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MATERIALS

Optimization of flat solar collector based on the principle of entropy

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Abstract:*This article describes the entropy method optimization based on the approach of minimal increase of entropy in the thermodynamic system. Here is presented the experimental set up of flat plate solar collector with liquid as working medium, effective absorber area of the c ollector 1,4 m², absorber plate of aluminum, copper pipes and selective coating. A comparative analysis is conducted between the efficiency of a theoretical model of nonisothermal solar collector and the efficiency obtained by measuring the physical model of a solar collector. Res ults show a general trend of growth the collector efficiency due to the reduction of irreversibility of the represented processes.*
Keywords*: OPTIMIZATION, SOLAR COLLECTOR, ENTROPY*

1. Introduction

Entropy expresses the direction of spontaneous changes in the system. It shows one process irreversibility, and not violating the conservation of energy. This term represents the measure of disorder in one system. Old misconceptions and new breakthroughs of definition of entropy is presented in [1]. The entropy generation analysis as a design tool is presented in [2], where this method is clearly explaining the possibility for designers to conceive more efficient systems.

Entropy generation in simultaneous heat and mass thansfer devices is shown in [3]. In studies of Torres, there are two additional developments: in one is presented the application of the entropy minimization generation in solar collectors for drying processes [4], and another presents the application of the entropy minimization generation to determine the temperature and length of the optimal fluid conduit channel, in solar collectors of different configurations [5].

In this paper the main focus is the optimization of flat plate solar collector based on minimum entropy generation. Analysis presented are comparison between efficiency of a theoretical model of non-isothermal solar collector and the efficiency obtained by measuring the physical model of a solar collector.

2. Optimisation with application of entropy method

The model based on minimisation of the entropy growth rate in this study is built upon the work of Bejan [6,7]. Collector with an effective surface of A_c in stationary conditions at operating temperature T_c, receives solar radiation Q^*, one part part of which is transformed into useful energy (Q_u), and one part is lost to the environment (Q_0):

$$Q^* = Q_u + Q_0 \qquad (1)$$

The approach in this work is based on endo-reversible thermodynamics, in which incident radiation energy to the collector is q^* (in W/m²). The model based is presented with simplified scheme fig. 1. A part of that energy, $dQ(t)$, is received and transmitted by the working fluid, another fraction, $dE(t)$, increases the internal energy of the collector, and the rest, $dQ_L(t)$, is lost in the surrounding ambient.

By setting the energy balance of non-isothermal collector, an expression for heat losses from the collector to the surroundings can be derived. From the Second main law of thermodynamics the following expression for the growth of entropy is derived:

$$\Delta S(\tau) = \int_0^{\tau} \left[\frac{q*}{T_C(\tau)} - \frac{dQ(\tau)}{T_C(\tau)} - \frac{dQ_L(\tau)}{T_C(\tau)}\right] \geq 0 \qquad (2)$$

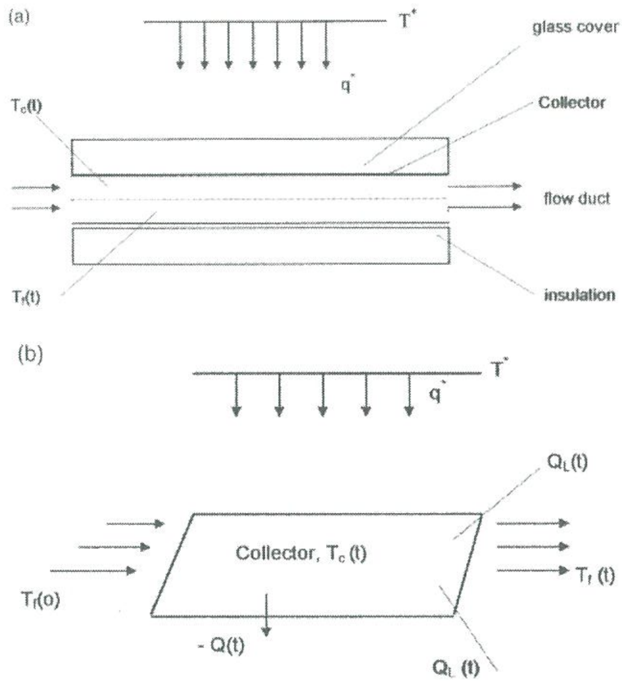

Fig. 1*. Elementary scheme of a solar collector for display of a model based on endo-reversible thermodynamics*

