OPTIMIZACIJA GEOMETRIJSKIH VELIČINA SOLARNIH PRIJEMNIKA

OPTIMIZATION OF SOLAR COLLECTOR GEOMETRIC VALUES

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U ovom radu izvršeno je određivanje optimalnih geometrijskih veličina solarnih prijemnika metodama slučajne pretrage. Razvijen je matematički model za određivanje povoljnih geometrijskih karakteristika solarnih prijemnika u cilju maksimizacije njihovog iskorišćenja. Optimalno rešenje dobijeno je za geometrijske karakteristike solarnihprijemnikasa cevima, kružnog poprečnog preseka, prijemnika sa cevima kvadratnog i prijemnika sa cevima pravougaonog poprečnog preseka. Izvršena je uporedna analiza iskorišćenja sva tri tipa solarnihprijemnika. Rezultatima ovog istraživanja predstavljen je značaj primene optimizacije u projektovanju prijemnika, kao i uticaj broja promenljivih na kvalitet rezultata optimizacije. Ova rešenja mogućeje jednostavno primeniti u praksi.

Ključne reči: *solarni prijemnici, faktor iskorišćenja, optimizacija, geometrijske veličine.*

In this paper optimization was used for determination of geometric values of solar collectors using random search method was conducted. A mathematical model was developed for determining favorable geometric values of solar collectors with a goal to maximize their efficiency. An optimal solution was created for geometric characteristics of a collector with circular, rectangular, and square cross-section shaped pipes. A comparative analysis for all three types was conducted. Results of this research present an important use of optimization in designing collectors, as well as the influence of variables on the quality of optimization results. These solutions can be simply put to practical use.

Key words: *solar collectors, efficiency factor, optimization, geometric values.*

I. Introduction

Efficiency of solar energy use presents an attractive research topic. The use of solar radiation energy is done through its transformation into heat, electric, or chemical energy. Due to cost effectiveness of solar radiation exploitation solar collectors for water heating are the most widespread. Solar collectors are divides which by absorbing solar rays convert radiation energy into heat energy of the fluid which circulates through the collector. Depending on the desired work fluid temperature there are two types of solar collectors: flat solar collectors which can achieve a temperature of over 100^0C, and focusing solar collectors which can achieve temperatures of over 3000^0C.

Design and technology development of flat solar collectors, done in order to increase their efficiency, decrease price of production and other unwanted effects are a current research topic. These effects can be achieved through optimization of geometric values of the solar collector, which is the topic of this paper.

Farhat et al. [1] optimized solar collectors in order to increase their performances. Their research covered a large number of parameters: absorber area, gross dimensions, pipe diameters, input and output temperatures, temperature losses, and many others. Authors in paper [2] concluded how to choose optimal performance in order to increase efficiency of solar collectors. In paper [3] Vargas et al. have maximized the performance of a solar collector according to their use in realistic weather conditions. Authors of paper [4] have optimized solar collectors from a thermos-ecological standpoint. Optimization of collector type according to climate conditions was done by authors in paper [5]. Paper [6] gave the authors research on optimal performances of collectors from an interior parts standpoint for collectors with square cells set in a honeycomb formation. This research included an analogy with natural solutions as an alternative in solar collector development.

This paper presents an approach to optimization of solar collectors. Optimization is directed towards geometrical values with a large number of variables, which are viewed as dominant for efficient use of solar collectors in practice. The mathematical model created is for calculating optimal absorber plate dimensions with pipes of various cross-sections.

II. Formulating the problem

For the development of the mathematical model pipes with a circular, rectangular and square cross-section were considered. Independent mathematical models were developed for these cross-sections, where for all cases as a goal function the efficiency factor for flat solar panels *F'* was taken into consideration.

In order to make a comparison between using collectors of various cross-sections, the following factors were considered: 1) inner area of the cross-section through which the fluid flows must be equal for all pipes regardless of cross-section shape, 2) total heat loss coefficient U_L must be the same, 3) absorber plate thickness δ must be the same, 4) wall thickness *t* must be the same, 5) distance between collector pipes W_f must be the same.

