

The Performance of Plastic Solar Collector as Part of Two Contours Solar Unit

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The use of solar collectors made of polymeric materials allows absorbing solar radiation most fully and reduce the material consumption of the solar installations. The results of experiments with flat plate solar collector with absorber made of special grade polyethylene are presented. The obtained correlations for dependences of the coefficient of efficiency and the specific heat flux from the flow rate of the heat carrier, the heat carrier temperature at the exit from the solar collector, the operating time of the solar installation during the daylight at different coolant flow rates can be used for reliable design of solar heating systems and for integration of plastic solar panels into heating systems in industry and communal sector.

1. Introduction

The experience of using natural alternative renewable energy sources, primarily the sun, demonstrates the high possibilities of simple conversion of this type of energy into thermal energy, which can be successfully used to provide a variety of technological and domestic needs in heat (Klemesš et al., 2015). The use of solar energy for heating in different industrial processes (Mekhilef et al., 2011) and in communal sector (Buker and Riffat, 2015) improves the ecological situation in the field of heat energy generation by reducing the emissions of pollutants, produced in the combustion of traditional types of fossil fuels used for the production of thermal energy at boiler plants. It stipulated the use of solar collectors in different applications requiring thermal energy and development of their different types like Flat plate collectors (FPC), Hybrid photovoltaic/ thermal (PV/T) collectors, Evacuated tube collectors, Compound parabolic collectors etc. (Suman et al., 2015). All these types of collectors can be used in integrating with traditional energy sources (Sathyamurthy et al., 2017), especially with thermal energy storage (Tian and Zhao, 2013). The simplest by construction and affordable from initial cost viewpoint are FPC solar collectors. The comprehensive review of different FPC types and their design is presented by Pandey and Chaurasiya (2017). Recent advances in FPC design are analysed by Colangelo et al. (2016). For applications in areas reached by the sun but limited in financial resources among most important questions on deciding solar collectors installation is investment cost, as is discussed by Carvajal et al. (2012). In such places, polymer solar collectors have a considerable advantage, as is discussed by de la Peña and Aguilar (2014).

The advantages of polymeric solar collectors on their cost and environmental performance are discussed by Carlsson et al. (2014). The climatic conditions in specific regions can make a significant impact on economic characteristics of FPC applications and influence the decision of their usage (Piekarczyk et al., 2016). It requires to pay attention to FPC performance in different conditions and develop optimal solutions in their design, as is discussed by Do Ango et al. (2013). The correct choice of polymer materials is one of the prerequisites for successful and economically viable application of FPC (Ramschak et al., 2016). The necessity to develop efficient FPC collectors from polymers for specific conditions and accurately predict their performance stipulated the experiments with polymer FPCs of different design (Ariyawiriyanan et al., 2013). Special attention is paid to the influence of different parameters on the performance of some FPC design, such as flow rate of the fluid studied by Chen et al. (2012).

The average yearly flow of solar energy into the territory of Ukraine for different regions (Kapustenko et al., 2004) is approximately from 1,070 at the North of the country up to 1,400 kW·h/m² at the area of Black and Azov

seas. The maximum solar radiation is observed in the Southern region of Ukraine, where according to meteorological observations the average annual number of sunny days is 250. For this reason, the development and improvement of non-traditional methods of obtaining thermal energy, the introduction of solar installations for obtaining low-potential thermal energy, which is used for hot water supply of various objects in the industry and communal sector, are the tasks of primary importance. However, in many practical applications, the capital cost of solar panels is limiting economic benefits and lengthening the payback of the investments. Solar collectors are made of various materials: ordinary black metal, stainless steel, aluminum, copper and polymeric materials. The construction and materials are usually designed for specific solar engineering installations and differ in technological, operational, technical and economic parameters.

In this article are presented experimental results on the performance of plastic solar collector that is designed, mounted and operate on the roof of one of the boarding houses of the southern region of Ukraine.

