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OPTIMIZATION OF Geometric parameters TO AUTOMATE solar collector DESIGN

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PAPER OVERVIEW

- This paper presents research to optimize and automate the collector design by optimization the absorber with pipes.

- To achieve this, a mathematical model was created for calculation of the optimal dimensions of the absorber plate with pipes.

- Then, a comparative analysis of circular and rectangular piped collectors was performed.

- The diagrams of all solutions were given and discussed.

- Paper concludes with parametric CAD model of optimal collector to automate a design of the solar collector.

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ITRODUCTION

- Direct sunlight energy can be used in practice for its transformation into heat, electric, or chemical energy.

- The most widespread use of solar energy is an application of solar collectors for heating water.

- Solar collectors are devices which by absorbing solar rays turn radiation energy into heat for fluids which flow through the collector.

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PROBLEM FORMULATION

- To choose optimal geometric parameters, it was necessary to prepare an appropriate mathematical model, for the case of circular and rectangular pipes.
- For both cases as an objective function, the efficiency factor *F'* of a flat solar collector was taken into account.

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ASSUMPTIONS

To compare use of collectors with circular and rectangular pipes, the following assumptions were made such as:

1) the inner section area through which the fluid flows must be equal for both circular and rectangular pipes,
2) the total heat loss coefficient *U*L must be equal for both cases,
3) the absorber thickness δ must be equal for both cases, 4)
4) the pipe wall thickness *t* must be equal for both cases, and
5) the distance between pipes in the collector *W*f must be equal for both cases.

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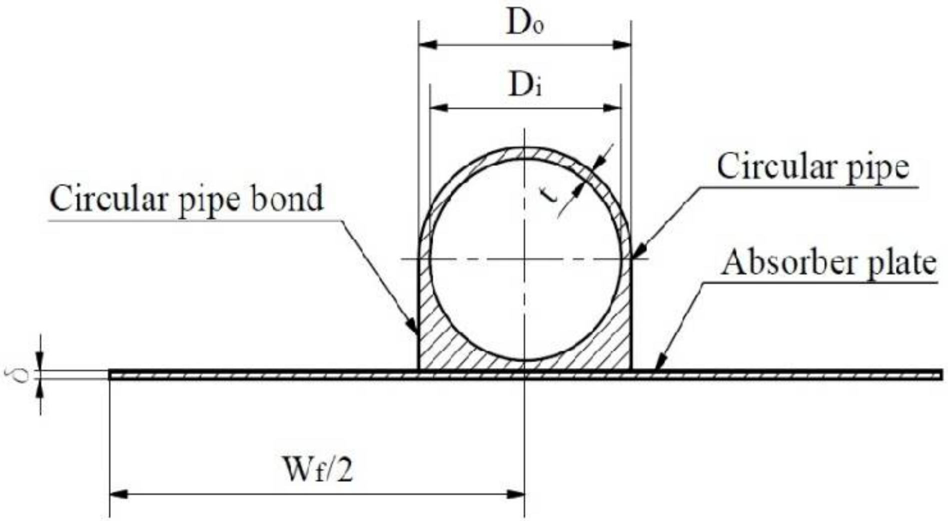
ROUND PIPES

Round pipe efficiency equation:

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

$$F = \frac{\tanh\left[M\frac{W_f - D_o}{2}\right]}{M\frac{W_f - D_o}{2}}$$

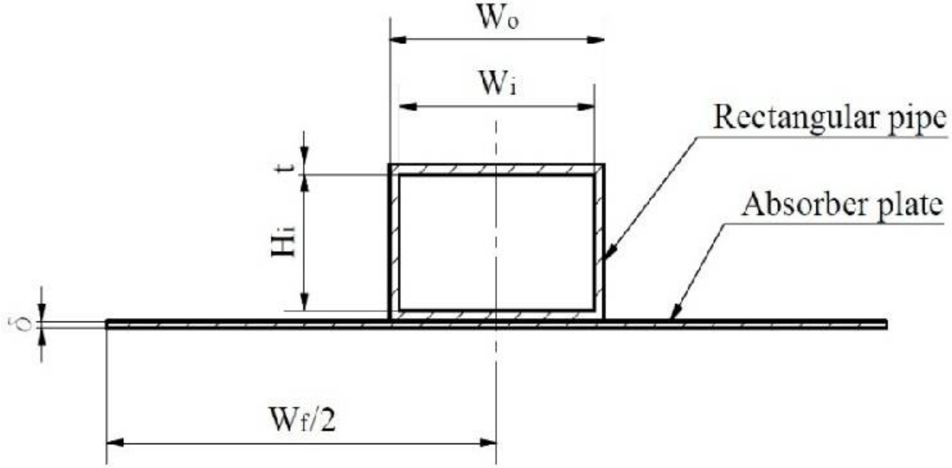
$$M = \sqrt{\frac{U_L}{k\delta}}$$



RECTANGULAR PIPES

Rectangular pipes efficiency:

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



$$F = \frac{\tanh\left[M\frac{W_f - W_o}{2}\right]}{M\frac{W_f - W_o}{2}}$$

$$M = \sqrt{\frac{U_L}{k\delta}}$$

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INPUT PARAMETERS

Input parameters – Variable constraints				
Symbol	Range	Qty	Unit	Name
Wf	Upper	250	[mm]	Fin width
	Lower	120		
Rectangular cross-section				
Wi	Upper	30	[mm]	Inside width of rectangular pipe
	Lower	5		
Hi	Upper	20	[mm]	Inside height of rectangular pipe
	Lower	3.33		
Circular cross-section				
Di	Upper	27.64	[mm]	Inside diameter of circular pipe
	Lower	4.61		
Input parameters – Constants				
t	1.5		[mm]	Pipe wall thickness
δ	1		[mm]	Absorber plate thickness
UL	4		[W/m2K]	Overall heat loss coefficient
Hfi	300		[W/m2K]	Heat transfer coefficient in the conduits
k	400		[W/mK]	Thermal conductivity of the absorber plate
Absorber				
L	1200		[mm]	Absorber length

DEPENDENT VARIABLES

Values dependent on *W*i are labeled yellow.

The inner height of the rectangle pipe *H*i is calculated from the previously mentioned ratio (3/2:1), while the inner diameter of the circular pipe is calculated by equating its area with the cross section surface area of the rectangular pipe.

The coefficient of heat transfer *k* depends on the choice material of absorber and pipe.

The length of solar collector is set according to standard. The calculation was done by using MS Excel by random search method.

Parameter *D*i was simultaneously calculated for all iterations from the rectangular pipe cross-section area, by formula:

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

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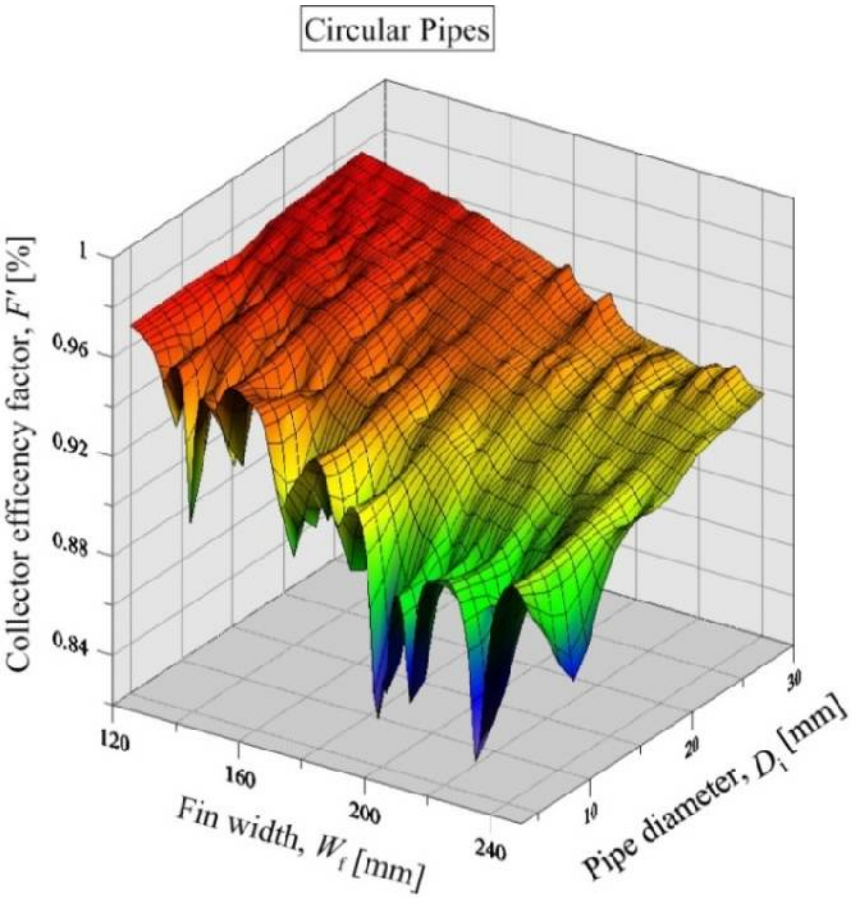
Collector efficiency surface of collector with circular pipes



