

FLAT-PLATE SOLAR COLLECTOR TECHNICAL CONSTRUCTIVE PARAMETERS DETERMINATION BY NUMERICAL CALCULATION, CONSIDERING THE TEMPERATURE CRITERION

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Abstract. The thermoleading fluid temperature variation depends on the magnitudes α and β for a given value of the radiant power density in the collecting plane of the solar energy. The quantities α and β depend on: the collecting area A_c , the efficiency η ($\alpha = A_c \eta$), the flow and the specific heat ($\beta = \dot{m} C_p$). The coordinates ΔT , α and β and the magnitudes A_c , η , \dot{m} , C_p can be established in the parametric graph of $\Delta T = f(\alpha, \beta)$, where G - parameter, generated by the computer, in order to satisfy the user's requirements related to the temperature.

Key words: thermocarrying fluid, increment, radiant power density, collecting area.

1. INTRODUCTION

During daytime, the solar radiation intensity in the collecting plane modifies, thus determining the modification of the heliothermal conversion efficiency and of the thermocarrying fluid temperature at the collector's outlet. To constantly maintain the efficiency and the temperature, it is necessary to modify the thermocarrying fluid flow.

The complexity of the efficiency and the temperature equations leads to many analytical and numerical simulation studies and also to experimental studies in natural or simulated (laboratory) conditions, in order to determine the standard tests of evaluation and reporting the performances of collectors used in conditions of variable climate in the same geographical place or various from a place to another.

Some achievements of considerable results are presented briefly as follows.

Kutscher et al. (1984) settled the physical properties of the materials used in solar energetic [5].

Whillier and Saluya (1965) settled the efficiency factor equation, F' , depending on the controllable variables. Particularly, if the distance between the tubes, W , tends to zero, the efficiency factor tends to unit, $W \rightarrow 0$, $F' \rightarrow 1$ [9].

Hotel and Whillier (1958) established that the usability factor, u , depends implicitly on $T_{f,i}$ and T_a , and particularly for $T_{f,i} = T_a$, $u \rightarrow 1$ [4].

Duffie and Beckman (1974) draw up the methodology of analyzing the flat plate solar collectors [2].

Thus, the instantaneous efficiency of the collector is

$$\eta = \dot{m} \cdot C_p \cdot \Delta T / HR \cdot A_c \quad (1)$$

where : $\Delta T = T_{f,o} - T_{f,i}$

$$T_{f,o} = (T_{f,i} - T_a - S/U_L) \cdot \exp(-F' \cdot A_c \cdot U_L / \dot{m} \cdot C_p) + T_a + S/U_L \quad (2)$$

Sokolov and Reshef (1992) settled for the collector G.R.C. (glass-reinforced concrete with a lattice of conduits) the dependence of the magnitudes $(T_{f,o} - T_{f,i})$, η and F_R , depending on the variables $T_{f,i}$, \dot{m}/A_c and W [8].

Choudhury and Garg (1993) established, by comparative digital analysis, the dependences of the power and of the efficiency of a solar heater with or without stocking materials in stream tube, depending on operational and geometrical variables [1].

The study proposes the use of the computer for determining the technic constructive parameters of the flat-plane solar collector, considering the temperature criterion. The parameters A_c (collecting area), flow (\dot{m}), specific heat (C_p) and efficiency (η) will be established considering the geografic place, so that the temperature T_F maintains in the limits established by the user.

2. ANALYTICAL ASPECTS. HYPOTHESIS.

2.1. Hypothesis

The analytical model was elaborated by using the relation (1) based on the following hypotheses:

a. Considering that $HR = G$, for a given value of solar radiation intensity, the equation (1), [2], [3] can be written

$$GA_c\eta = \dot{m} C_p\Delta T \quad (3)$$

From equation (3) results $\Delta T = f(G, A_c, \eta, \dot{m}, C_p)$.

b. Variables A_c and η determine the variable α defined by the relation (4):

$$\alpha = A_c \eta \quad (4)$$

c. Variables \dot{m} and C_p determine the variable β , defined by the relation (5):

$$\beta = \dot{m} C_p \quad (5)$$

d. Consequently, the temperature variation ΔT is dependent on the variables α and β as per the equation (6)

$$\Delta T = G \cdot \alpha / \beta \quad (6)$$

Noting $\gamma = \alpha / \beta$, we obtain:

$$\Delta T = G \cdot \gamma \quad (7)$$

Equation (6) may be used for drawing the surface determined by ΔT , α , β .

2.2. The way for to use the formulas

The variation of the α coordinate during the use of a collector leads to the efficiency modification. The variation of the α coordinate during the use of collector is possible by modifying the thermocarrying fluid flow. Relation (6) shows that for the magnitude ΔT stays constant for the pair set of the values α and β whose ratio is constant ($\Delta T = \text{constant}$ leads to $\alpha / \beta = \text{constant}$).

