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The negative influence of the hydraulic imbalance to the system performance in solar panels

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Abstract

This article presents how greater impact has the flow rate determining the system performance in the thermal solar panels. Starting from the general correlation between flow rate of thermal agent and the solar energy received by a flat plate collector the analysis is extended to an entire field of collectors where the flow rate is more or less uniform.
The bad performance determined by the hydraulic unbalance is being presented in relation to the general performance of the field. The drop in the performance of the system is that point where for less energy used a smaller amount of energy is produced.
In this article, it is justified the medium range of values for the flow rate that must be adopted in order to obtain a stable and balanced functionality of the entire system and best performance for the system. According to that, if a flat plate collector needs a minimum flow rate of 15 l/m2.h to work properly, for an entire field of collectors we need at least 60 l/m2.h to get good performance.
The purpose of this paper work is to show the negative consequences that affect the energy performance of solar panels, like the hydraulic unbalance inside the network that unites the solar panels.

The research has the 2 main objectives:
1. Determining the correlation between the dispersion of flow rate and the reduce of the system performance;
2. Determining the influence of initial designed flow rate to the correlation from point 1.

This aspect that we discuss in a solar panel network also appears in classic heating networks. In the case of the solar panel field, lowering the performance means lowering the power received from the sun, but in the classic heating networks lowering the performance means lowering the power supplied to heated spaces. In other words, in the case of the solar panel field the heat does not get high enough and in the case of the heating network it does not get as low as it could get. The lowered performance in solar panels field can be evaluated by reporting the new performance obtained to the maximum performance that can be obtain.

Key-word: solar panels, performance

1. Introduction

We consider a balance network that network where the flow rate in all the nodes has the same value for all the solar panels, in opposition to an unbalance network where the flow rate repartition is chaotic, even if the total flow rate generated at the source of the network is the same in both cases (that is determined from the project state).

The purpose of this paper work is to show the negative consequences that affect the energy performance of solar panels, like the hydraulic unbalance inside the network that unites the solar panels.

In the next chapters we will start analyzing one solar panel and then extend the analysis to a field of solar

2. The evaluation of the solar thermal performance

The solar panel theory is well known to current day, so we will only appeal to well know relations and we will utilize them in order to evaluate the solar power received [4,9,13]. If you refer to a single solar panel the relations that are used to evaluate the performance of the panel are:

$$\eta = F_R \cdot (\alpha\tau) - F_R \cdot k_c \cdot \beta \tag{1}$$

$$\beta = \frac{t_0 - t_e}{I} \tag{2}$$

$$F_R = \frac{a \cdot \rho c}{k_c} \cdot (1 - E) \tag{3}$$

$$E = \exp\left(-\frac{F' \cdot k_c}{a \cdot \rho c}\right) \tag{4}$$

Or if we refer to the medium temperature of the thermic agent:

$$\eta = F' \cdot (\alpha\tau) - F' \cdot k_c \cdot \beta' \tag{5}$$

$$\beta' = \frac{t_m - t_e}{I}$$

$$t_m = F \cdot t_0 + (1 - F) \cdot t_E \tag{6}$$

$$F = \frac{1 - E}{-\ln E}$$

$$t_E = \frac{\alpha\tau}{k_C} \cdot I + t_e \tag{7}$$

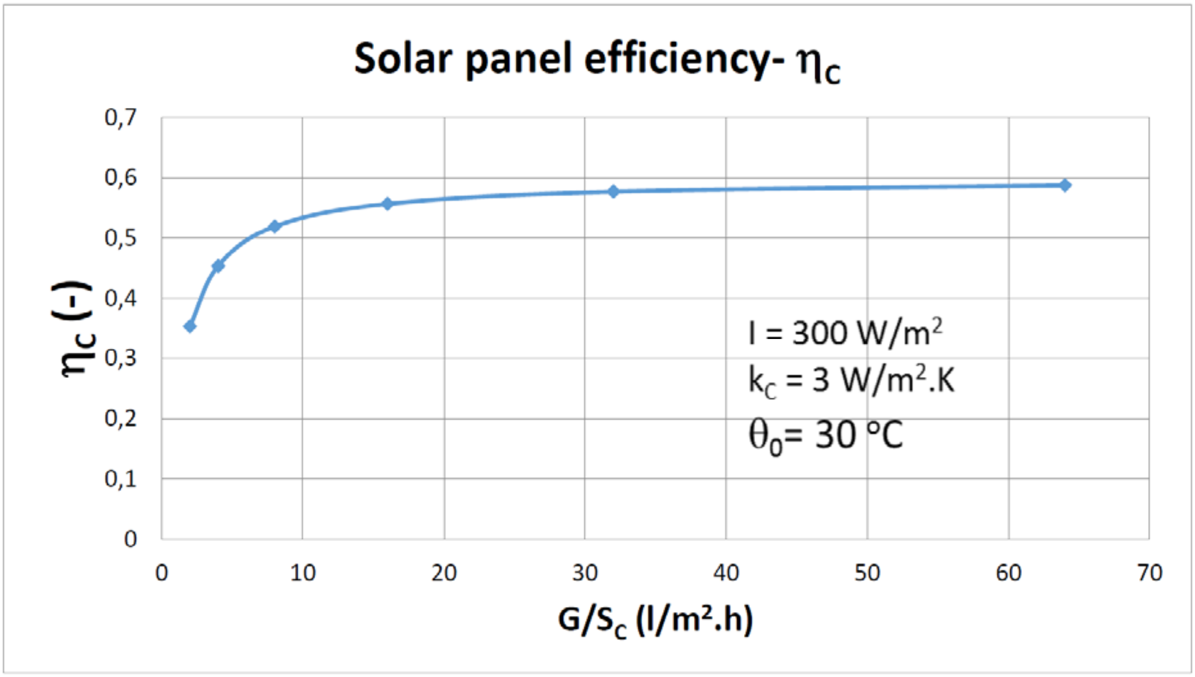

Fig. 1- Representation of theoretical solar panel efficiency

In order to calculate the efficiency of a solar panel we use relations (1), (2), (3), (4) or relations (5), (6), (7) depending what temperature of the thermal agent is used (inlet or medium).

In fig. 1 it is presented the evolution of the capture efficiency depending of the specific flow rate of thermal agent for a certain situation ($I = 300$ W/m^2, k_C = W/m^2.K, $t_0 = 30$ ^{o}C). We can see that after the value of 16 l/m^2.h of the specific flow rate of the thermal agent, the value of the efficiency remains almost the same, the increase being very little. We obtain the same result in other situations, changing the parameters.

Another way to express this thing is to represent in a graphic the thermal characteristic of the solar panel. By thermal characteristic of a solar panel we understand the graphic representation of relation 1 and 5.

