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COMPARATIVE FIELD EXPERIMENTAL INVESTIGATIONS OF DIFFERENT FLAT PLATE SOLAR COLLECTORS

Full-scale traditional metal solar collectors and solar collector specimens fabricated from polymeric materials were investigated in the present study. A polymeric collector is 67.8% lighter than a traditional metal solar collector, and a metal solar collector with transparent plastic covering is 40.3% lighter than a traditional metal solar collector. Honeycomb multichannel plates made from polycarbonate were chosen to create a polymeric solar collector. A test rig for the natural circulation of the working fluid in a solar collector was built for a comparative experimental investigation of various solar collectors operating at ambient conditions. It was shown experimentally that the efficiency of a polymeric collector is 8–15% lower than the efficiency of a traditional collector.
Keywords: Solar collector, Test rig, Hot water supply system, Polymeric materials.

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СРАВНИТЕЛЬНЫЕ РЕЗУЛЬТАТЫ ЭКСПЕРИМЕНТАЛЬНЫХ ИССЛЕДОВАНИЙ РАЗЛИЧНЫХ ТИПОВ ПЛОСКИХ СОЛНЕЧНЫХ КОЛЛЕКТОРОВ

В настоящей работе выполнено сравнительное изучение характеристик традиционных типов жидкостных солнечных коллекторов металлического типа (с теплоприемником, выполненным из алюминиевых и медных трубок) и нового типа солнечного коллектора, изготовленного из полимерного материала. Полностью полимерный солнечный коллектор (включая теплоприемник и прозрачное покрытие) на 67.8% легче, чем традиционный металлический солнечный коллектор. Полимерный солнечный коллектор был выполнен из многоканальных поликарбонатных плит и представляет собой многоярусную сэндвич-структуру. Экспериментальное оборудование обеспечивало проведение параллельных сравнительных испытаний в открытой среде при полностью идентичных внешних условиях (интенсивность солнечного излучения, уровень ветронагрузки и температура окружающей среды). Испытания проведены при естественной и вынужденной циркуляции теплоносителя. Экспериментальные результаты свидетельствуют, что эффективность полимерного солнечного коллектора сравнительно с традиционным металлическим коллектором снижается в среднем на 8 -15 %.
Ключевые слова: Солнечный коллектор, Экспериментальное оборудование, Система горячего водоснабжения, Полимерные материалы

NOMENCLATURE
$C_1 – C_{24}$ measuring points of temperatures (Fig. 4)
c_p constant pressure specific heat, kJ/kgK
E exergy, W
F_{SC} solar collector absorber area, m^2
I solar irradiance, W/m^2
$\dot{m}$ mass flow rate, kg/s
Q heat, W
T temperature, °C
T_a ambient temperature, °C
T_{in} inlet temperature, °C
T_{out} outlet temperature, °C
W energy, J

Greek letters

α	absorption factor
β, φ	coefficients
η_{SC}	solar collector efficiency
τ	transmittance
ω	number of years

1. Introduction

The utilization of solar energy for hot water supply systems (HWSS) has long been of particular interest because such systems are easy to design and solar energy is available for practical application almost anywhere on earth. The most expensive part of an HWSS is the solar collector (SC)–the heart of solar thermal power technology. The remaining system components comprise 20–60% of an SC's cost, depending on the complexity of the system (tubes, tank-accumulators, pumps, stop valves, automatic control system, supporting construction, etc.).

Currently, the most widely used HWSSs are those with flat plate SCs, although recently, the application of vacuum SCs increased considerably due to their significantly decreasing cost (Chen et al., 2010; Hamed et al., 2014; Hayek et al., 2011).

Nevertheless, the construction of an HWSS is expensive and this is the main reason for restraint in the application of such systems. Thus, the direction of the development of solar systems is toward the design of more economical SCs with high efficiency.

Researchers have been working on the development of new and more efficient and effective SCs. Although a great number of studies have been devoted to this issue, almost all of them are based on the application of non-ferrous metals in the construction of SCs (Chen et al., 2010; Raman et al., 2000).

The latest trend in products selection is the application of environmentally friendly goods. Life Cycle Assessment (LCA) methodology can assess and compare similar products and recommend those with the lowest environmental impact, beginning with raw material production, right up to the product disposal.

The concept of using polymeric materials (PM) to make cheaper, lower-weight SCs is not new (Martinopoulos et al., 2010; Nielsen and Bezzel, 1997). The current PM producers manufacture modern plastics that are stable against ultraviolet radiation (UVR). This property makes them suitable for solar energy applications. Undertaken LCA studies show that PM have several environmental advantages over the metals. The PM are also less costly than non-ferrous metals and have lower-weight, which decreases the material capacity of SCs and their supporting constructions.

The main idea of the present research is the creation of a flat plate polymeric SC featuring low cost with high thermotechnical characteristics congruous to the corresponding characteristics in traditional SCs. The first aim of the present study is a comparative experimental research of different designs of SCs and the confirmation of the viability of SC made from PM (SC-P).

