OPTIMIZACIJA GEOMETRIJSKIH VELIČINA SOLARNIH PRIJEMNIKA HEURISTIČKIM OPTIMIZACIONIM METODAMA

OPTIMIZATION OF SOLAR COLLECTOR GEOMETRIC PARAMETERS USING A HEURISTIC OPTIMIZATION METHODS

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Ovaj rad predstavlja nastavak istraživanja grupe autora u oblasti optimizacije stepena iskorišćenja solarnih prijemnika sunčeve energije. Dosadašnji rad se zasnivao na metodi optimizacije poznatoj kao metoda slučajne pretrage, koja je jedna od najstarijih heurističkih optimizacionih metoda. U radu su rezutati prethodni istraživanja upoređeni sa rezultatima dobijenim novom metodom optimizacije koja se naziva Teaching-Learning based optimization – TLBO. Predstavljen je način funkcionisanja ove metode, kao njena primena na optimizaciju solarnih prijemnika. Za potrebe novog rada unapredjen je dosadašnji matematički model, kako bi u optimizaciju bio uključen što veći broj promenljivih koje imaju uticaja kako na proizvodnju tako i na cenu solarnih prijemnika. U obzir su uzeti prijemnici sa cevima kvadratnog poprečnog preseka, kao i prijemnici sa cevim okruglog poprečnog preseka. Izvedeni su zaključci i data je uporedna analiza rezultata dobijenih metodom slučajne pretrage i metodom TLBO.

Ključne reči: *solarni prijemnici, faktor iskorišćenja, metoda slučajne pretrage, teachnig-learning based optimization.*

This paper is an extension of ongoing research in the field of solar collector efficiency optimization. The present research is based on a method known as a random search optimization, which is one of the oldest heuristic optimization methods. In this paper, the results of previous research are compared to results of a new optimization method named the Teaching-Learning based optimization - TLBO. It is presented the mode of this method operation, as well as its application in optimization of solar collectors. For the TLBO method an extended mathematical model is used in order to involve as many variables as it passible, which affect both the production and the costs of solar collectors. This research takes into consideration the collectors with the cross section of square pipe profile and collectors with the round

cross section pipe profile. At the end of the paper conclusions for the parallel analysis of the results obtained by the random search method and TLBO.
Key words: *solar collectors, utilization factor, random search optimization method, teaching-learning based optimization.*

Introduction

A popular field of research in the past few tears is the efficiency of solar energy use. Using solar radiation energy can, through transformation, give heat, electrical and chemical energy. Due to the cost effectiveness of solar energy exploitation the greatest use of solar collectors is for heating water. Solar panels are devices which through absorbing solar rays, transform radiation energy into heat energy of the fluid which is flowing through the collector. Depending on the desired temperature of the working fluid flat solar panels are used which can achieve temperatures over100 ^{0}C or solar collectors which focus solar radiation onto a small space, in theory into a single spot, and can achieve very high temperatures of even over 3000 ^{0}C.

The development of design and production technology of flat solar collectors is with the goal of increasing their efficiency, decreasing the cost of production and other undesirable effects, which presents a very attractive research direction. Positive effects in the development of solar collectors can be achieved through optimization of their geometrical values, which is the orientation of this research.

Farhat et al. [1] optimized solar collectors in order to improve their characteristics. Their research covers a large number of parameters: absorber area, gross dimensions, pipe diameter of circular cross-sections, input and output temperatures, heat loss, etc. Authors of paper [2] concluded how to choose optimal characteristics in order to increase the efficacy of solar collectors. In paper [3] Vargas et al. presented a maximization of performances of solar collectors according to their real time application. Authors of paper [4] optimized solar collectors from a thermo-ecological aspect. Optimization of collector types according to climate conditions was done by authors in paper [5]. In paper [6] authors researched optimal characteristics of solar collectors from an internal element standpoint with square cells, placed in a honeycomb formation. This paper includes the analogy of natural solutions as an alternative to the development of solar collectors.