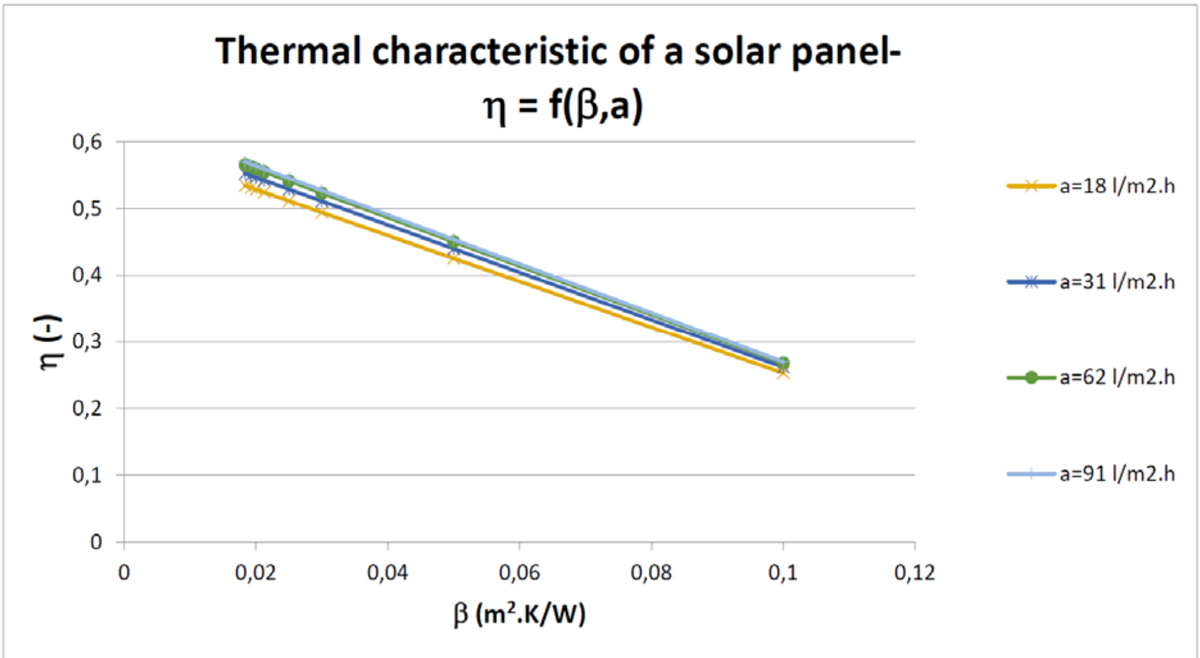

Fig. 2 - The thermal characteristics of solar panels at different flow rate rates

From fig. 2 observe how the thermic characteristic representative lines for different values of the specific flow rate of the thermal agent are starting to stock in the upper part of the diagram starting from the value of the 16 l/m^2.h. We can conclude from this that for a single solar panel the performance values will not increase after the flow rate value that we express. From fig 2 we can also see the lowering of the performance at specific flow rate lower than 10 l/m^2.h.

In fig. 3 it is the presented the shape of the thermal characteristic of a solar panel with absorption in the relation with the coefficient of entrance parameters β'. In this situation we have only one representative series for all the values of specific flow rate. The series in diagram from fig. 3 have a different global coefficient of thermic transfer k_C of the solar panel.

