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TRANSIENT EFFECTS IN SOLAR COLLECTORS CONNECTED IN LINE

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ABSTRACT: During our experiments about solar collectors we have developed a unit that is capable for measuring the efficiency as the function of the specific solar irradiation and the temperature difference between the collector and the ambient air. During the analysis of the collectors generally we can calculate the efficiency by average values of a time-period. The calculation of the momentary efficiency is conditioned, for example, it needs cloudless sky and – of course – correct temperature and volume flow rate values. We have to analyse the transient effects, too. Beyond the determination of the function of the efficiency our studies cover the analysis of the transient effects and the properties of the serial and parallel connection. By the operating of the unit we have several observations which could be important informations during the designing of a control system for solar collectors. In this article we represent the results of the analysis of transient effects.
KEYWORDS: solar collectors, efficiency, transient effects

INTRODUCTION - TRANSIENT EFFECTS

The temperatures of the solar collectors follow the changes of the weather with a time-delay. So during a period of a decreased irradiation that caused by a cloud rack the heat output of the collectors still high, then it decreases. Transient effects could be occurred by the changes of the inlet temperature of the fluid, too, when we take hot water from the tank of a solar collector system. If the intensity of the irradiation and the inlet temperature of the fluid are constant, the collectors run in a steady-state condition.

The response time of a solar collector is defined as the time taken for the temperature rise of the absorber plate to reach 90% of the final steady rise when the collector is subjected to a step change in the solar radiation level (N. E. Wijeysundera, 1976).

Patrick Pierson and Jacques Padet determinate the time constant of flat collectors (Pierson, Padet, 1990). They studied the effect of the different parameters (thickness of the covering and the absorber, number of glass layers, the heat capacity and the mass flow rate of the fluid).

INTRODUCING THE UNIT

With our unit we can operate two collectors in parallel or in line. In case of in line connection we can change the order of the two collectors. We can lock out each of the collectors from the operation.

The absorbers of the collectors have the typical tube systems: one of them is equipped with a single pipe, the other one has parallel pipes.

The temperature different between the collector and the ambient air in our system is well-controlled with the fan coil which transfers the heat from the collectors to the ambient air. The number of revolution of the fan is continuously adjustable, and the cooling capacity can be further reduced by a valve and a bypass pipe. It is possible to lock out the fan coil from the circuit. With this construction we can change the temperature of the fluid at the intake of the collectors: as we reduce the cooling capacity the temperature increases.

METHODOLOGY

Computations have been performed to select the optimum time interval ($\Delta\tau$) for calculations and also for data sampling. The results show that estimation of the parameters within ±4% of the steady state values could be obtained using $\Delta\tau$ of 5 s (E.H. Amer et al., 1999).

The temperatures were measured by K-type thermocouples with two Testo 177-T4 data logger. 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 (Eric C. Guyer, 1989).

For the measuring the collector efficiency we use a Lambrecht 16131 pyranometer. The response time of the pyranometer is less than 18s, the accuracy is ±5 %, the non-linearity is less than ±1 %. The pyranometer conforms to ISO 9060 "First class" standard (www.lambrecht.net). The pyranometer used during the tests shall be placed in a typical test position and allowed to equilibrate for at least 30 min before data-taking commences. (ISO 9806-1)

RESULTS

By the data loggers we have registered the values every 5 seconds, so we can analyze the transient effects. It is important for the measuring of the efficiency (the transient states make the measurement incorrect) and it could give useful informations about the operation of the collectors, too. For the correct measuring results we have to analyze the database and filter out the cloudy periods. This method was represented in our former publication (István Péter Szabó, Gábor Szabó, 2012).

During our measuring the two collectors were connected in line. Before 13:00 the first was the single pipe collector and the second was the one with parallel pipes. At 13:00 we have changed the order. Comparing the results of the two measurements we can eliminate the effects of the different structural design of the two collectors and we can see clearly the properties of the first and second position.

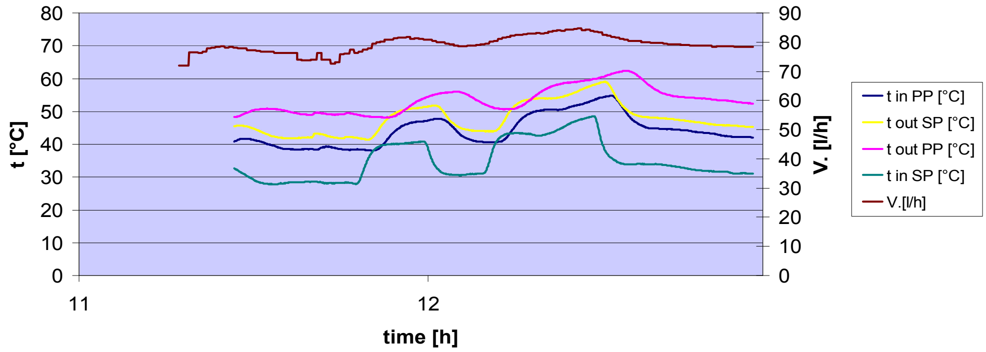

Figure 1. Inlet and outlet temperature of the collectors connected in line in the order of single pipe (SP) – parallel pipes (PP)