The collector efficiency, through the analyzed variables, can be represented by the following expression

$$\eta = \frac{K[T_c(\tau) - T_f(\tau)]}{q^*} \qquad (3)$$

Previous expressions make it possible to optimize the operation of the solar collector in terms of minimum increase in entropy. Moreover, on the basis of the further analysis carried out in the thesis, expressions are derived for optimal output temperature and the corresponding value of the optimal flow of working fluid in terms of minimum increase in entropy.

Optimal time τ needed for transfer of certain amount of heat, can be obtained by the following expression

$$\tau = \frac{2C_f}{K}\ln\left[2 - \frac{T_f(0)}{T_c(0)}\right] \qquad (4)$$

The diagram in Fig. 21 shows the time τ necessary to transfer a certain amount of heat, as a function of the ratio of the initial temperatures of the fluid t_f and the absorber t_c.

3. Results from the thermodynamic optimisation

The diagram in Fig. 2 shows the time τ necessary to transfer a certain amount of heat, as a function of the ratio of the initial temperatures of the fluid T_f and the absorber T_c.

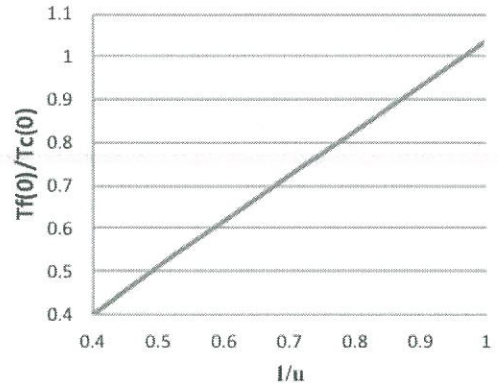

Fig 2. Dependence between the ratio $(1/u)=T_f(\tau)/T_c(\tau)$ *and* $T_f(0)/T_c(0)$

The diagram in Fig. 3 represents the time required to transfer a certain amount of heat, as a function of the ratio of the initial temperatures of the fluid and the absorber.

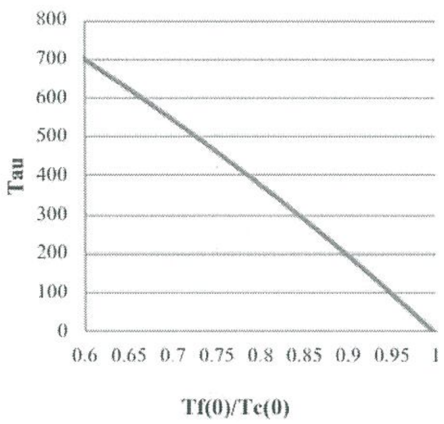

Fig 3. Optimal duration of the process τ *as a function of the ratio* $t_f(0)/t_c(0)$

The total increasing rate of entropy is a function of the parameters of the environment, q^* and T_a, the initial temperature conditions expressed by the ratio $T_f(0)/T_c(0)$, the conductivity K and the mass flow of working fluid m. Figure 4 shows the change of the increasing rate (generation) of entropy as a function of the mass flow of working fluid.

In Tables 1 and 2 are given results from experimental measurements, as well as results of calculations using the relations concerning non-isothermal model of the solar collector.

The basic specification of the test facility is given below:

- Individual flat plate solar collector with liquid as working medium;
- Absorber plate of aluminum, copper pipes, selective coating;
- Effective absorber area of the collector A_c = 1,4 m^2;
- Location - Shtip, Republic of N. Macedonia (latitude 41° 45' and longitude 22° 12');
- $\tau\alpha$=0,82, F_RU_L=7,78 W/m^{2}C, $F_R(\tau\alpha)$=0,64.