The equation for the efficiency factor of the solar collector *F'* for collectors with circular cross-section pipes is taken from [7]:

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

Variables are: C_b, conductivity of the connection between the circular pipe and absorber (W/mK), D_i, inner diameter of circular pipe (m), D_o, outer diameter of circular pipe (m), *F*, standard rib efficiency (-), *F'*, solar collector efficiency factor (-), H_{fi}, heat conductivity coefficient in the ribs(W/m^2 K), U_L, total heat loss coefficient (W/m^2 K) and W_f, rib width (m).

The equation for solar collector rib efficiency factor *F* for collectors with circular cross-section pipes is taken from [7]:

$$F = \frac{\tanh\left[M\,\frac{W_f - D_o}{2}\right]}{M\,\frac{W_f - D_o}{2}} \quad (2).$$

Equation (2) uses the variable *M* which is defined as:

$$M = \sqrt{\frac{U_L}{k\delta}} \quad (3).$$

Variables are: *k*, heat conductivity of absorber plate (W/mK), δ, absorber plate thickness (m).

The cross-section of the collector rib with circular pipes is shown in figure 1.

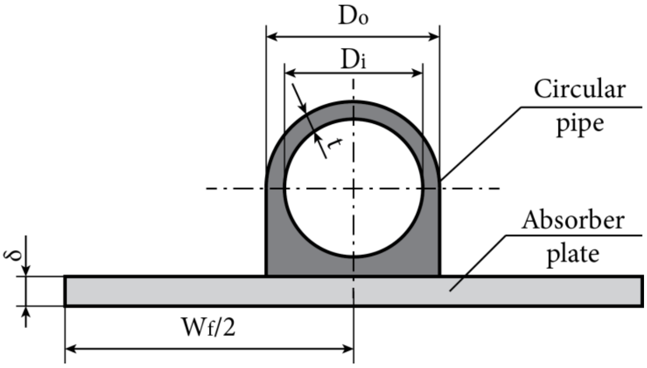

Figure 1 –Cross-section of circular pipe rib

A similar equation is used for determining the solar collector rib efficiency factor for pipes with rectangular cross-section:

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

Variables are: W_i, inner width of rectangular pipe (m),W_o, outer width of rectangular pipe (m).

The equation for solar collector rib efficiency factor$F$ for collectors with rectangular cross-section pipes is taken from [7]:

$$F = \frac{\tanh\left[M\frac{W_f - W_o}{2}\right]}{M\frac{W_f - W_o}{2}} \qquad (5).$$

Variable M, for the collector with rectangular pipes is also calculated using equation (3). The cross-section of the collector rib with rectangular pipes is shown in figure 2.

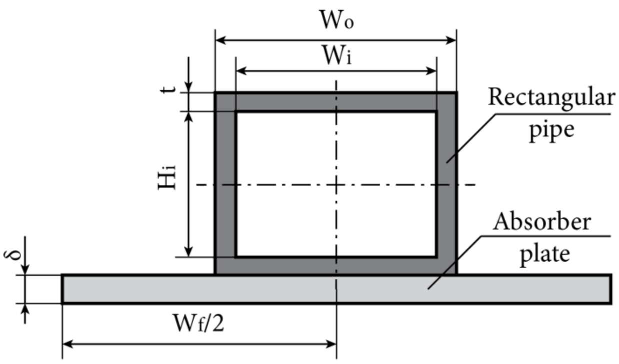

Figure2 – Cross-section of ribs with rectangular pipe

Ratio of inner pipe width W_i and inner height H_i is 1,5: 1. This ratio is frequent in cross-sections of rectangular pipes which are used for collectors.

A similar equation is used for determining the efficiency factor of solar collectors with square cross-section pipes:

$$F' = \frac{\frac{1}{U_L}}{W_f\left[\frac{1}{U_L\left[\left(W_f - B_o\right)F + B_o\right]} + \frac{1}{C_b} + \frac{1}{4B_i H_{fi}}\right]} \qquad (6).$$

Variables are: B_i, inner side of the pipe with a square cross-section (m), B_o, outer side of the pipe (m).