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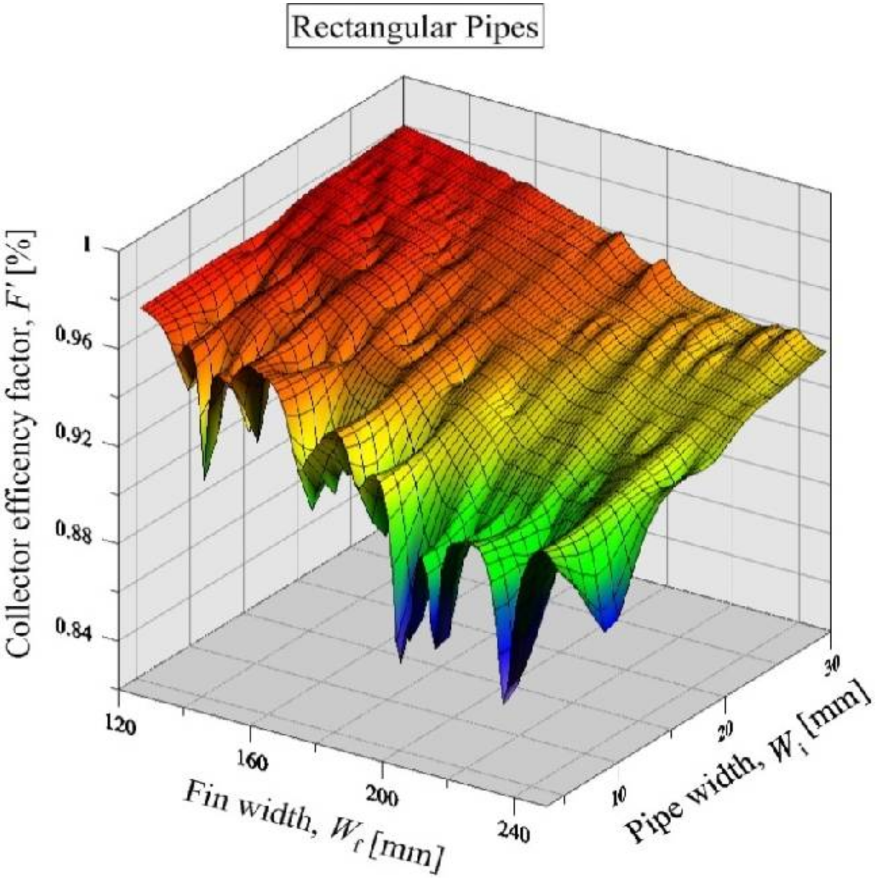
Collector efficiency surface of the collector with rectangular pipes