2. The construction of solar installation

The schematic drawing of studied solar installation is presented in Figure 1. The solar collector 1 of total area 210 m² consists of 21 sections with area 10 m² per section. The heat absorbing element of solar collector (Selikhov, 2006) is made from high-grade black polyethelene film (Selikhov and Bukhkalov, 2005) forming the inside channel for water flow. At upper and lower ends of the channel are situated manifolds for water distribution at the channel top and discharge from the bottom. The polymer heat absorbing element is situated at the bottom of a metal box 7 m x 1.5 m x 0.16 m. The top of the box is covered with window glass 4 mm thick, which is fixed and sealed. The bottom and sides of the box are heat insulated with foamed polystyrol of 30 mm thickness.

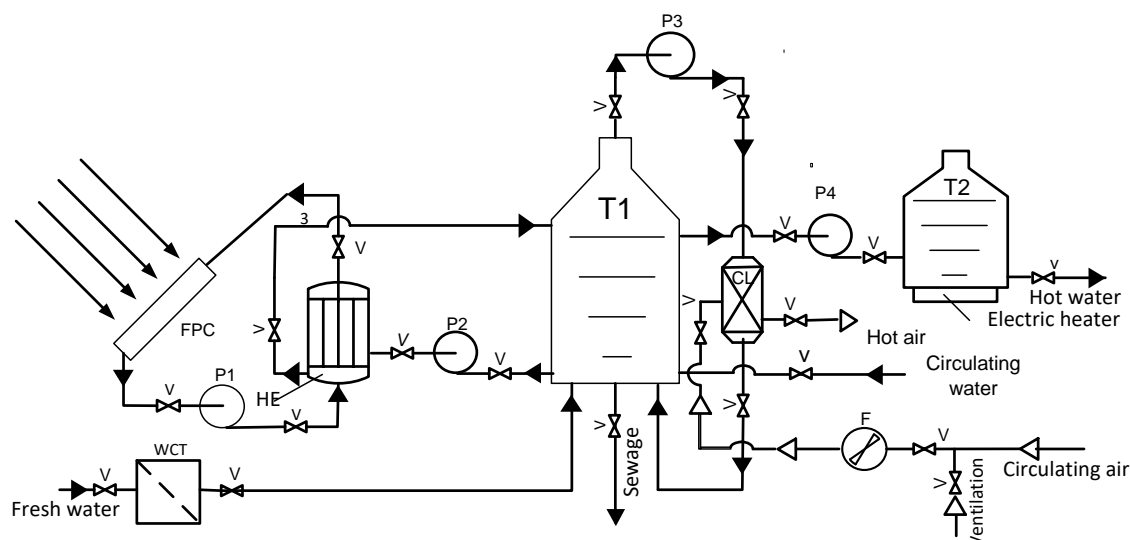


Figure 1: The schematic view of tested solar installation: CL – calorifer; P–circulating pump; T- accumulating water tank; HE-heat exchanger; V – valve; FPC flat plate collector; F – fan; WCT – water chemical treatment

The experiments were performed with the solar hot water supply system and results were obtained in different modes during the spring-summer seasons from May to November. A special design of the solar collector is developed and the formulation is made of the polymer material, which was used to produce a polymer coating that withstands high temperatures, solar radiation, air oxygen, moisture, industrial gases and other harmful impacts of surroundings for a long time without significant change in appearance, properties (physical-mechanical, physical-chemical, etc.). The purpose of this work was to obtain generalized correlations for the coefficient of efficiency (η) and the specific heat flux (q) depending of such factors as the heat carrier flow (V , m³/h), the heat carrier temperature (T , °C) in the solar collector, and the operating time (τ , h) of the solar installation during daylight hours.