2. Analysis of polymeric materials used for the solar collectors

Most SCs are composed of the following elements: an absorber, a transparent cover, insulation, and a frame. The main part of the SC, which determines its efficiency, is the absorber – the heat exchange device that transfers heat from the solar insolation to the working fluid. The frame and absorber are usually made from non-ferrous metals (aluminum and copper). Glass (a heavy, fragile material) is used as a transparent cover. The analysis and selection of the PM used for the making of the SC-P for the HWSS is presented in this section.

Long-lasting operation of SCs under open environment conditions necessitates several strict requirements for construction materials. When selecting a PM for solar energy technology, it is necessary to take into consideration the following conditions: the optical transmission capacity of the material should be higher than 90%; working temperatures (thermal stability) should be in the range of −15°C to +130°C; and the material should be stable to UVR. An analysis of the PM properties (Table 1) shows that only some of these materials are suitable for such applications (Nielsen and Bezzel, 1997). Polypropylene, polysulfone, polyethylsulfone and cellulose polymers are unsuitable because of poor optical properties; polysulfone and polyethersulfone are stable against UVR, but they have undesirable yellow color and mean transparency. Amorphous polyamide can be made with high optical transparency, but it is sensitive to hydrolysis and unstable to UVR. Acryl is highly resistant to UVR, but it is fragile and can only be used at the temperature under 100°C. Polyetherimide has notch in sensitivity and is relatively expensive.

Table 1. Selected properties of some polymeric materials

Full name	Title	Max. temperature, ˚C	Optical transmission, %	UVI resistance	Hydrolysis stability
Polypropylene	PP	90-120	70-80	Poor	Excellent
Polystyrene	PS	120	90	Poor	Good
Polymethylmethacrylate (acryl)	PMMA	100	92	Excellent	Excellent
Polycarbonate	PC	135	90	Good	Poor
Polysulfone	PSU	140	77	Poor	Middle
Polyethersulfone	PES	180	77	Good	Poor
Polyetherimide	PEI	200	90	Good	Excellent
Polyamide	PA	100	90	Poor	Poor
Cellulose polymers		115	88	Good	Excellent
Polyvinylchloride	PVC	90-100	77-92	Poor	Excellent
Polymethylpentene	PMP	160	90	Poor	Excellent

Several research centers and production companies have studied the problem of using PM in the construction of SCs. In the Solar Energy Laboratory of the Danish Technological Institute, Nielsen and Bezzel (1997) studied the application of polycarbonate in the construction of SCs. The results of this study showed that the measured performance was not as high as expected and that the collector was not watertight. Martinopoulos et al. (2010) presented a honeycomb polycarbonate collector, in which the solar energy was directly absorbed by a black-colored working fluid. The experimental average efficiency of the collector was found to be similar to that of the low-cost, commercially available flat plate collectors. Cristofari et al. (2002) modeled an SC made of polycarbonate. They analyzed the influence of the insulation thickness, the flow rate, and the fluid layer thickness on the thermal performance, productivity, and efficiency of the SC. The undertaken research indicated about the possibility of polycarbonate application in the construction of SCs.

One of the recent largest international collaboration activities focusing on PM for solar thermal energy application is "Task 39" performed by the IEA Solar Heating and Cooling Program (IEA SHC Task 39). All-polymeric collectors, as well as lightweight polymeric storage tanks and innovative material combinations for framing and mounting were studied by various companies in the framework of IEA "Task 39" (Koehl et al., 2014). The products presented on "Task 39" Exhibition showed that polycarbonate and polypropylene are the most often used materials in the construction of SCs (Koehl et al., 2014).

The polycarbonate plates were chosen as a transparent cover and absorber for the application in polymeric SCs in the present study. The plate of the honeycomb PC is represented by two parallel sheets with transversal diaphragms integrated into the whole structure, as shown in Fig. 1. The geometry and specific weight of such a multichannel plate with basic thicknesses applied in the SC construction are presented in Table 2. The temperature range for the PC operation is -40˚C to +135˚C, which allows its application in "open" systems. The maximum thermal dilatation (at $\Delta T = 80$˚C) is 2.5 mm/m. The optical transparence of the PM is crucial to its selection as a material for the transparent covering. The plates of PC have an optical transmission of 70–90%, depending on the plate thickness. The 4mm-thick plate with the highest transmission was chosen as the transparent cover.
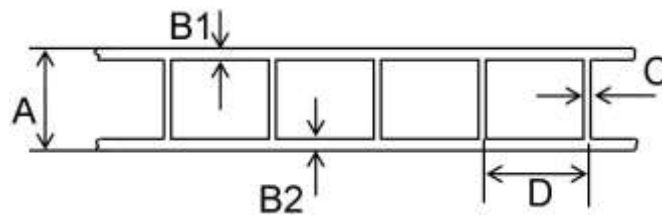

Fig. 1. Geometry of the multichannel polycarbonate plate

Table 2. Characteristics of the honeycomb polycarbonate plates (according to Fig. 1)

A, mm	Weight, kg/m^2	B1=B2, mm	C, mm	D, mm
4	0.80	0.27	0.18	5.70
6	1.30	0.38	0.29	5.70
8	1.50	0.45	0.35	11.00
10	1.70	0.46	0.39	11.00

The important property of the material used for solar application is its stability against UVR. Modern PC panels are produced with a special coating to prevent the penetration of UVR into the structure of the PC,

which causes degradation. UVR in the range lower than 390nm, which is the most destructive, barely penetrates PC panels. The transmission of the infrared part of the spectrum (more than 5000nm) is also minimal, causing the heat emitted by the SC absorber to stay inside the collector. Compared to other glassing of the same thickness, heat loss through the honeycomb PC panels is considerably lower and the heat insulation is much higher, ensuring higher SC efficiency. Solar panels made from PC feature high mechanical properties, such as hardness and resistance against impingement attack during long operation in ambient conditions.

