Solar Collectors of Buildings Facade Based on Aluminum Heat Pipes with Colored Coating

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Abstract: A variety of liquid thermal solar collectors designs used for water heating have been developed by the previous researchers. But the majority of them do not meet the requirements on small weight, easy assembling and installing, versatility, scalability and adaptability of the design, which are particularly important when they are facade integrated. In order to avoid the above mentioned drawbacks of the liquid thermal collectors, the authors propose to apply to them extruded aluminum alloy made heat pipes of originally designed cross-sectional profile with wide fins and longitudinal grooves. Such solar collectors could be a good solution for building facade and roof integration, because they are assembled of several standard and independent, hermetically sealed and light-weight modules, easy mounted and "dry" connected to the main pipeline. At that, their thermal performances are not worse than of the other known ones made of heavier and more expensive copper with higher thermal conductance, or having entire rigid designs. Some variants of the developed solar collectors shaping of the assembled modules for building facade or roof integration are proposed. Various colored coatings to the absorbers are developed and made of carbon-siliceous nano-composites by means of sol-gel method. Their optical performances were compared with "anodized black". It is stated that colored coatings have a good prospect in thermal SCs (solar collectors) adaptation to building facades decoration, but the works on study and upgrade of their performances should be continued.

Key words: Solar collector, heat pipes, selective coating, buildings facade.

1. Introduction

Solar thermal collectors are more and more used as sustainable energy devices, but their design constructions are far from being perfect. Therefore, a lot of attention is dedicated to developments of SCs (solar collectors) with HPs (heat pipes) as their main parts. HPs application to SCs' designs as highly efficient heat absorbing and transferring components makes possible to avoid several disadvantages of conventionally used ones. Thus, SCs with HPs as a core [1, 2] ensure very low hydraulic resistance, constant liquid flow, isothermal heat absorbing surface. Nevertheless, ensuring of high quality contact

of HP's external surface with heat absorbing surface is one of the main problems for copper made heat pipes applications to solar thermal collectors. For example, in the known evacuated tube SCs copper HPs are soldered, welded or pressed to the heat absorbing surface. The most important task is effective heat transfer from the HPs to the working liquid of the solar system loop at minimal hydraulic resistance. Besides that, the majority of traditionally designed SC does not meet the requirements on small weight, easy assembling and installing, versatility, scalability and adaptability of the design. The latter features are particularly important when SCs are facade integrated.

In order to solve the above mentioned problems, the authors propose to apply extruded aluminum HPs to the constructions of solar thermal collectors [3, 4]. The other reasons for using aluminum alloy made HPs

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in SCs are the following: They are cheaper, lighter and stronger than copper ones. This kind HPs technology is successfully applied to space engineering and satellites, and, moreover, it is perfectly worked out. Due to the proposed production method, cylindrical heat pipe and flat heat absorbing surface are obtained as a single unit. So, it is not necessary to think about the HP's contact with heat absorbing surface that means the design of heat exchanger could be improved fundamentally. To the authors' opinion, such solution can reduce the cost of SCs and improve their hydraulic and thermal performance. Besides, SCs based on aluminum HPs could be a good solution for building facade and roof integration.

The main goal of investigations was study of SCs efficiency which is based on aluminum HPs and its performances. Also, the authors show a possibility of the application aluminum HPs as constructional elements of SCs and at the same time of buildings facade constrictions. Such HP application need of special colored coating on their surface for the increasing efficiency of SC and the building facade decorate, so preliminary results of colored coating development are also represented in the article.

Experimental investigations have been carried out in Heat Pipes Laboratory of National Technical University of Ukraine (Kyiv) and "Heliocenter" (Crimea, Ukraine).

2. Laboratory Investigation

2.1 Experimental Samples

2.1.1 Solar Collector Samples

It was proved by the study that the most optimal design of aluminum HP applied to SC is, so-called, finned HP, where HP's container is made as a single unit with its heat absorbing—releasing surface. There is no thermal contact resistance between them. Such HPs can function within the span of tilt angle values from 0 deg (horizontal collector attitude) up to 90 deg (vertical collector attitude).