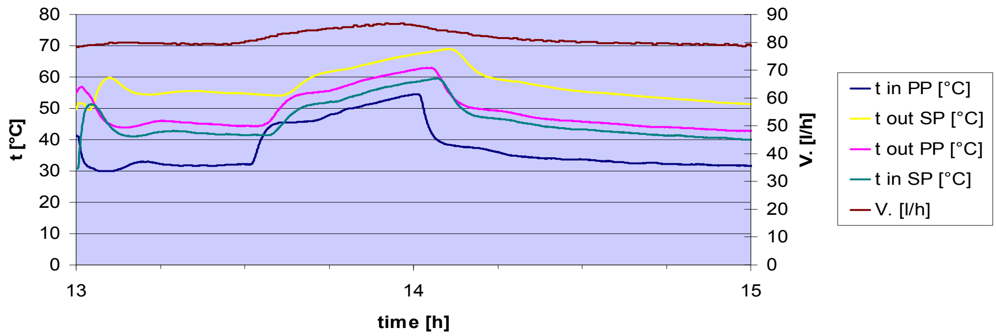

Figure 2. Inlet and outlet temperature of the collectors connected in line in the order of parallel pipes (PP) – single pipe (SP)

The transient effect was produced by the turning off and on of the fan coil – hereby the inlet temperature was increased then decreased. (The drop of the inlet temperature in solar collector systems is occurred by water taking.) We have repeated the measurement at the same volume flow rate after the changing the order of the collectors (Figure 3).

As we expected, the first collector – which was closer to the fan coil – had quicker reactions to the changes of the temperature. We can see that the transient effects not only start later but take more time on the second collector.

Table 1. Time of switching on and off the fan coil during the measurements in 03.10.2010

11:49:00	fan coil switched off
12:01:00	fan coil switched on
12:11:00	fan coil switched off
12:30:00	fan coil switched on
13:30:00	fan coil switched off
14:00:00	fan coil switched on

At the start of the first measurement when we switched off the fan coil the inlet temperature of the first collector was 28,3°C. It started to increase at 11:50:28, and reached the maximum 40,9°C at 12:01:48 (after the switching on of the fan coil at 12:01:00). We have switched off the fan coil again at 12:11:00. The inlet temperature of the first collector decreased to 31°C at 12:11:08, than kept this value to 12:11:58. Then increased again to the maximum of 48,6°C at 12:30:43, then – by the switching on of the fan coil at 12:30:00 – decreased back to 31°C at 12:55:18. You can see this data of the temperature at the inlet of the first collector in the Table 2 with the outlet temperature and the similar data of the second collector:

Table 2. Transient effects of the collectors connected in line in the order of single pipe (SP) – parallel pipes (PP)

Measuring point	Fancoil switched off		Start of the temperature increase	Fancoil switched on	Maximum temperature		Fancoil switched off	Minimum temperature	
SP in	28,3°C	11:49:00	11:50:28	12:01:00	40,9°C	12:01:48	12:11:00	30,7°C	12:06:08
SP out	42,2°C		11:52:48		51,8°C	12:03:18		44,1°C	12:10:18
PP in	38,2°C		11:53:23		47°C	12:05:38		40,7°C	12:11:53
PP out	49,4°C		11:57:38		56°C	12:06:48		50,8°C	12:16:48

Table 2 (continue). Transient effects of the collectors connected in line in the order of single pipe (SP) – parallel pipes (PP)

Measuring point	Start of the temperature increase	Fancoil switched on	Maximum temperature		Steady temperature	
SP in	12:11:58	12:30:00	48,6°C	12:30:43	34,1°C	12:35:38
SP out	12:13:58		59°C	12:32:58	48,2°C	12:40:43
PP in	12:14:23		54,9°C	12:33:43	44,8°C	12:41:23
PP out	12:16:48		62,4°C	12:36:13	54,1°C	12:48:18

Table 3 represents the duration of the transient effects at each measuring point. As we can see in the two last column of Table 3 going ahead in a serial connection the transient effects are slower and slower.

Table 4 represents the results of the measurement of the two collectors connected in line in the opposite order (Figure 3).