PC is stable against a number of chemical substances, including highly concentrated mineral acids, organic acids, neutral and acidic salt solutions, oils, paraffins, saturated aliphates, and cycloaliphates, except methyl alcohol. PC is susceptible to decay caused by alcoholic solution of alkalis, by ammonia and ammoniacal solutions and amines. The degree of sensitivity to the various chemical substances depends on such factors as concentration, temperature, surface contact time, pressure, and tension in the PC honeycomb panel. This makes PC a suitable material for glassing and an absorber in the construction of an SC, where water is used as a working fluid.

3. Solar collectors designed for the experimental research

Several SCs were used for the experimental research presented in this study. The first one was a traditional SC mass-produced in Ukraine. Aluminum ribbed, solid-drawn tubes made by the extrusion method, were used as an absorber in its construction. A transparent covering was made of 4 mm-thick glass. The total area of one SC was 1.1 m^2, and the weight was 23 kg. The frame and the bottom were made from aluminum and galvanized steel respectively. This SC is identified as SC-A in the present study. The structure and the general view of SC-A are presented in Figs. 2A and 3A. The absorber tubes and the hydraulic collector were connected by argon-arc welding. The absorber manufactured by the extrusion method (uniform item "tube/rib") results in minimal thermal resistance. Glass wool with thickness of 40mm was used as insulation in this SC. Since 1997, several solar HWSSs using SC-A have been installed in the southern part of Ukraine (Doroshenko and Glauberman, 2012). These systems show satisfactory efficiency during the period from spring to autumn.

The second SC examined was specifically designed for the present study. Flattened-out copper tubes tightly adpressed to a metal sheet were used as an absorber. It would be optimal to use a heat-conducting glue or solder to connect the tubes with the metal sheet. Special flattened-out copper tubes were manufactured to decrease the thermal resistance at the point of contact (tube/metal sheet) by increasing the tangency area. The SC with copper tubes used in its construction is specified as SC-C. A honeycomb PC plate of 4mm thick was used in this SC as a transparent cover. An aluminum profile also was used in this SC as a frame. The structure and general view of the SC-C are presented in Figs. 2B and 3B. The specific weight of SC-C was 14.4 kg/m^2. The use of a honeycomb PC plate simplified the mounting of the transparent covering. It also reduces weight and price of the SC. The resulted thickness of SC-C was 60 mm compared to 108 mm for SC-A. Polyfoam with thickness of 20mm was used in the SC-C construction as insulation.

The application of nonferrous metals, component manufacturing from those materials and their connection are the main reasons for the high cost of the construction of the traditional SCs. The creation of a polymeric SC was the second step in the application of the PM in the construction of the SCs for the present research. Honeycomb PC plates with thicknesses of 4 mm and 8 mm, respectively, were used as a transparent cover and an absorber. Aluminum was used only as a rigid frame. In the present study, this collector is specified as SC-P due to extensive application of the PM in its construction. The specific weight of the SC-P was 8.0 kg/m^2. The same insulation was used in the SC-P as in the previous collector. The structure and general view of the SC-P are presented in Figs. 2C and 3C. The honeycomb PC plate was also used as insulation in the several constructions of the SC-P as suggested by (Doroshenko and Glauberman, 2012; Nielsen and Bezzel, 1997). The technical characteristics of all SCs studied in this research are presented in Table 3.

Use of a honeycomb PC plate as an absorber leads to a problem of its connecting to the hydraulic collector, because it is necessary to take into account the thermal expansion factors for the different materials.

Two types of the SC-Ps with similar geometries were manufactured with different placement of the blackened absorber coating: in SC-P1.25 ↑ (Table 3), the coating was placed on the upper surface of the absorber; in SC-P1.25 ↓ - it was placed on the inferior surface. This is not an issue for the traditional SCs with metal absorbers. However, for the SC-Ps, this problem is caused by the transparency of the absorber material. In the first case, the solar energy passing through the transparent cover was absorbed by the upper surface of the absorber and was transferred to the working fluid mainly by thermal conductivity and convection. In the second case, after passing through the transparent cover, the solar energy penetrates the upper side of the absorber (partially being absorbed), then passes through the transparent working fluid, and finally is absorbed by the lower side of the absorber. Nielsen and Bezzel (1997) and Martinopoulos et al. (2010) used black-colored working fluid to prevent this problem. (Such fluid was used almost for experimental purposes, it is rarely done in actual systems.) Comparative experimental tests on SC-P1.25 ↑ and SC-P1.25 ↓ showed that the placement of the covering of the transparent absorber (upper or lower) does not affect the cumulative daily thermal per-