3. Results and discussion

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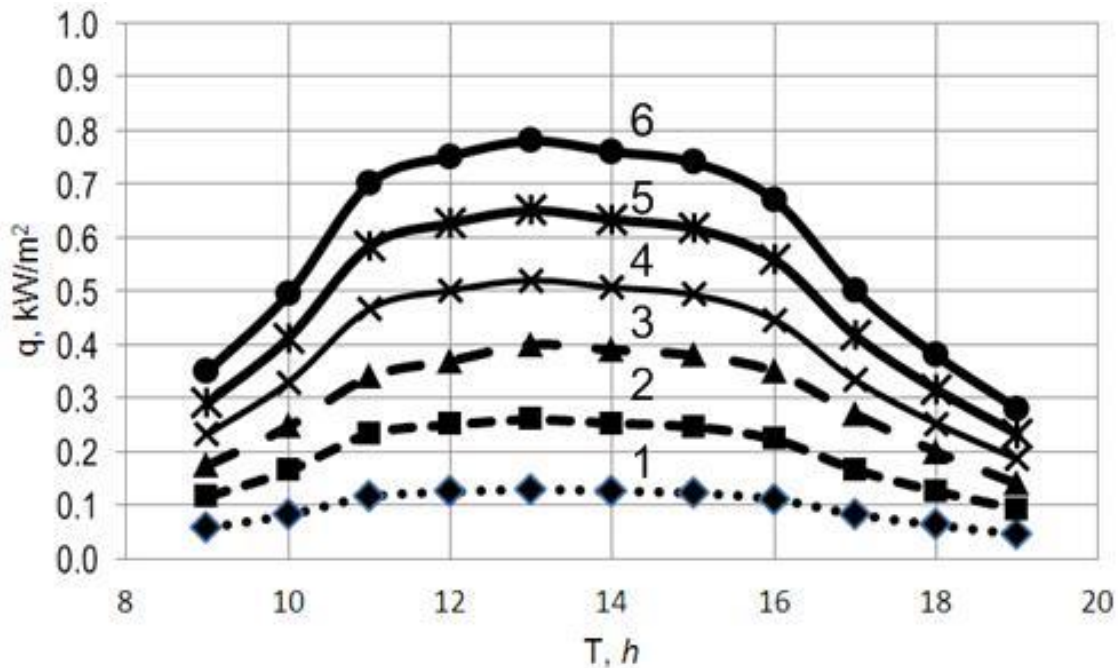


Figure 2: The density of heat flux at different flow rates: 1 – $V = 0.5 m^3/h$; 2 – $1.0 m^3/h$; 2 – $1.5 m^3/h$; 2 – $2.0 m^3/h$; 2 – $2.5 m^3/h$; 2 – $3.0 m^3/h$

One of the main characteristics the solar collector performance is the change in the density of the heat flux (q) with variable flow rate (V) of the working fluid. The experimental data are obtained with a change in the flow rate V in the range from 0.5 to $3.5 m^3/h$. The influence of flow rate on the density of heat flux (Figure 2) is much influenced by the temperature of working fluid T and the time of the day τ with maximum close to the middle of the day. But in all cases, the increase of flow rate is leading to higher heat flux. The correlating data Equations of the form $q = f(T, \tau)$ at $V = \text{const}$ are obtained. When analyzing experimental data in order to represent the functional dependencies in an analytical form, the selection of formulas describing the results of the experiment, the Excel add-in environment regression analysis package is used. The obtained correlations are as follows, with the numbers corresponding to flow rates as designated in Figure 2.

$$q = 0.010339 \cdot 1.027805^T \cdot 1.01145^\tau \quad (1)$$

$$q = 0.02069 \cdot 1.021806^T \cdot 1.011405^\tau \quad (2)$$

$$q = 0.026081 \cdot 1.02701^T \cdot 1.032366^\tau \quad (3)$$

$$q = 0.041415 \cdot 1.021796^T \cdot 1.011428^\tau \quad (4)$$

$$q = 0.051707 \cdot 1.027809^T \cdot 1.011443^\tau \quad (5)$$

$$q = 0.06211 \cdot 1.0278^t \cdot 1.011416^{\tau} \quad (6)$$

The important characteristic of solar collector performance is its efficiency η . It is considerably changing with a variation of heat flux density and working fluid flow rate, as presented in Figure 3. The regression analysis of the data obtained for different constant flow rates is performed and obtained correlations are as follows (the numbers in brackets are corresponding to designations in Figure 3).