There is a large number of heuristic optimization methods which are used today for solving engineering problems. The dominant of them are Genetic Algorithm (GA), Particle Swarm Optimization (PSO), Ant Colony Optimization (ACO), Teaching Learning Based Optimization (TLBO), and many others. TLBO represents a modern heuristic method primarily developed for solving engineering problems. The algorithm was developed in 2011 [7] and consists of two basic phases, Teacher Phase, and Learner Phase. The algorithm was tested on numerous problems [8, 9] very demanding for optimization, which verified the operation of this method. In this paper the benefits of using TLBO method over the Random search method are presented.

Heuristic optimization methods

Random search method

Random search method is one of the oldest heuristic optimization methods. The method is based on narrowing the given search interval when the goal function achieves an extreme value. In the following steps the search for an extreme value in the shortened search interval is conducted. The steps are repeated until a satisfactory solution is achieved. This method can, in theory, work with an infinite number of variables and with an infinite number of constraints. Also, the random search method can search for both minimal and maximum values of a function. For the purposes of this research an algorithm has been developed which can work for any given values of the interval, [10]. The solution is derived in MS Excel. A bloc diagram of the random search algorithm is given in figure 1.

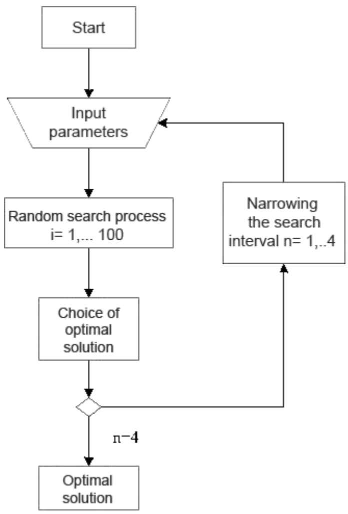


Figure 1 – Basic algorithm for random search

The start of the algorithm operation consists of the input of variables and determining constraints. With the introduction of variables, the search interval is determined. After that, the method is processed, followed by the choice of optimal solution in that interval, in order to finish the step with a narrower interval. The narrowing of the interval is done in four iterations in order to achieve a satisfactory precision of the solution.

Teaching-learning based optimization method

The algorithm consists of two key phase- Teacher and Learner phases. In the beginning the number of students is defined, which represents the total number of potential solutions. From this group the best value which can become the teacher can be separated. The best solution in an iteration is the teacher for the next iteration. The teacher can be named X_{Teacher} and this value is tied to the teacher phase. Aside from that it is necessary to determine the mean value, X_{Mean}, for the whole solution. The mean value represents the new group of variables, where each variable has a mean value of the total number of students. The algorithm structure is shown in figure 2.

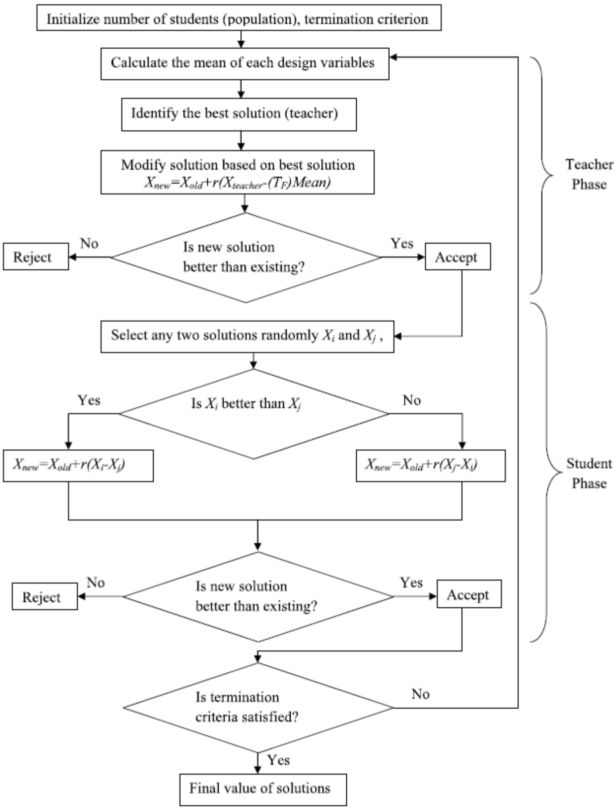


Figure 2. Structure of Teaching-Learning-Based optimization [7]