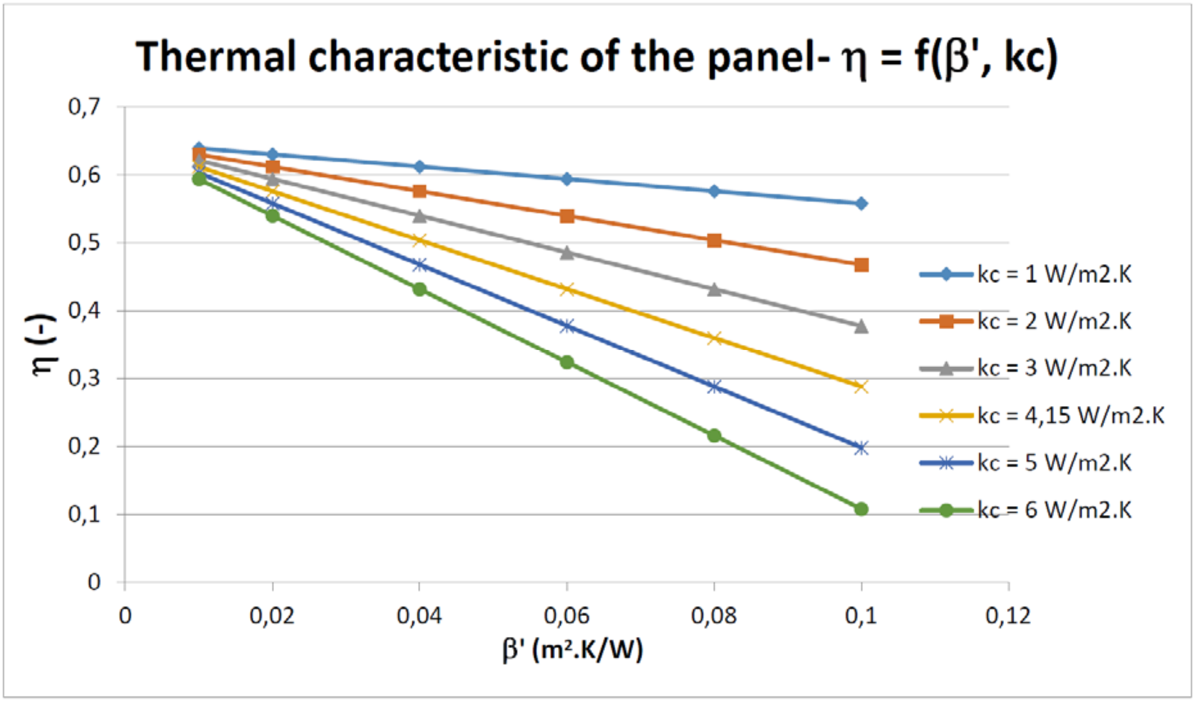

Fig. 3- Thermal characteristics of solar panels at different k_c

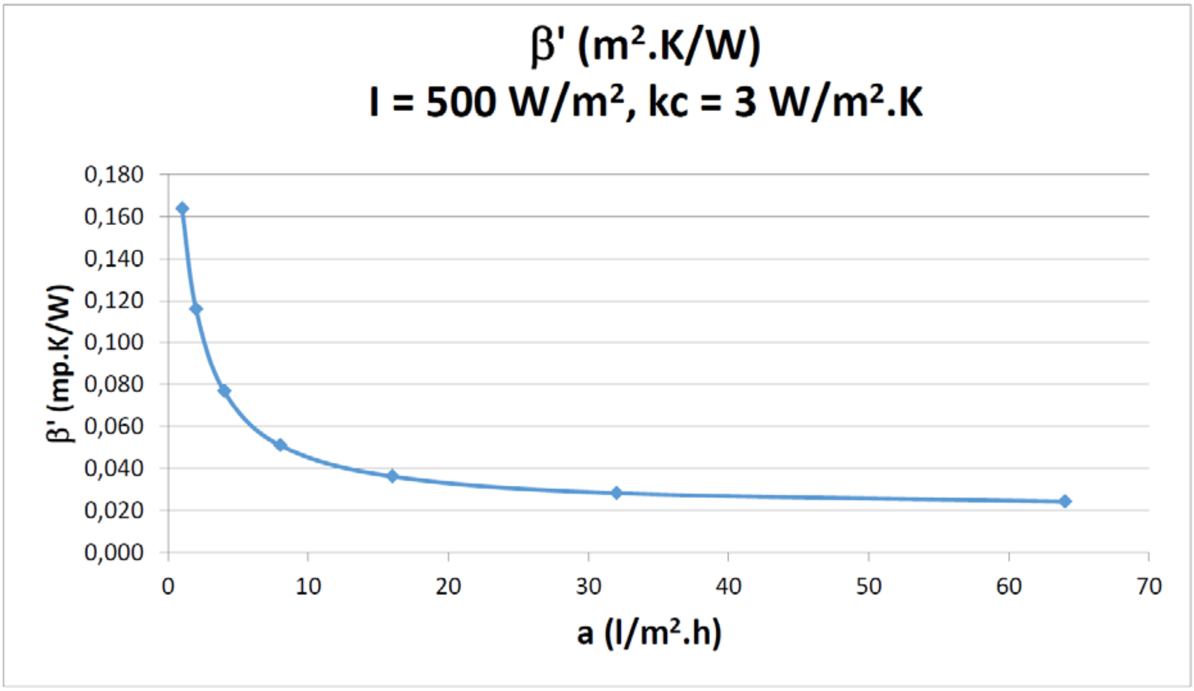

Fig. 4 – Representation of β'

The influence of the specific flow rate can be pointed from the fig. 4. It can be seen from here that the values of the specific flow rate below the value of 16 l/m^2.h lead to big increases of the values β' and from here on, in fig 3 to lower values of efficiency η.