Table 3. Duration of the transient effects

Measuring point	Duration of temperature Increase	Duration of temperature drop	Duration of temperature Increase	Duration of temperature drop	Total duration on the first transient effect	Total duration on the second transient effect
SP in	0:11:20	0:04:20	0:18:45	0:04:55	0:15:40	0:23:40
SP out	0:10:30	0:07:00	0:19:00	0:07:45	0:17:30	0:26:45
PP in	0:12:15	0:06:15	0:19:20	0:07:40	0:18:30	0:27:00
PP out	0:09:10	0:10:00	0:19:25	0:12:05	0:19:10	0:31:30

Table 4. Transient effects of the collectors connected in line in the order of parallel pipes (PP) – single pipe (SP)

Measuring point	Fancoil switched off		Start of the temperature increase	Fancoil switched on	Maximum temperature		Steady temperature	
PP in	32,2°C	13:30:00	13:31:13	14:00:00	54,5°C	14:00:18	38,3°C	14:06:23
PP out	44,4°C		13:33:03		63°C	14:02:23	50,2°C	14:10:33
SP in	41,5°C		13:34:48		59,5°C	14:04:23	47,2°C	14:12:33
SP out	54,7°C		13:36:48		69°C	14:06:33	59°C	14:16:03

Table 5. Duration of the transient effects in the order of parallel pipes (PP) – single pipe (SP)

Measuring point	Duration of temperature Increase	Duration of temperature drop	Total duration on the transient effect
PP in	0:29:05	0:06:05	0:35:10
PP out	0:29:20	0:08:10	0:37:30
SP in	0:29:35	0:08:10	0:37:45
SP out	0:29:45	0:09:30	0:39:15

Comparing the gradients of the temperature drops at the switching on of the fancoil we get the results of Table 6 and Table 7.

Table 6. Average speed of the temperature drop in the collectors connected in line in the order of single pipe (SP) – parallel pipes (PP)

Measuring point	Start of the inspected duration	Initial temperature [°c]	End of the inspected duration	Ending temperature [°c]	Average speed of the temperature drop [°c/s]
SP in	12:31:28	46,6	12:32:28	39,7	0,1150
SP out	12:33:58	57,1	12:35:43	52	0,0486
PP in	12:35:08	53	12:37:38	47,4	0,0373
PP out	12:38:48	60,5	12:41:08	57,1	0,0243

Table 7. Average speed of the temperature drop in the collectors connected in line in the order of parallel pipes (PP) – single pipe (SP)

Measuring point	Start of the inspected duration	Initial temperature [°c]	End of the inspected duration	Ending temperature [°c]	Average speed of the temperature drop [°c/s]
PP in	14:01:13	53,9°C	14:02:28	45,3°C	0,1147
PP out	14:04:33	60,5°C	14:06:38	54,3°C	0,0496
SP in	14:05:48	57,1°C	14:07:53	51,3°C	0,0464
SP out	14:08:38	66,5°C	14:10:53	62,3°C	0,0311

We can see the effect well on the functions of Figure 2 and Figure 3: going ahead in the serial connection the speed of the temperature drop is lower and lower and the reaction time is longer.

We can see a similar effect if the intensity of the solar irradiation is unsteady (Figure 2).

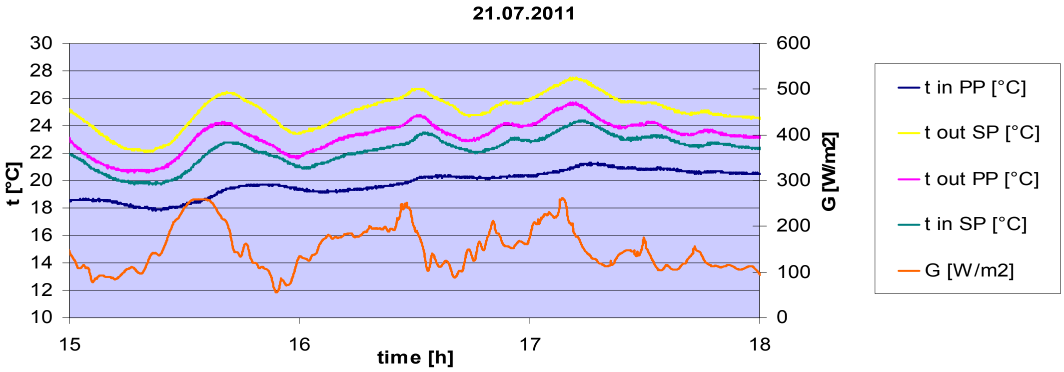

Figure 3. Transient effects caused by the unsteady intensity of the solar irradiation

During the measuring of the parallel pipes – single pipe ordered connection the changes of the temperature appears quicker at the first collector, it distinctly shows well comparing the $t_{out\ PP}$ and $t_{in\ SP}$ curves.

CONCLUSIONS / SUMMARY

At the Department of Process Engineering we have developed a device for the determination of solar collectors' efficiency in outdoor conditions. By the processing of the database made with the unit we can not only measure the efficiency but study the operation – so the transient effects – of the solar collectors.

We have established that going ahead in the serial connection of solar collectors the speed of the temperature changes is lower and lower and the reaction time is longer. The duration of the transient effects are shorter at the front end of the line and longer at the output of the last collector. The effect was detected by the simulation of water consumption – the reducing of the inlet temperature – and the deviation of the intensity of the solar irradiation.

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