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formance (the difference was negligible). The presented results for the SC-P in this study are related to the SC-P with the coating placed on the upper side of the absorber.
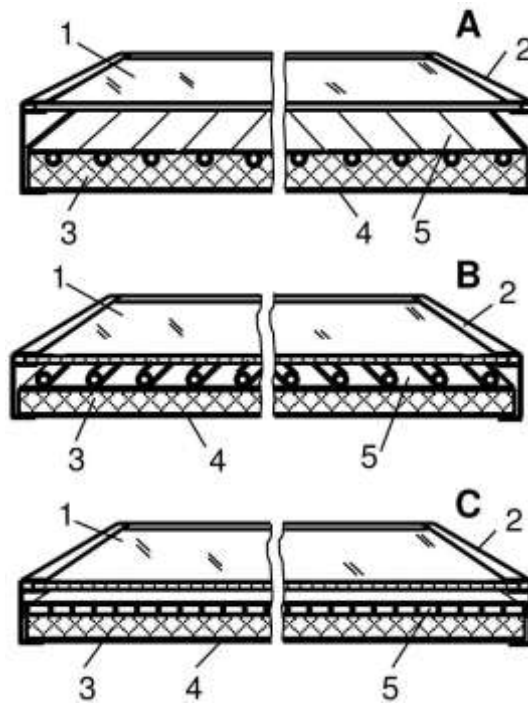

Fig. 2. Schematic diagrams of the studied solar collectors structure:
A – SC with aluminum absorber (SC-A), B – SC with copper tubes (SC-C),
C – polymeric SC (SC-P).
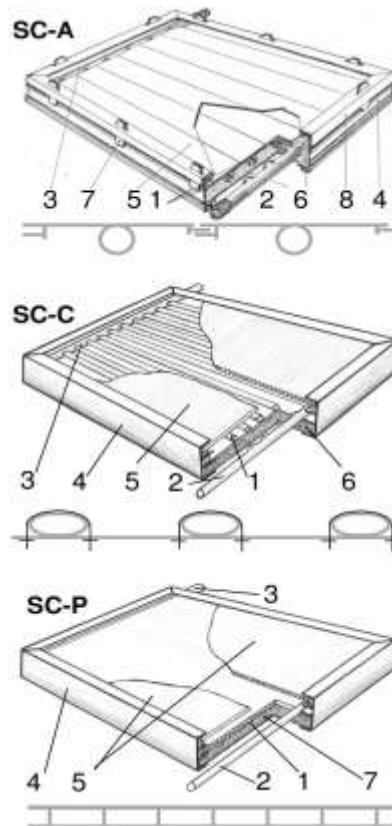1 – transparent cover, 2 – frame, 3 – thermal insulation; 4 – bottom; 5 – absorber

Fig. 3. General views of the studied solar collectors:
1 – absorber; 2,3 – hydraulic collectors; 4 – frame, 5 – transparent cover;

6 – thermal insulation; 7 – bottom; 8 – fastening element

Table 3. Technical characteristics of the studied solar collectors.

Characteristic	Solar collector type			
	SC-A 1.1	SC-C 1.25	SC-P1.25 ↑	SC-P1.25 ↓
Overall dimensions, mm	1200x900	1250x996	1250x996	1250x996
Thickness, mm	108	58	58	58
Weight, kg	23	18	10	10
Transparent cover material	glass	PC	PC	PC
Placement of the absorber coating	upper	upper	upper	bottom
Absorber area, m^2	1.04	1.16	1.16	1.16
Insulation material	glass wool	polyfoam	polyfoam	polyfoam
Insulation thickness, mm	40	20	20	20
Air gap, mm	30	22/32[*]	16	16
Transparent cover thickness, mm	4	4	4	4
Number of channels in absorber	10	10	86	86
Shape of the channels in absorber	⭘	⬭	▭▭▭	▭▭▭
Inner diameter of absorber channel, mm	14	9	7/11[**]	7/11[**]
Absorber thickness, mm	-	-	8	8

Remarks:
[*] The first value is the distance from the transparent cover to the tube; the second value is the distance from the transparent cover to the absorber metal sheet.
[**] The first value is the vertical size of the channel; the second value is the horizontal size of the channel.

4. Description of experimental setup: Testing technique

Rojas et al, 2008 described different testing standards used worldwide for SC performance determination including ASHRAE-93 Standard and EN-12975 for USA and European Union, respectively. The main challenges in the present study, based on international standards for SC tests, included:
1.   Comparative testing of the different SC modifications when the SCs operated in similar systems under the same conditions.
2.   The resolution of the technological and the constructive problems connected with the development of SC-P.
3.   Comparison of the experimental results with results of the previous similar studies.