The modification of one the magnitudes α or β determines the temperature variation, under the condition $G = \text{const.}$

Equation (7) explicited in relation (8),

$$T_{f,0} = T_{f,i} + G \gamma \quad (8)$$

shows that under the conditions $T_{f,i} = \text{const.}$ and $G = \text{const.}$, the fluid temperature at its outlet from the collector varies linearly with the magnitude γ that was defined as the ratio of the magnitudes α and β .

By physical standpoint, the slope of the straight line has the significance of radiant power density, and the intersection of the straight line $T_{f,0} = f(\gamma)$ with the temperature axis represents the temperature of the fluid at its inlet in the collector.

3. NUMERICAL CALCULATION

The Physics Department initiated a program named "Temp", in order to determine the constructive and functional parameters of the flat-plate solar collector by digital simulation [6].

The program sets the dependence $\Delta T = f(\alpha, \beta)$ for a value of the magnitude G given from the keyboard and displays the values in interest: α , β , ΔT , G , $T_{f,0} = \Delta T + T_{f,i}$.

Fig .1 shows the graph the area drawn by the computer for $G = 600 \text{ W/m}^2$.

The discrete running of the program allows the user to draw the area $\Delta T=f(\alpha, \beta)$ point by point and to obtain the coordinates of each point depending on the incremental step of the magnitudes α and β .

In fig.1 the significaces of the capital letters are:

- A - running with display,
- F - running without display,
- C - continuous display,
- D - discrete display

The running regime is established by pressing one of the tastes A, F, C, D.

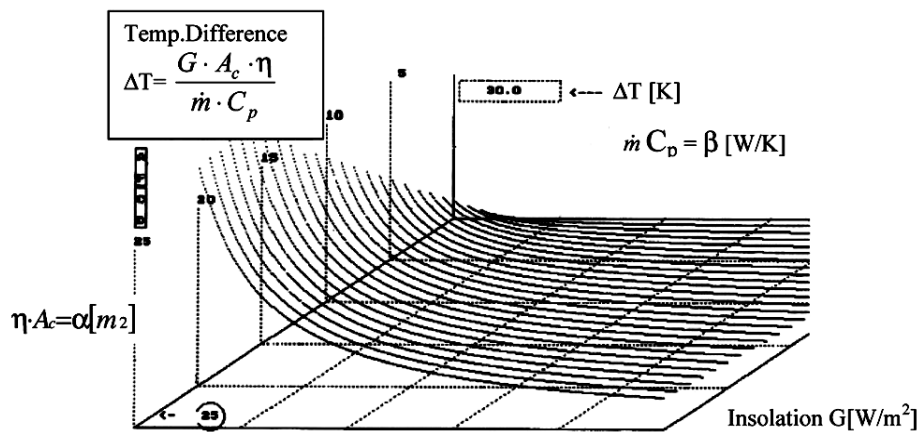


Fig. 1 - Dependence $\Delta T=f(\alpha, \beta)$, the magnitude G being the parameter

The successive point coordinates are obtained by pressing the taste D. They are pointed by a circle for magnitudes α and β and by a rectangle for ΔT . Thus, the coordinates of the last point of the area in Fig.1 are:

$$\alpha = 25m^2, \quad \beta = 500 \text{ W/K}, \quad \Delta T = 30K$$

A difficult notices by using this program is that if the quantity γ defined by relation (7) satisfies the inequalities (9)

$$\gamma \geq (T_b - T_{f,i})/G \tag{9}$$

As T_b being the boiling temperature of the fluid, the magnitude $T=T_{f,i} + \Delta T$ displayed on the screen will become bigger than the magnitudes T_b .

This difficulty was eliminated by communicating from the keyboard the boiling temperature of the fluid and also by the instruction “write error “ if $T \geq T_b$.

4. RESULTS OF THE NUMERICAL CALCULATION

Table 1 present for exemplification some values of the representative point coordinates in parametrical representation $\Delta T=f(\alpha, \beta)$, the parameter being the radiant power density (G).

The increment of the radiant power density by $\Delta G=200W/m^2$ determines the raising the over temperature by $\Delta T=15K$ if the magnitudes α and β remain constant.

Table 1. - Point coordinates representation

Magnitude			
$G [W/m^2]$	$\alpha [m^2]$	$\beta [W/K]$	$\Delta T [K]$
400	15	200	30
600			45
800			60
1000			75

For the western Romania, the reference value of radiant power density is $G=600W/m^2$

The user of heliotechnical device can be interested in obtaining certain values of rthe thermocarrying fluid temperature.

As a result ,Table 2 presents the values of the magnitudes α and β if $\Delta T=40,60,80K$ and if $G=600W/m^2$.