Teacher Phase

The first phase of the algorithm is the Teacher Phase, which directly influences convergence. Each teacher strives to increase the quality of his students. The new iteration value can be determined according to the following expression.

$$X_{\text{New}} = X_{\text{Old}} + r_i \left(X_{\text{Teacher}} - T_{\text{F}} X_{\text{Mean}} \right) \tag{1}$$

The new value in this phase X_{New} will be accepted only if it is better than the previous X_{Old} , and if it suits all the constraints. Random value, *r*, can have a quantitate value in the interval between 0 and 1. Random value T_F can only be 1 or 2, depending on the iteration. In each iteration this phase is repeated and thereby the solution converges towards the optimum. Aside from this, for convergence, the Learner Phase is also important.

Learner Phase

The basic working principle of this phase is the interaction between students. In the vase that $X_i > X_j$ where these are values of two randomly selected students in the algorithm, the following equation is used.

$$X_{\text{New}} = X_{\text{Old}} + r\left(X_{\text{i}} - X_{\text{j}}\right) \tag{2}$$

The second case is when $X_i < X_j$ and then the algorithm uses the following expression.

$$X_{\text{New}} = X_{\text{Old}} + r\left(X_{\text{j}} - X_{\text{i}}\right) \tag{3}$$

Random value *r* is in the interval between 0 and 1, and the new value is adopted only if it has a better value than the previous one.

The advantage of Teaching-Learning-Based optimization algorithm is in that its creators recognized modern tendencies to decrease the number of parameters required for operation and that it is easy to use. Aside from this it has exceptional convergence characteristics and fast operating speed, which makes it good for solving complex engineering problems.

Comparison results of Random search and TLBO methods

For the purposes of this paper authors used mathematical model, parameter intervals and constants from their previous research [10]. Efficiency optimization using TLBO on models of flat solar collectors with circular cross-section pipes, and rectangular cross-section pipes. Compared to previous research of these authors, the analysis omits the flat solar collector with a square cross-section. The omission is due to the fact that this cross-section has proven to have the lowest efficiency.

For optimization of solar collectors with rectangular cross-section pipes, the following objective function was used:

$$F' = \frac{\dfrac{1}{U_L}}{W_f \left[\dfrac{1}{U_L \left[\left(W_f - W_o \right) F + W_o \right]} + \dfrac{1}{C_b} + \dfrac{1}{2\left(W_i + H_i \right) H_{fi}} \right]} \tag{4}$$

where: C_b, conductivity between the rectangular pipe and absorber (W/mK), W_i, the internal width of the pipe (m), W_o, outer width of pipe (m), H_i inner height of pipe (m), *F*, standard efficiency of the rib (-), *F'*, factor of efficiency of the solar collector (-),H_{fi}, heat conductivity coefficient in the ribs (W/m^2 K) U_L, total losses coefficient (W/m^2 K) and W_f, width of rib (m).

For optimization of solar collectors with circular cross-section pipes, the following objective function is used:

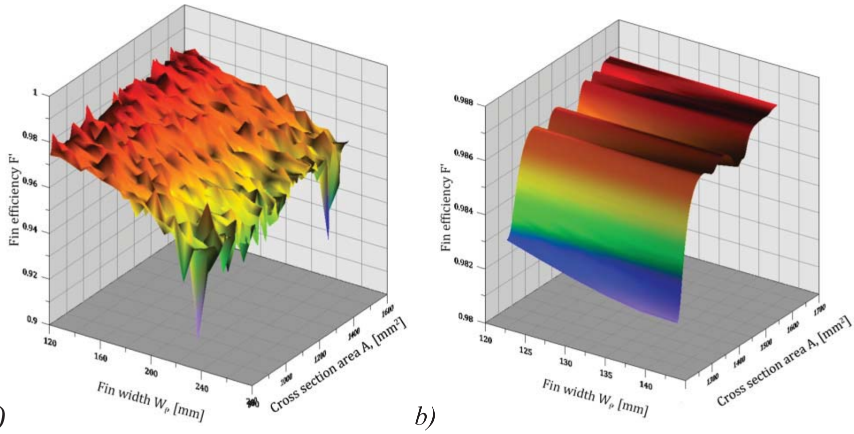
$$F' = \frac{\frac{1}{U_L}}{W_f \left[\frac{1}{U_L \left[\left(W_f - D_o \right) F + D_o \right]} + \frac{1}{C_b} + \frac{1}{\pi D_i H_{fi}} \right]} \tag{5}$$