Comparative testing of the various SCs was carried out in 2011 and 2012 for the ambient conditions experienced in Ukraine (Odessa, coordinates: 46°28′N, 30°44′E) in the period from the early spring until the late autumn. The test rig was constructed for the full-scale experimental study of the efficiency and the other characteristics of the various SCs. The schematic diagram and a photograph of the experimental setup are shown in Figs. 4 and 5, respectively. The test bench is symmetric and it includes two similar systems for acquisition of the comparative working characteristics of the SCs. Each circuit was equipped with a water supply tube (2), a valve (1) connected to a tank-accumulator (3) with a volume of 85 liters, and two isolated pipelines (down- (6) and up-flow (9) tubes) for connecting the SC to the tank-accumulator. Each down-flow pipe has a stop valve (4), and the up-flow pipe was equipped with a flow-metering device (a scaled glass tube (10) and a dosing unit (11) filled with a paint).

Several K-type thermocouples were installed at appropriate locations (C_1–C_{24}) for the temperature measurement. The temperatures were measured at the following points on the test rig: at the entrance and the exit of the SC, at different heights in the tank-accumulator, and in the insulation of the tank-accumulator. The ambient temperature was also recorded.

A control panel (13) was equipped with different instrumentations and various standard components, such as a pyrometer (14) for the measurement of solar radiation intensity and an anemometer (15) for the air

velocity estimation. A computer-based monitoring and control system was developed, as well, for the test rig in the present study. The measurements were recorded every 15 seconds by a data acquisition system. Temperatures and solar radiation intensity were also recorded, and the results were calculated. The test rig allowed the comparison of the heat efficiency of two different SCs in natural conditions (solar irradiation and ambient conditions) as they would operate in the actual solar HWSS.
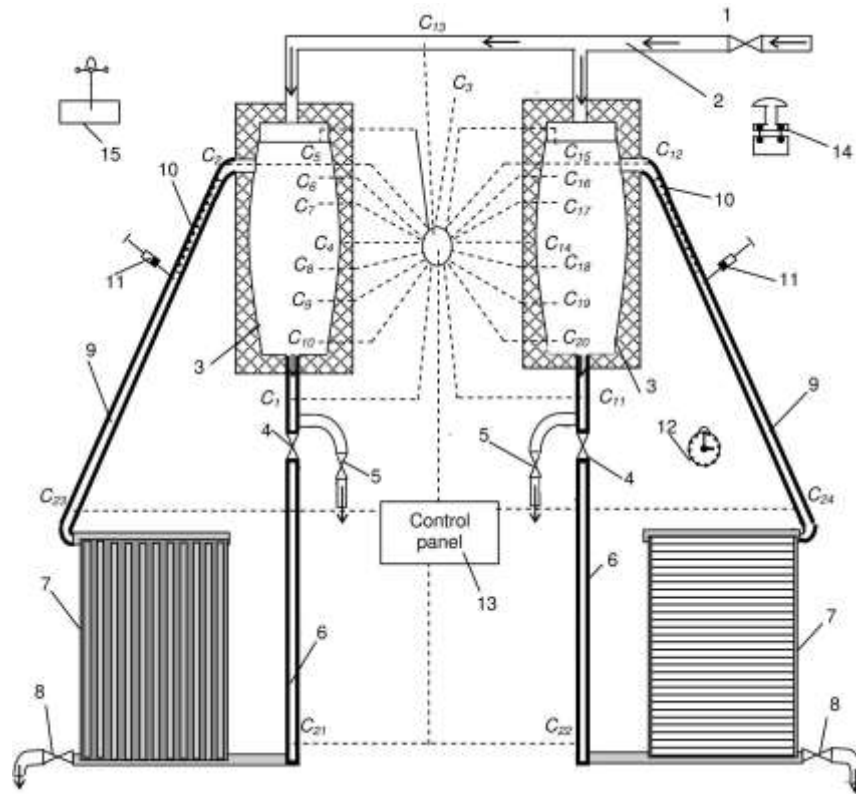

Fig. 4. Schematic diagram of the test rig.
1 – valve; 2 – water supply tube; 3 – tank-accumulator; 4 – stop valve; 5, 8 – drain valves;
6 – down-flow tube; 7 – solar collector; 9 – up-flow pipe; 10 – scaled glass tube; 11 – dosing unit; 12 – stopwatch; 13 – control panel; 14 – pyrometer; 15 – anemometer;
$C_1 - C_{24}$ – temperature measurement points.

Fig. 5. Photograph of the test rig.

The tests were carried out under natural convection conditions (without a pump) when the motion of the working fluid was a result of the density difference due to a temperature increase caused by the solar energy.

The maximum flow rate (at midday in summer) was about 50 l/h (per 1 m^2 of the SC). Landener and Späte (2008) differentiated solar heating systems according to the flow rate values of the circulated working fluid. Three different types of the working fluid motion through the SC exist, the according classifications are: a) «Low Flow» – the systems with a small flow rate: 10-20 l/(h m^2) – the temperature difference at the exit and at the entrance of the SC can reach 50ºC; b) «Match Flow» – the systems with an average flow rate: 20-40 l/(h m^2) – the temperature difference is about 20ºC; c) «High Flow» – the systems with a large flow rate: 40-70 l/(h m^2) – the temperature difference is up to 15ºC. The present study corresponds to the type (c) – the high working fluid rate and relatively small temperature drop.