3. The influence of the hydraulic aspects to the thermal performance of the solar panel surface

Those presented until now make reference to the direct influence of the flow rate to the performance of the solar panels and this study was necessary to obtain the final goal that will extend the study from one solar panel to a field of solar panels. Balancing a hydraulic system requires that the flow rate of thermal agent that pass different segments of the pipe network to be aligned with the panels that supply those pipe nodes. Usually, the general scheme used to supply the panels is a Tichelmann type that implies every solar panel network is equal in size and diameters to all other panels. This way, from the linear hydraulic resistance point of view is almost the same for all panels that will determine a low possibility to get a hydraulic unbalance. The hydraulic unbalance of the system can easily come from mistakes made in designing or building the system. If that happens some nodes of the network will have higher values of flow rate than others. The increase of the flow rate in some regions does not have any impact to the system but the lower values of flow rate in opposite regions will impact negatively the energetic performance of the system. This is why we must threat with attention this aspect and try to appreciate the consequences.

We want to evaluate what negative influence has the flow rate dispersion all over the field of solar panels and over the performance of the solar intake surface.

The hypothesis of work is that the system is designed to a certain flow rate that is considered to be respected.

$$
\begin{aligned}
&P_R = 1.163 \cdot a_R^* \cdot (1 - E_R) \cdot (t_E - t_0)\\
&E_R = \exp(-NTU_R)\\
&NTU_R = \frac{F' \cdot k_c}{1.163 \cdot a_R^*}
\end{aligned}
\tag{8}
$$

In the case which from the solar panel flow rates a different flow rate than the base value, the thermic power will be also differ from the base value:

$$
\begin{aligned}
&P = 1.163 \cdot a^* \cdot (1 - E) \cdot (t_E - t_0)\\
&E = \exp(-NTU)\\
&NTU = \frac{F' \cdot k_C}{1.163 \cdot a^*}
\end{aligned}
\tag{9}
$$

Reporting the thermal specific power P to the base thermal power P_R we obtain:

$$
\frac{P}{P_R} = \frac{a^*}{a_R^*} \cdot \frac{1 - E}{1 - E_R}
\tag{10}
$$

And now:

We have a total surface S and a total flow rate G. The specific base flow rate will be G/S. The total surface it is considered to be composed from two surfaces S_1 and S_2 that have different percentages from the total surface S. Like this:

$$\begin{aligned} S_1 &= s_1 \cdot S \\ S_2 &= s_2 \cdot S \end{aligned} \tag{11}$$

In turn, the flow rates corresponding to those two surfaces will be :

$$\begin{aligned} G_1 &= g_1 \cdot G \\ G_2 &= g_2 \cdot G \end{aligned} \tag{12}$$

The specific flow rates from those two zones will be :

$$\begin{aligned} \frac{G_1}{S_1} &= \frac{g_1}{s_1} \cdot \frac{G}{S} \\ \frac{G_2}{S_2} &= \frac{g_2}{s_2} \cdot \frac{G}{S} \end{aligned} \tag{13}$$

Or:

$$\begin{aligned} a_1^* &= \frac{g_1}{s_1} \cdot a_R^* \\ a_2^* &= \frac{g_2}{s_2} \cdot a_R^* \end{aligned} \tag{14}$$

A measure of the disperse flow rates of thermal agent within the catchment area, utilized in this paper work was the absolute value of the difference between the two surface percentage and the percentage of flow rates that correspond to those two zones $|s_1 - g_1| = |s_2 - g_2|$. It can be seen that the estimated dispersion is the same even if we refer to the first or the second zone.

In fig. 5 and 6 it is presented a graphical representation of the situation in which the surface collector is uniformly filled with the flow rate of thermal agent (fig. 5) and another situation in which the surface collector has two zones, one with a little surface that has a higher flow rate and other with a bigger surface and a lower flow rate (fig. 6) – unbalance fluid circulation for the collector surface. The horizontal lines in each graphic indicate the energetic performance for each surface. It can be seen that fig. 6 has lower performance than fig. 5.