where: D_i inner piper diameter (m), and D_o outer pipe diameter (m).

The initial interval is given with variable constraints according to suggestions from [2-6]. Parameter W_f is searched between 120 and 250 mm. Parameter W_i is searched between 30 and 50 mm, Parameter D_i is simultaneously calculated for all iterations from the cross-section area of the circular pipe cross-section using:

$$D_i = \sqrt{\frac{4 W_i H_i}{\pi}} \tag{6}$$

Other parameters in goal functions (5) and (6), are set as constants. The achieved comparative results of random search and TLBO optimization methods for pipes with a rectangular cross-section are shown in figure 3.



a) b)

Figure 3 –Optimization results for rectangular cross section pipe a) using random search method; b) using TLBO method

The achieved comparative results of random search and TLBO optimization methods for pipes with a circular cross-section are shown in figure 4.

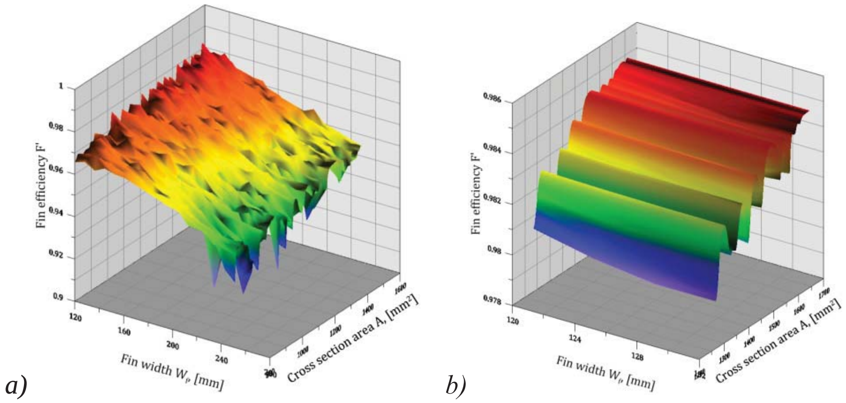


Figure 4 – Optimization results for round cross section pipe
a) using random search method; b) using TLBO method

From diagrams on figures 3 and 4 a more rapid convergence using TLBO method can be noticed compared to random search method.

Conclusion

In this paper optimization of the efficiency factor as a function of rib pipe geometry for flat solar collectors was conducted. Compared to past research of these authors, the square pipe cross-section solar collector was omitted from optimization. The omission was done as the previous research has proven this type of collector heaths worse results than those of circular and rectangular cross-section pipes. Optimization was conducted using Teaching Learning based optimization and compared to previous optimization conducted using random search method.

The best solution is achieved when the width of the collector rib W_f converges to limits of the given interval with the largest internal measurements D_i and W_i. With random search method, it can be seen that the collector with rectangular cross section pipes has the greater efficiency factor than the circular cross-section pipe collector. Optimization using TLBO also shows a larger factor of efficiency for the rectangular cross-section, however the difference is notably smaller than with random search method. From the given diagrams it can be concluded that TLBO has a far quicker convergence to the optimal solution.

Further research of this problem would require considering hear losses as well as the change of wall thickness of pipes. All materials should be considered which are used in solar collector production. In order to achieve optimal solutions of this problem, the problem should be adapted to multi-criteria optimization, with experimental verification of results.

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