5. Experimental results and analysis

A special series of tests were carried out in the late autumn to analyze efficiency, peculiarities, and the mode of the operation. These tests showed that the system becomes more sensitive to meteorological conditions when irradiance is low.

The typical behavior of the average temperature in the tank-accumulator and the SC output temperature is shown in Fig. 6 for the all tested SCs. The results for the autumn period were chosen to indicate the temperature levels reached. The SC-A and SC-C tested during the same conditions and the SC-P was tested a few days later, but the weather conditions were nearly identical.
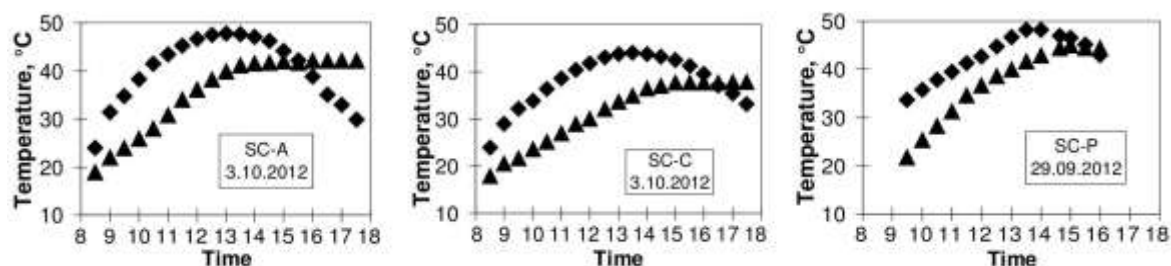

Fig. 6. Water temperature at the exit of SC (♦) and the average temperature in the tank-accumulator (▲) for SC-A, SC-C, and SC-P.

It can be seen from Fig. 6 that the average temperature in the tank-accumulator reached 42ºC, 37ºC and 40ºC for the SC-A, SC-C and SC-P, respectively, in the late September and the beginning of October. This temperature level was high enough to supply hot water systems not using additional heating within this period.

The comparative behavior of the average temperature in the tank-accumulators versus time is presented in Figs. 7A and 7B for the SC-A and SC-P and for the SC-P and SC-C, respectively. Fig. 8 shows the comparative temperature distribution of water at the different heights in the tank-accumulator for the SC-A and SC-P (Fig. 8A), and for the SC-C and SC-P (Fig. 8B). One can see from Figs. 7 and 8 that the efficiency of the SC-A is higher than for the SC-P, although the performances of the SC-P and SC-C are similar.
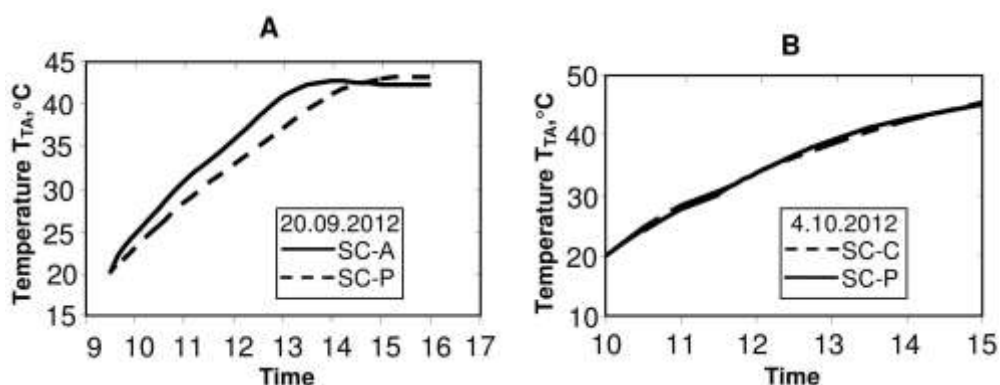

Fig. 7. Comparative data for the average water temperature in the tank-accumulator for the SC-A and SC-P (A), and for the SC-C and SC-P (B).
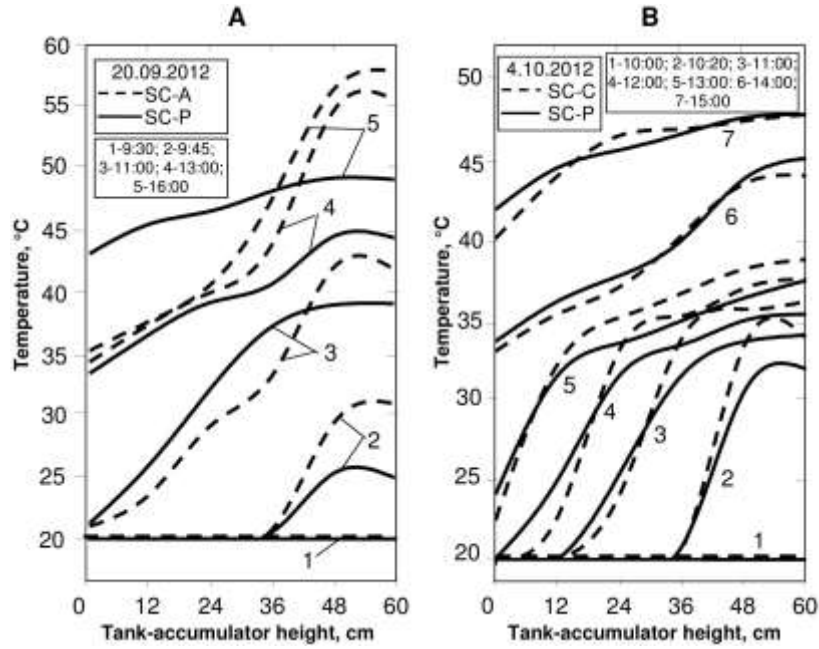
Fig. 8. Comparative data for the water temperature distribution in the tank-accumulator for the SC-A and SC-P (A), and for the SC-C and SC-P (B).