$$\eta = 0.68 - 1022q^3 + 264.99q^2 - 21.4q \quad (7)$$

$$\eta = 1.3 - 255.04q^3 + 132.45q^2 - 21.39q \quad (8)$$

$$\eta = 2.04 - 113.45q^3 + 88.28q^2 - 21.4q \quad (9)$$

$$\eta = 2.72 - 63.83q^3 + 66.22q^2 - 21.4q \quad (10)$$

$$\eta = 3.4 - 40.8q^3 + 52.92q^2 - 21.38q \quad (11)$$

$$\eta = 2.95 - 19.72q^3 + 30.94q^2 - 14.34q \quad (12)$$

Analyzing the accuracy of correlating experimental data revealed that the error of Eqs (7) – (12) is not more than $\pm 5\%$.

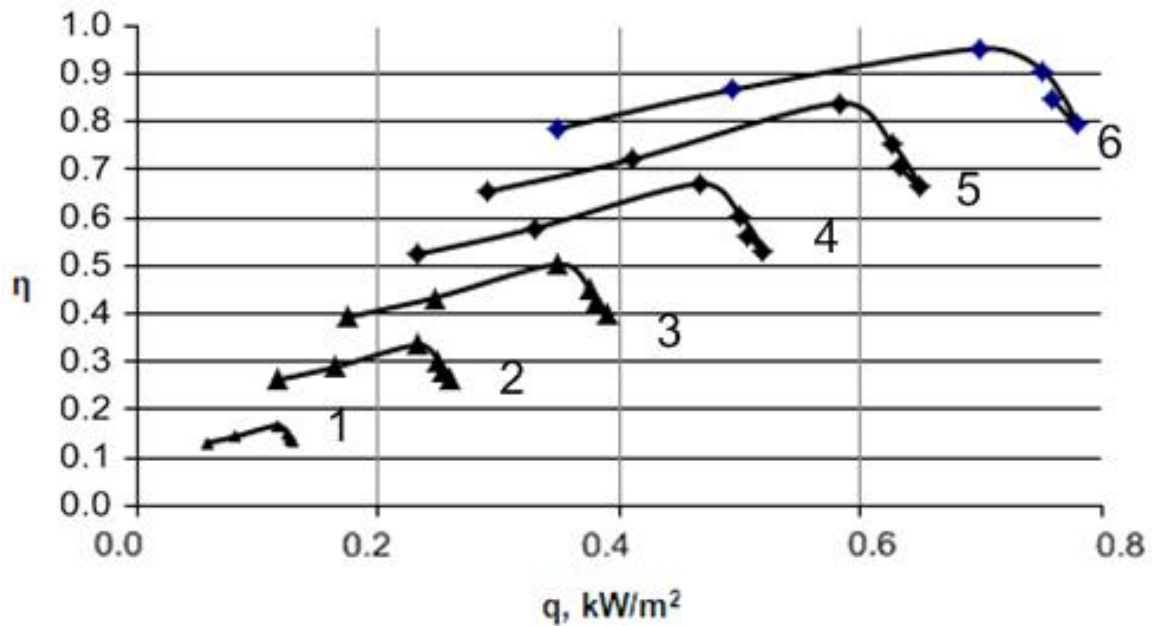


Figure 3: The influence of heat flux density and flow rate on polymer FPC efficiency: 1 – $V = 0.5 \text{ m}^3/\text{h}$; 2 – $1.0 \text{ m}^3/\text{h}$; 2 – $1.5 \text{ m}^3/\text{h}$; 2 – $2.0 \text{ m}^3/\text{h}$; 2 – $2.5 \text{ m}^3/\text{h}$; 2 – $3.0 \text{ m}^3/\text{h}$