The analysis counted only two base values for the flow rates:

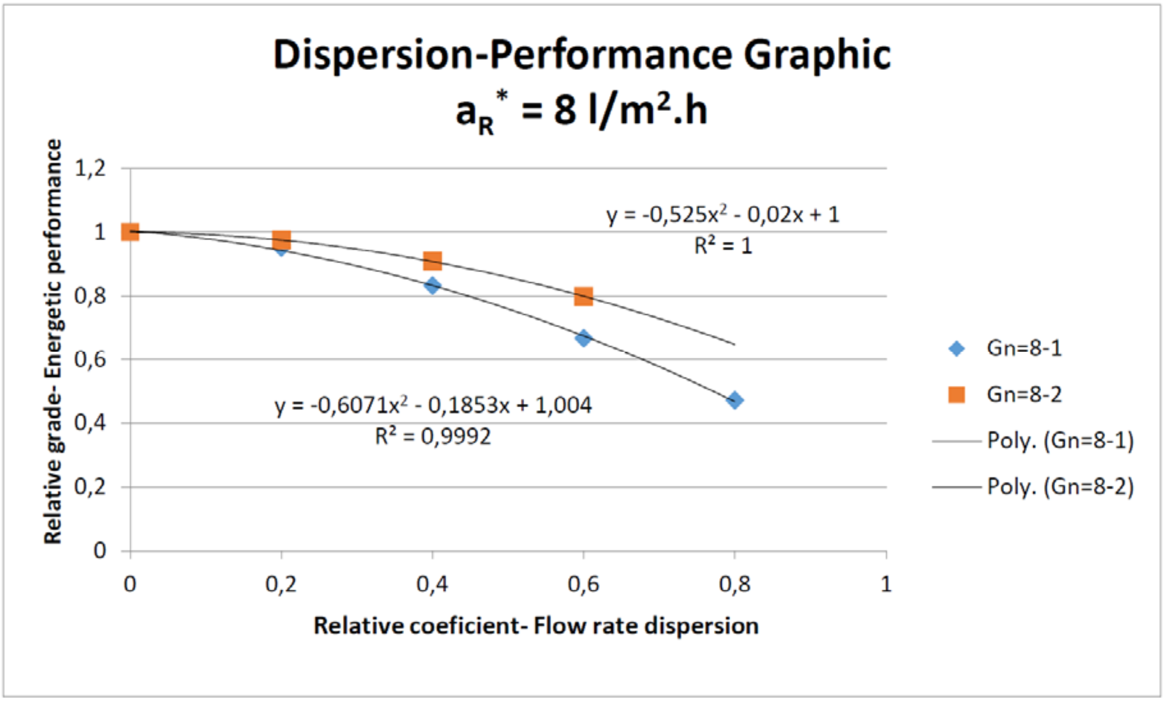

Fig. 5- Performance graphic representing the dispersion at 8 l/m^2.h

In fig. 5 it is presented the correlation between energetic performance of the intake solar system and the dispersion grade of the flow rate of thermal agent inside the solar surface where the reference flow rate is 8 l/m^2.h. It can be observed a great influence of the flow rate dispersion in this situation.