The average water temperature in the tank-accumulator reflects the amount of energy collected by the SCs. Integral data regarding the efficiency of the SC show that the thermal efficiency of the traditional SC-A is 8 – 15% higher compared to the SC-C and SC-P, according to the difference in average water temperature in the tank-accumulator at the end of the day.

The experimental results (Fig. 8) show that the dynamic behavior of the water temperatures at the exit and at the entrance has several zones, which are similar for the all tested SCs. The first zone characterizes the time when the water temperature increases in the tank-accumulator (the first circulation). The second zone characterizes the gradual increase of the water temperatures proportional to solar irradiation. The third zone appears when the temperature of the water coming from the SC drops slowly due to the decrease of solar irradiation after midday. The fourth zone corresponds to the tranquility of the system during the night. The duration of each zone is a function of the solar irradiation intensity. The duration of the first and second zones was longer in the spring and autumn due to lower solar irradiation.

A reverse circulation, featured in thermosiphon HWSS, mentioned by García-Valladares et al. (2008) and Tang et al. (2010), never occurred in the present study, mainly because the bottom of the tank-accumulator was placed 40 cm above from the top of the SC.

The traditional method for presenting the SC thermal performance relies on calculated efficiency of the collector η_{SC} as a function of the value $(T_{in} - T_a)/I$. The SC efficiency was calculated on basis of the Eq. (1) according to Martinopoulos et al. (2010):

$$\eta_{SC} = \frac{Q}{F_{SC}\, I} = \frac{\dot{m}\, c_p \left(T_{out} - T_{in}\right)}{F_{SC}\, I} \tag{1}$$

where Q - is the absorbed heat by the SC (W); F_{SC} - is the useful (absorber) area of the SC (m^2); I - is solar irradiation (W/m^2); $\dot{m}$ - is the mass of the flow rate of the working fluid (kg/s); T_{in} and T_{out} - are the temperatures of the working fluid entering and exiting the SC (ºC).

The comparative thermal efficiencies for the tested SCs is presented in Fig. 9. It can be seen that the characteristics of the SC-P (line 4) are similar to those of the SC-C (as it was shown previously). The higher efficiency of the traditional SC-A can be explained by the superior transparency of the glass compared to the honeycomb PC panel and by worse thermal conductivity of the PC panel compared to aluminum.
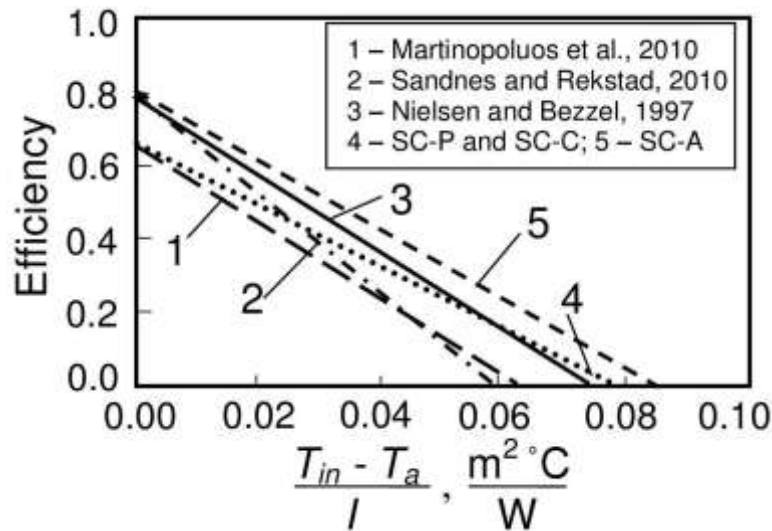
Fig. 9. Thermal efficiency of the different SCs.

The obtained results were compared with the results of the experiments conducted in other studies on PM solar collectors. Nielsen and Bezzel (1997) discovered an SC in which a transparent cover, absorber, thermal insulation, and frame were integrated into the whole structure, composed of a fully transparent four-walled plate with channels. The side channels served as a frame, the upper channels served as a transparent cover, and the bottom channels served as a thermal insulation. The channels in the middle were connected with a hydraulic collector served as absorbers. The material used for this SC was polycarbonate. The experiments took place in the laboratory at I = 800 W/m^2, ambient temperature - 25°C, and air velocity - 5 m/s. The efficiency of this SC is illustrated in Fig. 9 (line 3).

