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TRANSIENT EFFECTS IN SOLAR COLLECTOR SYSTEMS

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ABSTRACT: One of the main problems of the systems that use renewable energy resources is the long payback time of the investment. Beyond the quality of the parts of a system the payback time is strongly affected by the degree of utilization and the suitable control, too. The goal of the measuring is the calculation of the momentary and average efficiency of the collectors and the analyzing of the influential factors. The efficiency of the collectors is most affected by the difference between the temperature of the collector and the external air, and the intensity of the solar irradiation. It means that this measuring is not reproducible. According to this fact it needs to make numerous measuring. During the processing of the database we have to average the results that have similar external parameters. With the device we can measure the momentary efficiency of the collectors. In this article we represent the limitations and the sources of error of this measuring. With the device we can analyze the transient effects of the collectors in the event of changing weather.
KEYWORDS: solar collector, efficiency, solar energy

❖ INTRODUCTION

Fig. 1 represents the equipment. For the measuring we used our own-designed experimental flat collectors (1, 2). The covering of these collectors is removable, so we could test the collectors with different polycarbonate sheets and uncovered. With the unit we can operate the collectors in parallel or serial connection. In the serial connection we can change the order of the two collectors. It is possible to lock out either collector.

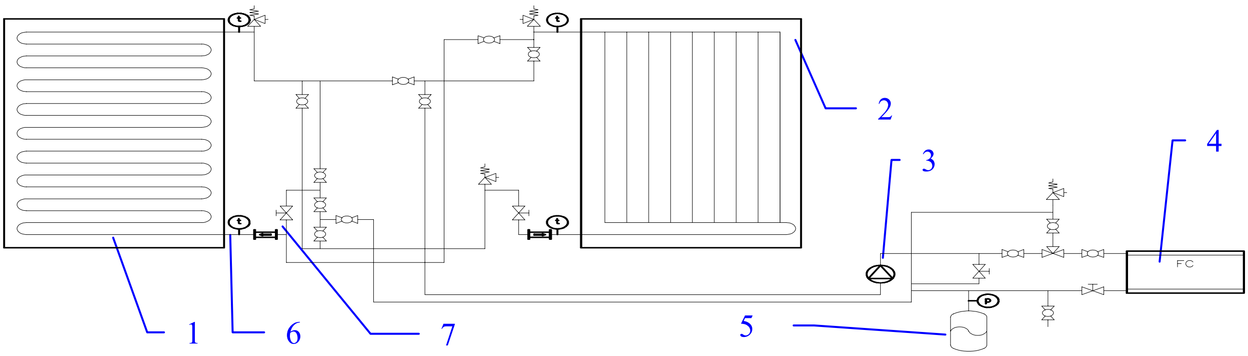

Fig. 1. Experimental equipment for measuring the efficiency of solar collectors
1 – collector with coil-pipe, 2 – collector with parallel pipes, 3 – circulation pump, 4 – fancoil,
5 – expansion tank, 6 – thermometers, 7 – volume flow rate measuring

The equipment transfers the heat output of the collectors to the external air by a fancoil (4). The cooling fan can be adjusted continuously and the cooling capacity can be decreased further with a bypass pipe, so we can adjust the temperature of the entering fluid of the collectors.

Besides the measuring of the volume flow rates and the temperatures we measured the temperature and humidify of the external air and the solar irradiation. The irradiation was measured by a Lambrecht 16131 pyranometer mounted between the collectors in the same plane.

The circulation pump is adjustable in five steps. In function of the return temperature the pump does further adjusting.

Differently from the conventional ones the water-meters in the equipment measures by displacement, with rotating piston. The volume flow rate could be measured from 7.5 l/h, which is an extremely low value. The accuracy of the water-meters is ± 2%. The impulse-relays signal by liters. We saved the impulse signals with a two-channel datalogger.

The temperatures were measured by K-type thermocouples with two Testo 177-T4 datalogger. The accuracy of the measuring is ± 0.3 °C. The response time is affected by the type of measuring junction and the outside diameter of the metal sheath thermocouple. The response time was very low, because we used unsheathed thermocouples [1].

Besides the measuring of the volume flow rates and the temperatures we measured the temperature and humidify of the external air and the solar irradiation. The irradiation was measured by a Lambrecht 16131 pyranometer mounted between the collectors in the same plane.

During the most of the measuring we have saved the data by 5 sec. It enables to analyze the transient effects. It results very high amount of data, so it requires database management software.