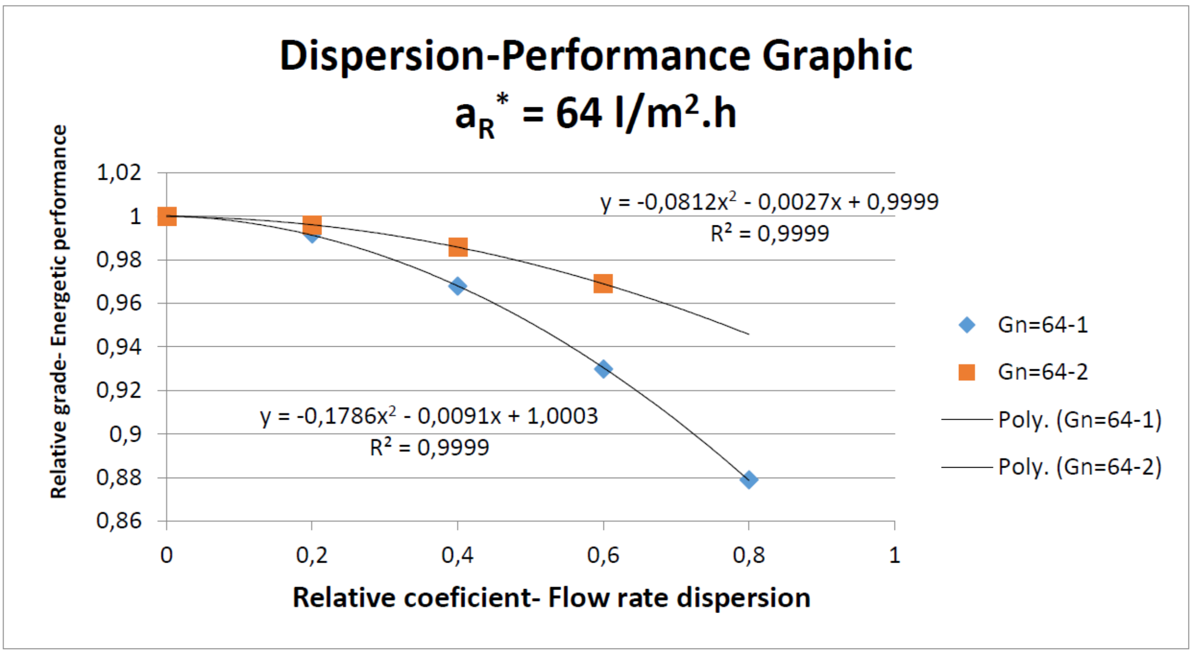

Fig. 6 Performance graphic representing the dispersion at 64 l/m^2.h

Fig. 6 is similar to the fig. 5, with the difference of the base designed flow rate that was 64 l/m^2.h this time. The resulted influence over the flow rate dispersion was considerably low within the solar surface. In other words, the energetic performance of the intake surface is more stable now than in the first case.

In both graphics from fig. 5 and fig. 6 are two series that limits a correlation zone between the energetic performance and the flow rate dispersion. Each time appears a new zone because of the fact there are multiple ways in making this dispersions affecting the panel surface.