Martimopoulos et al. (2010) studied a fully polymeric SC (Fig. 9, line 1). The hydraulic channels for this SC were made from a single sheet of a transparent, UVR stabilized, honeycombed, 10 mm-thick LEXAN plate. The upper and lower collector channels were made from a semi-transparent acryl. The SC top cover consisted of a 3 mm-thick solid, transparent, UVR stabilized LEXAN sheet, while the back insulation consisted of nanogel filled honeycomb LEXAN sheet 10 mm thick. The sides of the collector were insulated using 30 mm-thick extruded polyurethane. All of it was packed in an aluminum casing.

Sandnes and Rekstad (2002) studied an SC with a polymeric absorber, developed by SolarNor AS, a joint venture of the University of Oslo and General Electric Plastics. The absorber plate is modified polyphenylene oxide (PPO) plastics containing internal wall-to-wall channels filled with ceramic granulates. The heat carrier fluid (water) was pumped up to the internal distribution channel at the top of the collector, and flowed down through the parallel absorber channels by the force of gravity. Water filled vacant spaces between ceramic particles and was brought into contact with the top absorber sheet, enabling good heat transport from the absorbing surface to the heat carrier fluid. The fluid flows within the square wall-to-wall channels covered the entire back of the absorber surface. This made the temperature distribution a uniform across the width of the absorber. The absorber plate of the collector was 0.59 m wide and 0.82 m long. The radiation absorptance for the PPO material was - α = 0.94 at the incidence angle normal to the surface. A glass cover was used instead of the polycarbonate cover sheet normally installed with this type of the collector due to the superior optical properties of glass. The thickness of the glass plate was 4 mm, and the transmittance at the incidence angle normal to the surface was - τ = 0.9. The distance between the absorber and the glass plate was 1.2 cm. The efficiency of this SC is illustrated in Fig. 9 (line 2).

When the efficiencies of the SCs (Fig. 9) cross the horizontal axis they match the coefficient of performance (COP) for the correspondent SC. The SCs, studied by Sundles and Rekstad (2002) and by Nielsen and Bezzel, had the highest efficiency among polymeric collectors, as working fluid: a) circulated through ceramic granules for intensification of the heat transfer process (line 2) and b) working fluid colored with Xerox paint (NORYL ® PX507) with an absorbance of 0.99 (line 3). Martimopoulos et al. (2010) used a 1/1000 solution of a black India ink in water as the heat transfer fluid (line 1). A black flat (dull) paint as an absorber coating for the SC-P was used for the present study (line 4).

Fig. 9 shows that efficiency of all types of the polymeric SCs under consideration in this study has a dispersion up to 20 % and even higher. This fact can be explained by the variation of the construction of the tested SCs (thickness of the thermal insulation, absorber plate, air gap between transparent cover and absorber, etc.); flow rate of the working fluid and general peculiarities of the experiments, all conditions of which are not fully available.

6. Conclusions

This experimental investigation showed that the efficiency of the polymeric solar collector considered in the present study was decreased by 8-15% compared to the traditional SCs. The placement of the absorber coating did not play an important role in the efficiency of the transparent polymeric absorber. The efficiency of the tested collector with the polymeric transparent cover and the metal absorber (copper tubes appressed to a metal sheet) was similar to the efficiency of the polymeric collector; however, its weight was 35% higher and it was more expensive to be built compared to the polymeric collector.

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ПОРІВНЯЛЬНІ РЕЗУЛЬТАТИ ЕКСПЕРИМЕНТАЛЬНИХ ДОСЛІДЖЕНЬ РІЗНИХ ТИПІВ ПЛОСКИХ СОНЯЧНИХ КОЛЕКТОРІВ

У роботі виконано порівняльне вивчення характеристик традиційних типів рідинних сонячних колекторів металевого типу (з теплоприйомником, виконаним з алюмінієвих і мідних трубок) і нового типу сонячного колектора, виготовленого з полімерного матеріалу. Повністю полімерний сонячний колектор (включаючи теплоприйомник і прозоре покриття) на 67.8% легше, ніж традиційний металевий сонячний колектор. Полімерний сонячний коллектор був виконаний з багатоканальних полікарбонатних плит і являє собою багатоярусну сендвіч-структуру. Експериментальне обладнання забезпечувало проведення паралельних порівняльних випробувань у відкритому середовищі при повністю ідентичних зовнішніх умовах (інтенсивність сонячного випромінювання, рівень вітронавантаження і температура навколишнього середовища). Випробування проведені при природній і вимушеної циркуляції теплоносія. Експериментальні результати свідчать, що ефективність полімерного сонячного колектора порівняно з традици-онним металевим колектором знижується в середньому на 8 -15%.

Ключові слова: *Сонячний колектор, Експериментальне обладнання, Система гарячого водопостачання, Полімерні матеріали*