ICA terminology, country is basically a vector of input parameters as below:

$$X_i = \begin{bmatrix} Re_i \\ R_i \end{bmatrix} \quad (14)$$

Population in defined as the collection of countries competing internally in order to minimize their costs to become an imperialist. It also indicates the optimum level of those input parameters which gives maximum heat transfer. After the competition between the countries is completed then the second stage is started.

The second stage is the external competition between imperialists. In this stage, that particular Imperialist having the least cost is taken as the winner as shown in Fig. 6, which is equivalent to the maximum heat transfer obtained in this study. The main parameters used in ICA model are brought in Table 3. Also, the results of optimization are shown in Table 4. Fig. 7 shows the minimum and mean costs of all imperialists. As it can be understood from these results, the maximum value of Nusselt number being the objective function occurs at, the twist ratio of 1.76, Reynolds number of 16,118 meaning that, by adjusting the twist ratio to its lowest level and Reynolds number to its highest level, as shown in Table 1, maximum heat transfer is obtained. This can be explained by that, the swirl intensity increases by decreasing the twist ratio and therefore, increases the Nusselt number.

## 6. Conclusions

In this paper, experiments were carried out based on general full factorial design of experiments for generating data. A correlation was developed to gain relationship between two optimization parameters namely Reynolds number, the twist ratio and an output variable, the average Nusselt number. Then the correlation was embedded into the ICA to be optimized. Simplicity, accuracy, and time saving are some of advantages of the ICA algorithm. According to the optimization results, the maximum value (Nusselt number) of the correlation (Nu) occurs at the twist ratio of 1.76.

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