Special flat heat exchanger is used for heat removal

from the HP. Heat is transferred from the condensation zones of the HPs to the circulating coolant by means of contact method.

Experimental flat solar collector prototypes (Fig. 1) with the following dimensions: 2.13 m—length, 1.0 m—width, 0.085 m—height, 1.98 m²—area of anodized (black) aperture heat absorbing surface has been manufactured in order to prove the expediency of the HPs application to solar collectors.

Prototype of SC's panel for absorbing heat from solar irradiation consists of eight finned aluminum heat pipes, made of aluminum alloy 6060 by means of extrusion. Each heat pipe has a special black coating which was made by aluminum anodizing process. This technological process is prevalent today and usual use as the protection of aluminum buildings elements at air humidity. Solar heat is collected by flat longitudinal fins of the HPs and then immediately transferred to the condensation zones of HPs, which contact with small flat heat exchanger. Such effective heat transfer line ensures very low hydraulic resistance of solar collector.

The environmental friendly refrigerant was selected as a work fluid for heat pipes that allow their lifetime more than 15 years.

2.1.2 Colored Coating Samples

Anyway, heat absorbing surface is one of the main constructional element, which can influence greatly on the optical efficiency of SC. Better performance of the absorber means the increased share of absorbed thermal energy. In order to improve the absorber

Fig. 1 A flat plate collector based on the aluminum HPs: (a) SC structure; (b) general view; 1—heat absorber made of HPs' fins, 2—HP container, 3—heat exchanger, 4—inlet of coolant, 5—outlet of coolant heated.

performance, the authors are creating a new kind of selective coating to the absorber. Such coatings consist of the carbon-siliceous nano-composite, which are obtained by means of sol-gel technology [5]. The authors are developing spectral-selective composite coatings made of carbon nano particles dispersed in a dielectric matrix of SiO_2 and NiO .

The main feature of such coating is the possibility of variously colored effective layers (Fig. 2), and due to that, the use of SCs in building constructions might be expanded. One has a choice in color of the flat SC with higher performance in order to match or decorate the building facade.

The samples were made of aluminum alloy 6060 plates sized as 50 mm × 50 mm × 3 mm and then covered with variously colored experimental selective coatings.

2.2 Laboratory Tests

2.2.1 Efficiency Study of SCs

Efficiency study of SCs, having aluminum heat pipes as a core, was carried out at two independently functioning full-scale solar heating plants in Ukraine.

Solar thermal efficiency is defined as a ratio of useful solar heat:

$$Q_{use} = G_e \cdot C_p (t_{out} - t_{in}) \quad (1)$$

to total solar heat, which falls to the collector:

$$Q_{total} = E_{irr} \cdot F_{h.a.} \quad (2)$$

where, C_p , G_e —heat capacity and flow rate of a coolant in the circulation loop, respectively; t_{in} , t_{out} —temperature values of the coolant at the inlet and outlet of the collector manifold, respectively; $F_{h.a.}$ —heat absorbing area.

Fig. 2 Coatings of various colors: 1—black (sample number 1); 2—brown (sample number 2); 3—purple (sample number 3); 4—green (sample number 4); 5—red (sample number 5); 6—“anodized (black)” (sample number 6).

2.2.2 Optical Performances of the Developed Coatings

The ratio of the total absorbed radiant or luminous flux to the incident flux (the absorption factor As) as optical characteristic of coating was determined with the help of FM-59 photometer (Russia) in accordance with GOST 92-0909-69 within the wavelength band of $0.3 \div 2.4 \mu\text{m}$. The emissivity ε was determined by means of special device—“AE1” emissometer (USA) within the wavelength band of $3 \div 30 \mu\text{m}$.