Table 2. - Value of quantities ΔT , α and β for $G=600W/m^2$

ΔT [K]	40	60	80
α [m ²]	15	20	25
β [W/K]	225	200	187.5

Thus, the increasing of over temperature under

constant insolation conditions is possible by increasing the magnitude α and by diminution of the magnitude β .

In the condition $\eta=const.$, the magnitude α increases by enlarging the collecting area A_c and the magnitude β decreases by reducing the flow (\dot{m}).

For a given value of the quantity α defined by relation (4), the magnitude A_c and η vary hyperbolically so that their product remains constant.

For a given value of the magnitude β defined by relation (5) the magnitudes m and C_p vary hyperbolically so that their product to remain constant.

Variation of the flow depending on the specific heat of the thermocarrying fluid is showed on fig.3

The curves, which are seen on fig. 2 and fig. 3 may be used by thermosolar installations designers for determining collecting area, the isolation thickness, the efficiency, the flow and chemical nature of the thermocarrying fluid.

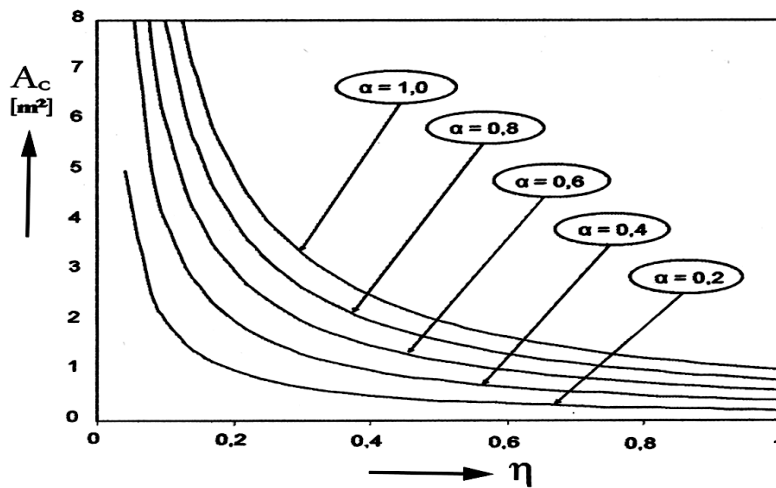


Fig. 2 - The variation of collecting area depending on the efficiency

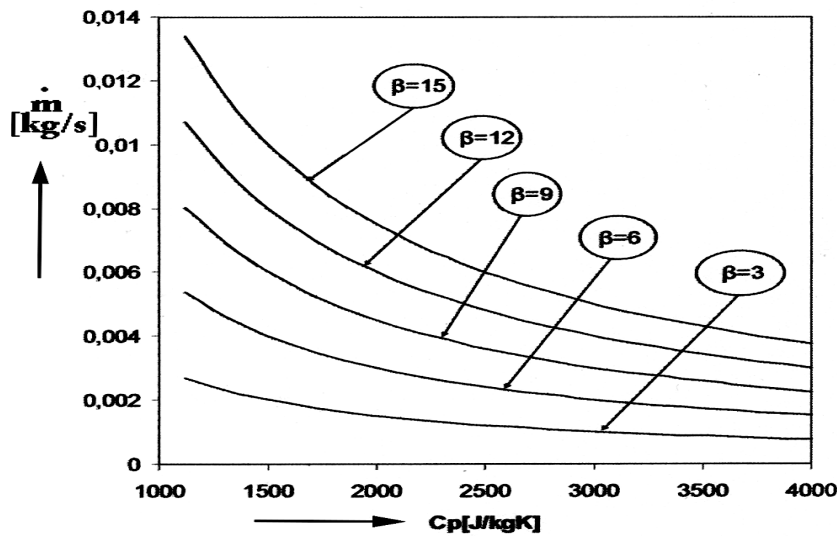


Fig. 3 - Thermocarrying fluid flow variation with its specific heat

5. EXPERIMENTAL VERIFICATIONS

The experimental verifications of the numerical calculation were done in two cases: on an installation made locally at “Electrica” swimming pool in Timisoara and on an installation described in literature.

The experimental installation made at “Electrica” swimming pool for supplying the showers with warm water in summer clear days includes three modulus of flat-plate collector, each of the area $A_c = 4\text{m}^2$. The angle with respect to the horizontal plane is $\alpha = 30^\circ$ and the azimuth angles are $\gamma_1 = -30^\circ$, $\gamma_2 = 0$, $\gamma_3 = +30^\circ$ (fig.4). The installation geometry helps that the solar radiation intensity during June, July, August on the collectors to be approximate equal to the global solar radiation intensity ($H_R = G$, a. hypothesis). Thus, between 9.00 a.m. – 11.00 a.m., it will be on the first collector, between 11.00 a.m. – 1.00 p.m. it will be on the second collector, and between 1.00 p.m. – 3.00 p.m. it will be on the third collector.