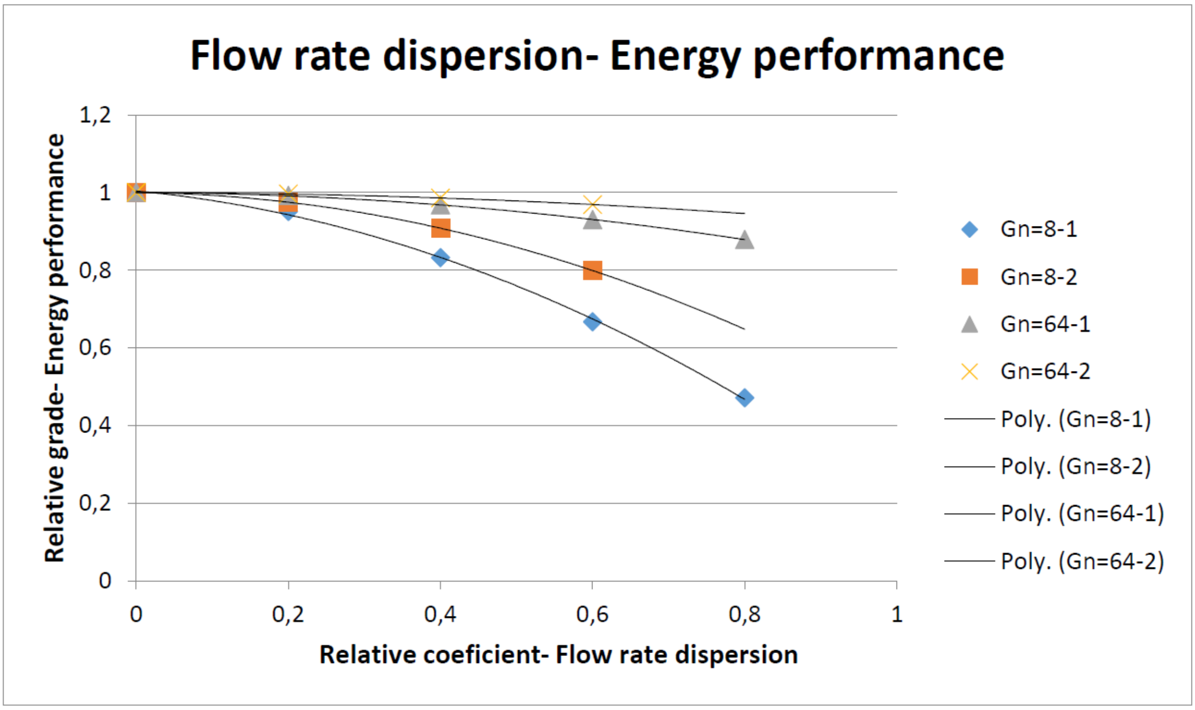

Fig. 7 – Performance graphic representing the dispersion at different flow rate values

In fig. 7 it is presented on the same graphic the situation between the dispersion grade of the flow rate and the energetic performance of those. It can be seen that the characteristic zone of the flow rate value of 8 l/m^2.l is considerably lower than the zone corresponding to the flow rate of 64 l/m^2.h value.

4. Conclusions

From the current paper we can set 2 big conclusions:

- The thermic performance of the plane solar panels with absorption will lower very fast at flow rates lower than 15 l/m^2.h and will raise very little above this value

- The working area of a solar panel field should be above the specific flow rate of 60 l/m^2.h

♦ A bigger value for the flow rate of the thermal agent supplies a better evacuation of air and a good functionality of the entire system;

♦ A bigger value for the flow rate protects from having big performance loses when unexpected hydraulic unbalance occurs.

The first conclusion is referring to singular solar panels. We found the value of 15 $l/m^2.h$ the turning point where the more we increased the input energy, the energy created by the system was starting to limit to a certain value and could not get a slighter performance increase. But at values below of 15 $l/m^2.h$ even a small amount of input energy increase will determine big increases for the output energy of the solar panel.

The second conclusion refers to a solar panel field. We studied the quantitative and qualitative aspects of the efficiency in relation with the specific flow rate. For the quantitative aspect, the dispersion of flow rate is higher the lower the flow rate is. That will decrease even more the system performance because will allow the system to run at lower values that have a big performance drop in relation to the small increase at higher values. So the dispersion of the flow rate just amplifies the influence of the flow rate to the system performance. We strongly recommend to design systems (up to 30 solar panels) that are using specific flow rates above the value of 60 $l/m^2.h$.

A practice usage for the current study is that we can determine the dispersion in a hydraulic solar system using the performance losses. The theoretical and experimental system performance can be compared and the difference between then represents the reduced performance. If none other factors are involved in lowering the system performance, we can determine the dispersion because we know how much the dispersion influence the system performance.

Nomenclature

α - absorption coefficient of the solar panel, -;
τ - transparency coefficient, -;
F' - efficiency factor of solar panels, -;
F_R - intake efficiency -;
η - efficiency of a plane solar collector, -;
β, β' - synthetic parameter for input measurements, $m^2.K/W$;
E - intrinsic feature, functional, for solar surface,-;
a - specific flow rate of thermal agent, m^3/s;
θ_0 - initial temperature of the thermal agent inside the solar panel, ^oC;
t_0 - inlet temperature of the thermal agent inside at the solar panel, ^oC;
t_m - medium temperature of the thermal agent inside the solar panel, ^oC;
t_e - outside temperature, ^oC;
I - solar radiation intensity, W/m^2;
t_E - equivalent temperature, ^oC;
k_C - global transfer coefficient for solar panels, $W/m^2.K$;
P_R - specific base power – thermic power for a surface of 1 m^2 de for the base

flow rate demand (design), W;

a_R^* - specific base flow rate (design flow rate), l/m^2.h;

s_1 si s_2 – percentage of the two zones of surface used, $s_1 + s_1 = 1$;

g_1 si g_2 – percentage of the two flow rates used for the two surfaces, $g_1 + g_2 = 1$;

a_1^* - specific flow rate for zone 1, l/m^2.h;

a_2^* - specific flow rate for zone 2, l/m^2.h;

1.163 – transformation factor, W.h/l.K;

NTU- number thermal units, -;

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