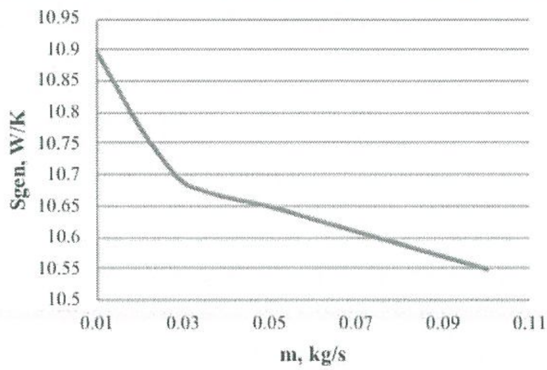

Fig. 4. *Relationship between the entropy growth rate (generation) and mass flow of working fluid*

In Table 1 and Table 2 are presented experimental results obtained on the static collector experimental set-up.

Table 1: *Results obtained on the static collector experimental set-up*

N	Time	Temp. t_a	Temp. t_{in}	Inc. thermal power q^*, W/m^2
1	10.30	15	40	780
2	11.00	15	41	855
3	11.30	16	42,5	893
4	12.00	16	44	890
5	12.30	17	45	875
6	13.00	17	46	825
7	13.30	18	47	775
8	14.00	18	48	705

Table 2: *Results obtained on the static collector experimental set-up*

N	Time	t_{out}, °C	θ_{out}	M	$N_s + 1/\theta^*$
1	10.30	43,5	2,90	2,348	0,649
2	11.00	47	3,13	2,142	0,436
3	11.30	48	3,00	2,188	0,514
4	12.00	50	3,13	2,195	0,457
5	12.30	52	3,06	2,373	0,366
6	13.00	53	3,12	2,442	0,340
7	13.30	54	3,00	2,836	0,291
8	14.00	53,5	2,97	3,118	0,386

Results concerning the efficiency of the collector, obtained experimentally using the theoretical model presented in this material are given in Table 3.

Table 3. *Results for the collector efficiency obtained experimentally and with the theorethical model*

$(t_i-t_a)/q^*$	η_{exp}	η_{th}
0	0,68	0,65
1	0,675	0,64
2	0,67	0,63
3	0,665	0,62
4	0,65	0,61
5	0,645	0,6
8	0,62	0,58
10	0,605	0,56
15	0,585	0,54
16	0,584	0,525
20	0,58	0,51
22	0,57	0,495
25	0,56	0,48
26	0,55	0,47
30	0,54	0,46

Diagram in Figure 5 shows the comparative results for the efficiency of the collector as a function of $(t_{in} - t_a)/q^*$, obtained by experimental research and by the theoretical analysis, by applying the model for minimization of the increase of entropy. They show a general trend of growth the collector efficiency due to the reduction of irreversibility of the represented processes.

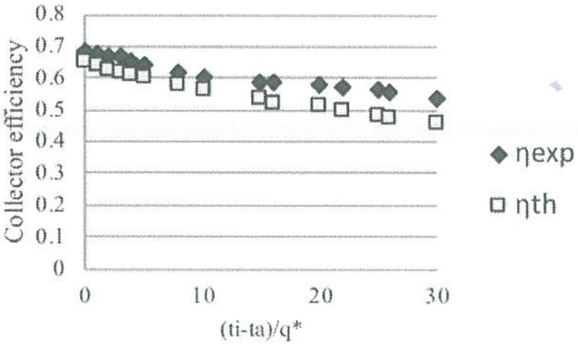

Fig. 5. *Change of the collector efficiency as a function of $(t_i - t_a)/q^*$ obtained by applying the model for entopy growth minimization*

4. Conclusion

In the section on thermodynamic optimization, a model for optimization of solar collector based on the principle of minimizing the growth of entropy is presented. A comparative analysis is conducted between the efficiency of a theoretical model of non-isothermal solar collector and the efficiency obtained by measuring the physical model of a solar collector.

By the conducted analysis, optimal regime parameters of the collector are obtained - optimal operating temperature of the collector, the intensity of useful heat extraction, optimal flow of working fluid etc. From the deduced results it can be concluded that the performance of the collector shows a tendency to decrease with increase in the value of the ratio $(t_i - t_a)/q^*$.

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