❖ EFFICIENCY CALCULATION

We can calculate the efficiency of a collector by the inlet and outlet temperature, specific heat, volume flow rate of the fluid and the intensity of the solar irradiation:

$$\dot{m} = \dot{V} \cdot \rho$$

$$\dot{Q} = c \cdot \dot{m} \cdot (t_{out} - t_{in})$$

$$\dot{q} = \frac{\dot{Q}}{A}$$

$$\eta = \frac{\dot{q}}{G}$$

$\dot{m}$ - mass flow rate of the fluid in the collector $\left[\frac{kg}{s}\right]$

$\dot{V}$ - volume flow rate of the fluid in the collector $\left[\frac{m^3}{s}\right]$

ρ - density of the fluid $\left[\frac{kg}{m^3}\right]$; η - collector efficiency

$\dot{Q}$ - heat output of the collector $[W]$, c - specific heat of the fluid $\left[\frac{J}{kgK}\right]$

t_{in} - fluid inlet temperature $[°C]$; t_{out} - fluid outlet temperature $[°C]$; A - surface of the collector $[m^2]$;

$\dot{q}$ - specific heat output of the collector $\left[\frac{W}{m^2}\right]$; G - intensity of solar irradiation $\left[\frac{W}{m^2}\right]$

❖ COMPARISON OF THE COLLECTOR ABSORBERS WITH SINGLE PIPE AND PARALLEL PIPES

In the period from April to October in Hungary it is absolutely advisable to utilise the solar energy. The average energy yield of the summer months (April - October period) is 3690 MJ/m2, which equals a total value of 1025 kWh/m2 meaning a monthly value of 170.83 kWh/m2 and a daily value of 5,69 kWh/m2 [2]. We have made measuring from March to November of 2010.

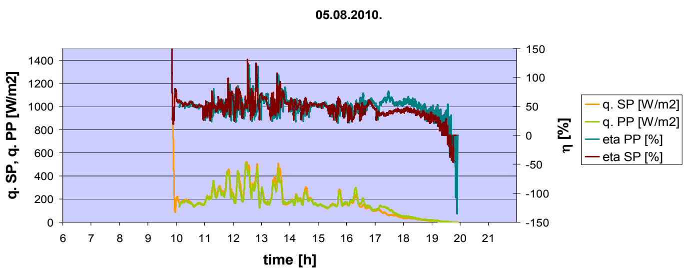

Fig. 2. Comparison measuring of absorbers with single pipe and parallel pipes

To this measuring we have used collectors with the same covering. Because of the parallel connection the inlet temperatures were the same.

As we can see in the Fig. 2 the heat output and accordingly the efficiency curves of the two collectors are alike, the difference is negligible. The difference between the two curves after 17:00 is occurred by the shadow that covers the single pipe collector and after 18:00 the both collectors. The high values at the start before 10:00 occurred by the stagnation temperatures of the collectors. These values are not usable in the further calculations. The decrease and the negative values of the efficiency after 19:00 are occurred by the lower and lower intensity of solar irradiation: the fluid cool down flowing through the collector. These values are not used in further calculations. The useful results are the values between 10:00 and 17:00. The deviations of the heat output are occurred by the clouds. These transient effects could cause inaccuracy as we can see on the values of the efficiency above 100 % in the Fig. 2.

❖ MEASURING THE MOMENTARY EFFICIENCY OF THE COLLECTORS

In the Fig. 2 we can see the deviation of the efficiency. The clouds make the solar irradiation unsteady. The pyranometer detects the changes in less than 5 seconds. By the higher thermal inertia the reaction of the collectors are much slower, so the outlet temperatures start to decrease later, so the efficiency values calculated directly after a decrease of the solar irradiation are wrong. These errors could be eliminated in two ways:

– averaging,
– elimination of the cloudy periods.

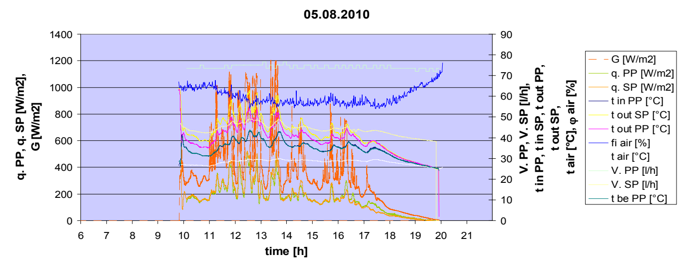

Fig. 3. Solar irradiation, temperatures and volume flow rates

Fig. 3 represents the values of solar irradiation (G), temperatures (t), and volume flow rates (V.) during a diurnial measuring:

As we can see in the Fig. 3 the sky was cloudy during the whole measuring period. The momentary efficiency values are not usable, the next table represents the diurnial average results:

Table 1. Average results of the measuring in 05.08.2010

Date	efficiency		air	collector temp.		t köz-t lev		G	total	total heat output	
	OGY	CSK	temp.	PP	SP	PP	SP	average	solar irrad.	OGY	CSK
			°C	°C		°C		W/m2	[Wh/m2]	Wh/m2	
05.08.2010	48,74%	48,55%	28,2	36,5	37,9	8,3	9,6	331,8	3260,4	1589,1	1582,8

The next diagrams (Fig. 4., Fig. 5.) basically represents unclouded periods:

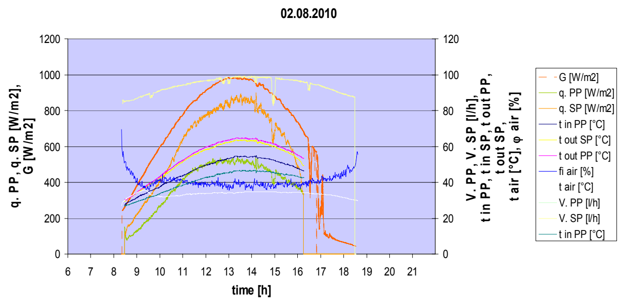

Fig. 4. Results of a sunny period

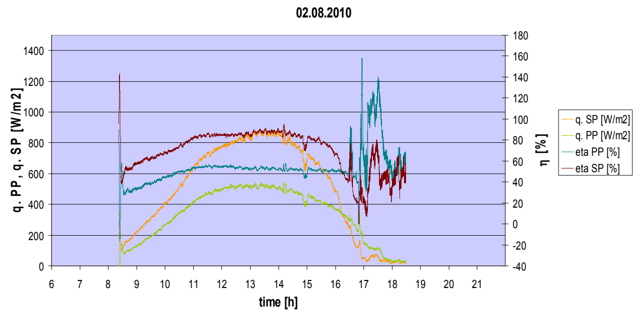

Fig. 5. Momentary efficiency values in unclouded and cloudy periods

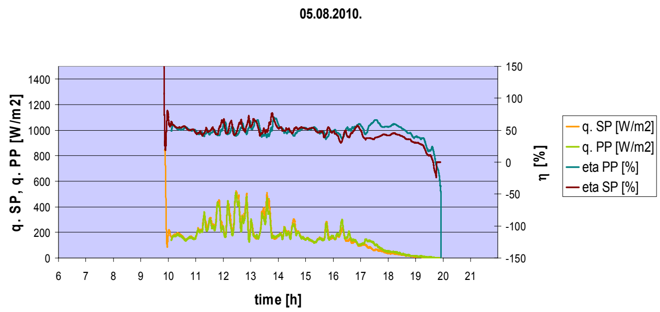

Fig. 6. Average values of efficiency of five minutes

(The collectors were in line, it is the reason of the difference between the efficiencies.) In Fig. 4 we can see a cloudy period after 16:30. In this period the curves become unmeaning (Fig. 5.).

The Fig. 7 represents the efficiency as average values of every 500 seconds. This averaging eliminates the deviations as you can see in Fig. 2 and Fig 6.

❖ EFFICIENCY OF COLLECTORS CONNECTED IN LINE

In Fig. 6 we can see the results of a measuring of collectors connected in line. The fluid flows from the parallel-pipe collector to the single-pipe one. There is not difference between the efficiencies if the two collectors work in parallel connection (have the same parameters) as we can see in Fig. 2 and Fig. 4) There is significant difference between the efficiency of the first and the second collectors: as the Fig. 6 shows the efficiency of the second collector is lower because the average temperature is higher. Between 11:00 and 14:00 the values of the efficiencies are approximately equal. The Table 2 shows the average results.

Table 2. Average inlet temperatures and efficiencies

	CSK	OGY
¤	85,71%	53,72%
t be	43,67 °C	50,82 °C

❖ TRANSIENT EFFECTS

During the most of the measuring we have saved the datas by 5 seconds. It enables to analyze the transient effects. (It results very high amount of datas, so it's processing requires a database management software.)

As we can see in the Fig. 8. above, the appearance of the changes in the heat output is quicker on the first collector and slower on the second collector in line. After the measuring we have changed the order of the two collectors connected in line, and the effect was the same: the reaction of the second collector was slower.

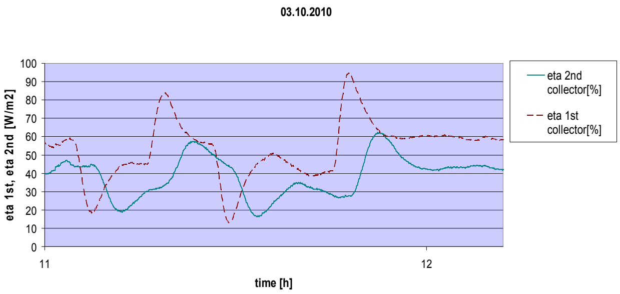

Fig. 8. Transient effects in collectors connected in line

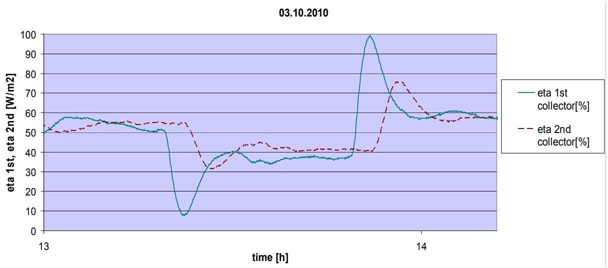

Fig. 9. Transient effects in collectors connected in line

❖ CONCLUSIONS

Our own-designed equipment is suitable to test solar collectors and measure it's momentary and average efficiency. With very short time interval of datalogging we can analyze the transient effects of the collectors. It could be useful for designing control system for solar collectors.

❖ ACKNOWLEDGEMENT

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HUNGARY'S RENEWAL

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