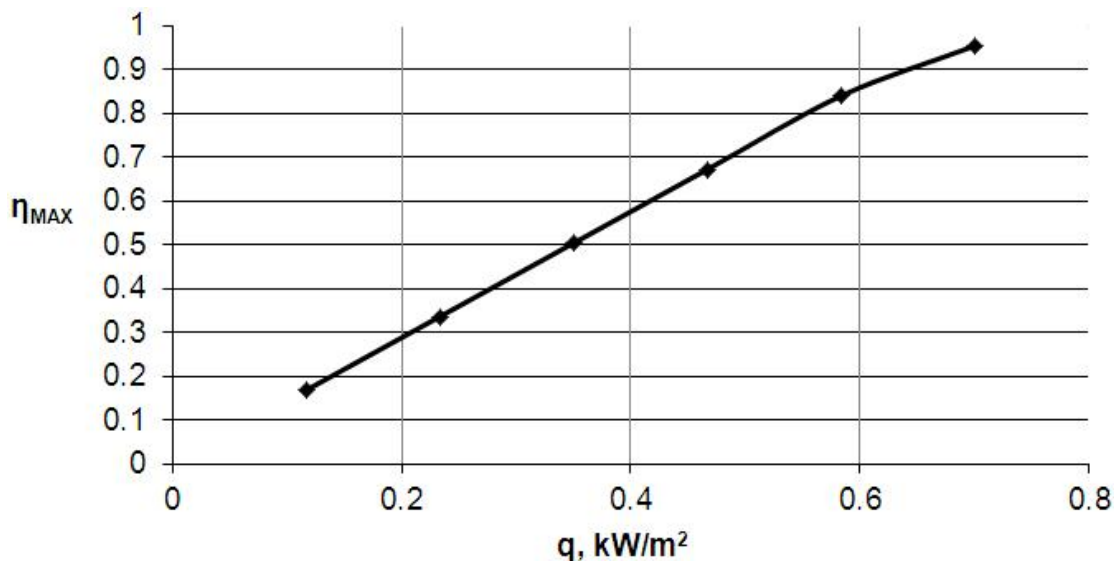


Figure 4: The maximal efficiency at different flow rates

Analyzing the curves in Figure 3 it is concluded that the dependence of efficiency from heat flux density at any constant flow rate has a maximum. The dependence of maximal efficiency η_{\max} from heat flux density at different flowrates the is presented in Figure 4. This dependence is linear and can be correlated by Equation $\eta_{\max} = 1.37 q + 0.018$ with Pearson correlation coefficient $R^2 = 0.99$ and error not above $\pm 3\%$. The obtained correlations are used in designing polymer FPCs for installations in Ukraine.

The comparison with the results of experiments of Chen et al. (2012) for FPC with heat absorbers made with copper and aluminium shows that maximal values of efficiency about 0.84, that is substantially lower than 0.95 reported here for polymer FPC of investigated design. Lee and Baek (2014) in experiments with two evacuated solar collectors have obtained the maximal value of averaged efficiency about 0.6. The conclusion can be made that investigated polymer FPC has efficiency at least not lower. It allows concluding about the higher efficiency of investigated polymer FPC, which is at least not lower than of traditional FPCs with the sufficiently smaller cost of production.

4. Conclusions

The Flat Plate Solar collectors with heat absorber from polymer materials are efficient equipment for generating thermal energy in climatic conditions of Ukraine. The performance of plastic solar collector of specific design is investigated experimentally and correlations for calculation of collector efficiency and heat flux density are obtained with accounting the effect of working fluid flow rate, temperature and operating time. These correlations are used for the design of polymer FPCs in real conditions of application. The comparison with data available in literature reveals that the efficiency of investigated polymer FPC is not lower and in some conditions even higher than for FPC from a metallic material. It has lower cost that gives the advantage for application of polymer FPCs in regions reach with solar energy but low in investment funding.

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