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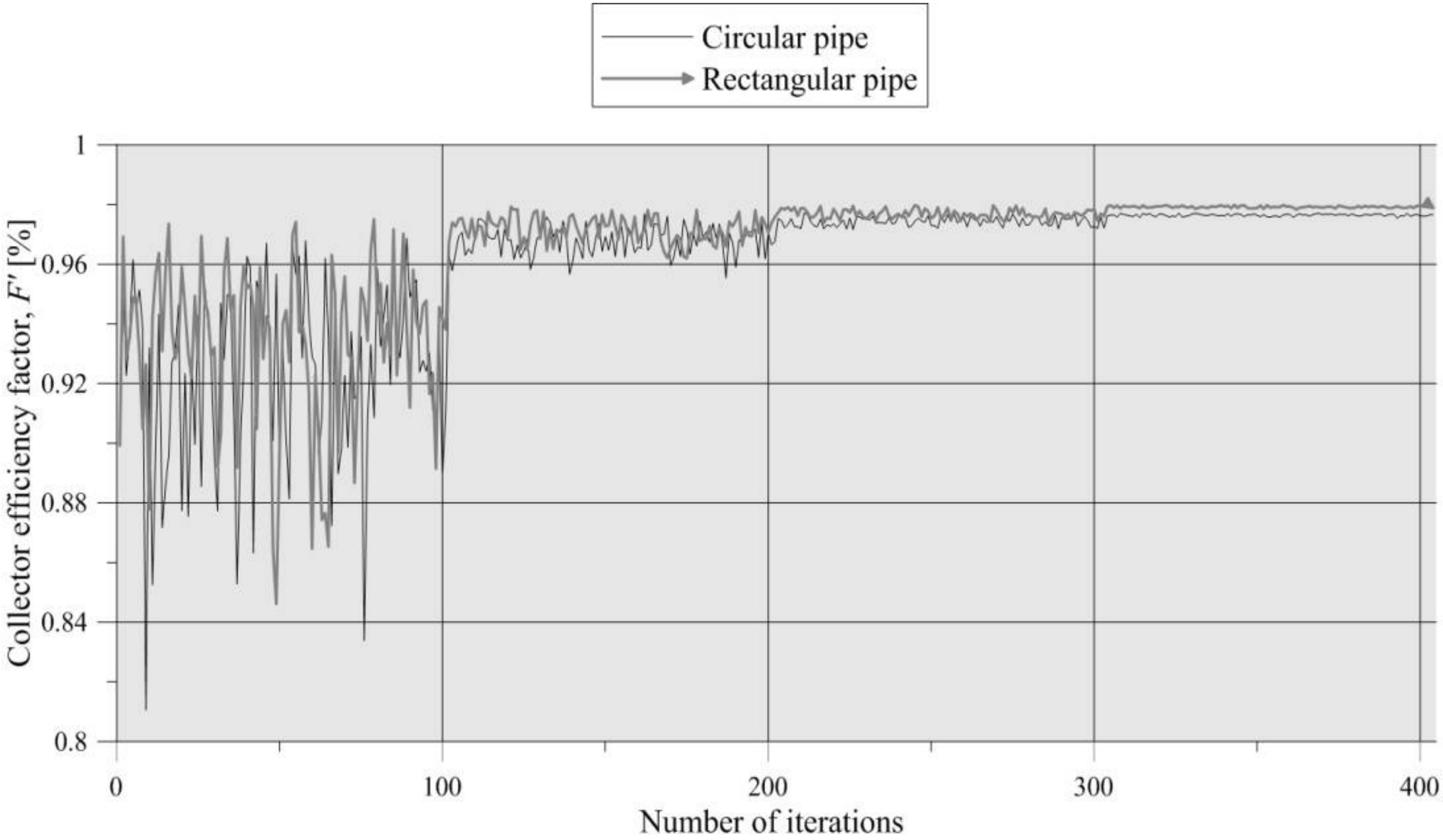
Comparative diagram of circular and rectangular pipes objective function F' trough all iterations



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Collector designing based on optimization results

The optimal dimensions for both collectors were found.

In every iteration, the collector efficiency factor *F'* was slightly higher for the pipes with rectangular cross-section than that for the pipes with circular cross-section.

There is slight advantage of the collector with rectangular pipes to that with circular pipes regarding the collector efficiency factor.

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Collector designing based on optimization results

The optimal solution of this problem was found at the start of the collector fin width interval *Wf* and at the end collector pipe dimension interval *Di* and *Wi* a for both collectors.

The optimal geometric parameters are given in Table 2. In every iteration, the collector efficiency factor *F'* was slightly higher for the pipes with rectangular cross-section than that for the pipes with circular cross-section.

Symbol	Value	Unit
Wf	120	mm
Wi	30	mm
Hi	20.00	mm
Di	27.64	mm
t	1.5	mm
Δ	1	mm
Nf	8	ul
L	1200	mm
B	960	mm

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Collector designing based on optimization results

To automate a design of the solar collector, first, we establish the optimization model for the collector, and second we establish a parametric CAD model based on the optimal dimensions of the collector.

In practice, first we input the non-optimized dimensions of the collector to the optimization model, second we get the optimized dimensions of the collector (given in Table 2) from the optimization model, and third we establish a CAD design.

With every change of the input dimensions, we get optimal ones, which are directly linked to the CAD model and final design.

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Collector designing based on optimization results

After achieving an optimal solution for both cases their design was performed.
Design of both solutions was done in Autodesk Inventor software. The achieved results of the collector optimization were directly linked to the model of the absorber plate with pipes.
Figures 6.a and 6.b show optimal CAD models for the input dimensions given in Table 2:

Circular pipe

Rectangular pipes

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CONCLUSION

- In this paper, the change in the collector efficiency as a function of geometry of pipes and the width of a flat solar collector fin was examined and optimized by using random search method. All combinations of variables of pipes for circular and rectangular pipes were considered.

- The best solution was achieved when the collector fin width *W*f is the smallest, with the largest pipe inner dimensions *W*i and *D*i. The collector with rectangular pipes had the efficiency 0.3 % higher than that of the collector with circular pipes.

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Thank you for your attention.

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