The equation for the efficiency factor of the solar collector with a square pipe cross-section F is as follows:

$$F = \frac{\tanh\left[M\dfrac{W_f - B_o}{2}\right]}{M\dfrac{W_f - B_o}{2}} \qquad (7).$$

The cross-section of the collector rib with square pipes is shown in figure 3.

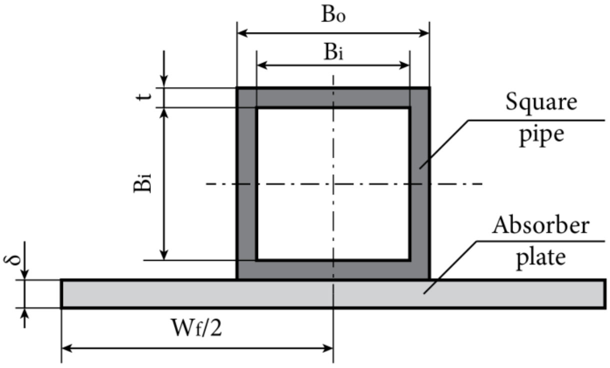

Figure 3 – Cross-section of square shaped pipe rib

III. Problem solving methods and discussion of results

Function (1) was used as a goal function for the collector with circular cross-section pipes, (4) for the collector with rectangular pipes, and (6) for the collector with square pipes. Limits were created based on suggestions from [2-6, 7, 8].

Heat conductivity coefficient depends on the choice of absorber material and pipe. The length of the solar collector is given according to standard values for length of the collector. Solving is done in MS Excel.

Optimization for all three cases is done using random search method [9, 10] through 1000 iterations for more precise results.

Initial interval is given through constraints of the variable from [2-6, 7, 8]. Parameter W_f is searched between 120 and 250 mm. Parameter W_i is searched between 5 and 30 mm. Parameter D_i is simultaneously calculated for all iterations from the area of the rectangular cross-section using equation:

$$D_i = \sqrt{\frac{4W_iH_i}{\pi}}. \qquad (6)$$

Other parameters in the goal function (3) and (5), are set as constants. Achieved results for circular pipe cross-section area are presented in figure 4.

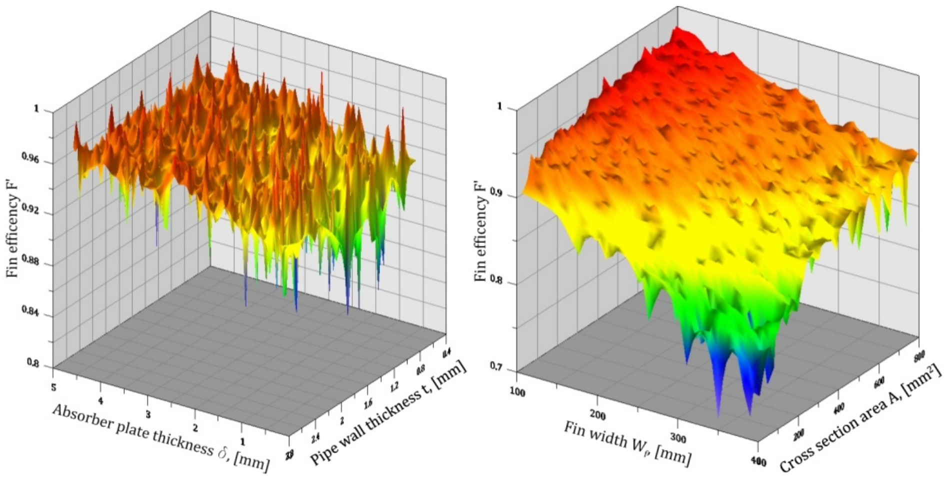

Figure 4 –Optimization results for circular pipe

Achieved results for rectangular pipe cross-section area are presented in figure 5.