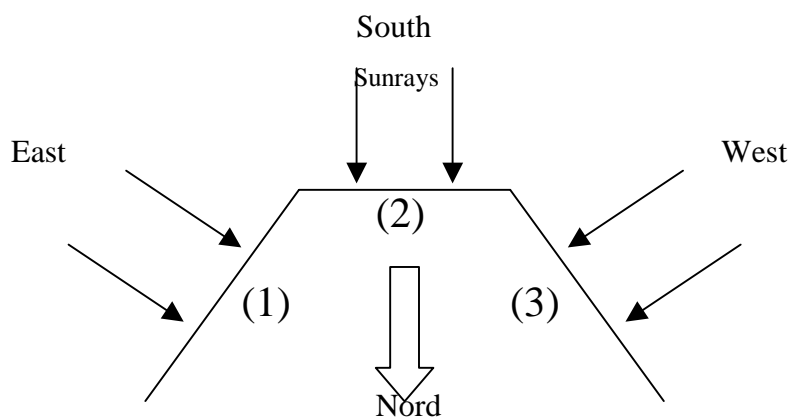


Fig. 4 - Geometry of flat-plate solar collector from ‘Electrica’ swimming pool

The solar radiation intensity is $G=900\text{W/m}^2$ (clear days, summer). The expected efficiency is $\eta=0.5$, so, $\alpha=2(\text{m}^2)$. The water flow was measured by a water meter, is $\dot{m}=0.04\text{ Kg/s}$.

The desired variation of temperature is $\Delta T=10\text{ K}$. Under these circumstances $\beta_{\text{calc.}}=180\text{ W/K}$.

The medium variation on the temperature during the use of collectors is $\Delta T=11.5\text{K}$. As a results we have $\beta_{\text{exp.}}=157\text{W/K}$, $\beta_{\text{exp}} = \beta_{\text{calc}}$

The experimental results are according to the results presented by other authors. Consequently, the paper [4] describes a thermosolar system with the following characteristics: $A_c = 156\text{m}^2$, $\eta = 48\%$, $G = 553\text{W/m}^2$, $\Delta T_{\text{exp}} = 44^\circ\text{C}$, $\dot{m} = 0.23\text{Kg/s}$

As a results $\alpha = 74.9\text{m}^2$, $\beta = 920\text{W/K}$.

Consequently, $\Delta T_{\text{calc.}} = G\alpha/\beta=45.02\text{K}$ and $\Delta T_{\text{calc}} \cong \Delta T_{\text{exp}}$

6. METHODOLOGY OF USING THE PROPOSED METHOD

In order to establish the operational parameters (\dot{m} , η), the constructive parameters (A_c) and those of the material (C_p) of the collector, the following steps are to be followed:

- a) depending on the sequence of operations in which the heat supplied by the collector is implied, the value of the magnitudes $T_{f,o}$ and ΔT is settled;
- b) knowing the reference value of the radiant power density of the geographical place in which the collector is settled, the set of the pairs of the values α and β that satisfy the requirement imposed at point (a) for ΔT is established by the computer
- c) depending on the admitted weight, the collecting area A_c , is to be calculated
- d) the desired medium efficiency is settled. Next, from the list of values is chosen the α value, the closest one to the product $\eta \cdot A_c$;
- e) from the set of pairs of the values α and β is chosen the magnitude β which is in biunique correspondence with the magnitude α settled at the point (d);
- f) being known the magnitude β and the chemical nature of thermocarrying fluid, finally, the fluid flow will be calculated.

7. CONCLUSIONS. THE POSSIBLE ENLARGEMENT OF THE PAPERS

The paper may be continued by elaborating digital programs that will design the quadridimensional portrait of the efficiency in the space of axes η , α , β , $T_{f,o}$, the parameters may be $(\tau\alpha)_{\text{ef}}$ or $T_{f,i}$.

The hyper surface designed on four axes would give the advantages:

1. the designers would establish rapidly the point whose coordinates satisfy the requirements relating to A_c , η , $T_{f,o}$, \dot{m} , C_p , U_L and $(\tau\alpha)_{\text{ef}}$.
2. in the didactic activity, the teachers will be able to offer the students an intuitive image that would stimulate them to study thoroughly heliotechnics.

The method presented above allows establishing the technical and the constructive parameters of the solar flat-plate collector in a very short time.

Based on the measurements developed over many years, the use of the method supposes to be informed over the reference value of the radiant power density of the any geographical place.

The paper may be enlarged upon the introducing an automation element assisted by the computer. This element will modify the fluid flow of the thermocarrying fluid during daytime, depending on the solar radiation intensity in order to maintain exactly the efficiency and the temperature at the established values.

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