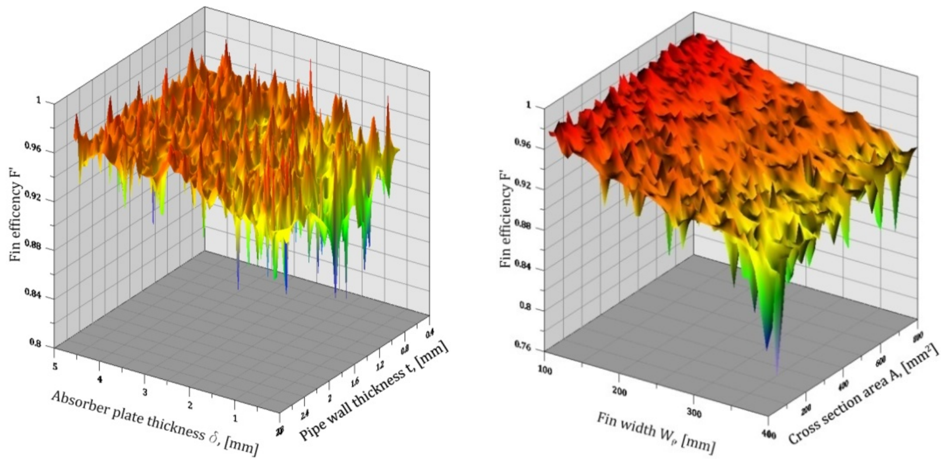

Figure 5 – Optimization results for rectangular pipe

Achieved results for circular pipe cross-section area are presented in figure 6.

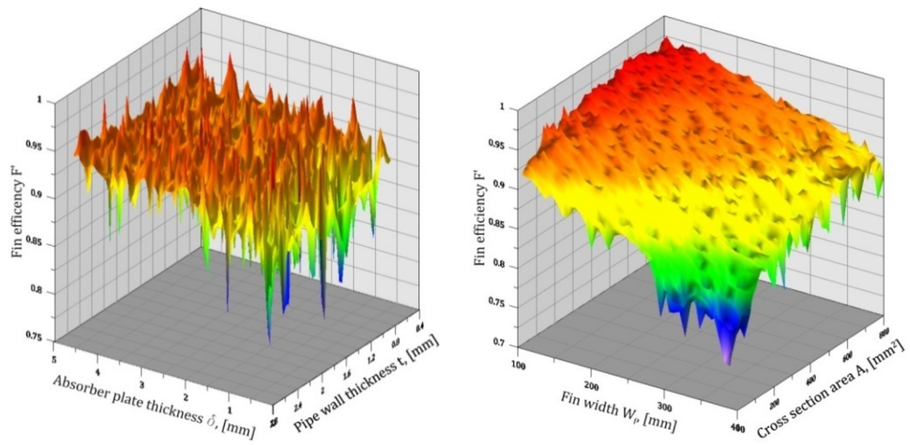

Figure 6 –Optimization results for square pipe

Based on achieved results conclusions can be made for the favoring of solar collectors with rectangular cross-sections. A large number of variables were taken into account, and using the right combination of these values an optimal concept of geometric values can be achieved.

IV. Conclusion

In this paper using the change of efficiency factor as a function of pipe geometry and rib width of flat solar collectors an optimization using random search method was conducted. All combinations of pipe variables for circular, rectangular and square cross-sections were taken into account.

The collector with rectangular pipes had a greater factor of efficiency than the circular and square cross-section pipe collectors. Square pipe collectors presented the least favorable choice for practical use.

Further research of this problem would require taking into account all types of materials used in the making of solar collectors. In order to achieve an optimal solution to this problem it is necessary to use multi-criteria optimization, with experimental verification of results.

V. Acknowledgment

This paper is a result of two projects: (1) TR33015 project of the Ministry of education, science and technological development, and (2) III 42006 Integral and interdisciplinary research in Serbia project. The first project is called " Research and development of a Serbian zero-net energy house", and the other is " Research and development of energy and ecological high frequency systems of poly-generation based on renewable energy". We would like to thank the Ministry of education, science and technological development on their financial support during this research.

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