Lifetime tests of designed coatings were also carried out. Such investigations are necessary for the determination of coatings instability to operation conditions at the early stages of the development. In this case samples with designed coatings were subjected to temperature change from -40°C to $+250^\circ\text{C}$ by heat/cold chamber TABAI at more than 40 cycles. After that the control of coating quality was got by visual method by the microscope LOMO MBS-10.

3. Results

3.1 Design Analysis

The calculated hydraulic resistance of SCs with aluminum HPs is not higher than 70 Pa at coolant flow rate of about 130 L/h. Thus highly effective operation of solar heating plants, where many SCs are connected in serious, is possible, as well as electric power consumption of circulation pumps could be lessened.

The merits of this kind SCs are of great importance for photovoltaic powered autonomous solar systems, where low power consumption circulation pumps are used. The result of such technical solution is shorter payback period of solar heating plants.

Besides that, modular solar systems of various shapes and appearance could be created by means of aluminum HPs. Varying numbers and sizes of the HPs like a building kit one can create various kinds of modular systems. These make easy not only facade layout of solar heating systems, but also using them as

building construction elements (Fig. 3). In this case, aluminum HPs could be used as elements of solar collectors and at same time as building elements. The extrusion technology of aluminum buildings construction is prevalent and mature today. So it is possible an application of different combinations of heat pipes case and building constructions as one unit.

Solar heating systems with HPs could be upgraded easily by removing or adding HPs, and there is no need to discharge the working fluid from the loop, to stop it and to recharge.

The price of a solar thermal energy system depends on the size of the installation and this again depends on energy needs. The price per m^2 of flat solar collector [6] is around 350€ (470\$), including installation of flat solar collectors, solar heat storage, connections, pipes and a solar thermal energy system control unit. Part of the cost for the installation is around 35%, therefore the price of 1 m^2 of flat solar collector is 227€ (305\$). A preliminary cost analysis of production the flat SC which is based on Ref. [7] which showed that the expected price of 1 m^2 will be about 157€ (210\$). This is 1.45 times less than the average price of the other traditional flat SC. It should be noted also that the cost of installation of the solar system will also be lower due to the simplicity and flexibility of integration into building facades. This kind of thermal SCs might be adapted to the facade outer view and construction by means of their various shaping and assembling of the similar light weight modules (Fig. 3). Each aluminum alloy made HP is autonomous hermetically sealed device which might be connected “in dry” to the main pipeline. They need no service and, if it becomes necessary can be simply dismantled without recharging of cooling agent.

3.2 Efficiency Study of Solar Collectors

Thermal efficiency of various solar collectors designs versus $X = \Delta t/E_{irr}$ are given in Fig. 4, where Δt is temperature difference between heat absorbing surface and ambient air, E_{irr} is irradiative solar flux value:

Fig. 3 Variants of flat SCs made of aluminum profiled HPs as an element of building facade shell: 1—facade glazing; 2—absorber, made of HPs; 3—facade insulation; 4—finned HPs; 5—main pipeline; (a)—structure; (b)—full size SC; (c)—SC of trapezoidal shape; (d)—SC with HPs of different length; (e)—several SC modules .

Fig. 4 The efficiency of flat SCs: 1—calculated values for the SC with heat-absorber covered with non-selective coating; 2—calculated values for the Vitosol 100-F; 3—calculated values obtained according to the formula given in Ref. [8] for flat SC with non-selective coating; 4—experimental values for the SC based on aluminum HPs.

(1) Calculated values for $E = 800 \text{ W/m}^2$ for flat SC with non-selective coating. Datum were provided by SolarTek;

(2) Calculated values for $E = 800 \text{ W/m}^2$ were obtained using data from German certification center “DIN CERTCO” (solar KEYMARK certification, reg. No. 011-7S329-F) for flat SC Vitosol 100-F prototype ($C_o = 0.776$, $C_I = 4.14$, $C_2 = 0.0145$). The prototype has an absorber, covered with selective coating layer;

(3) The calculated values were obtained from the empirical formula given in Ref. [8] for flat SCs with non-selective coating;

(4) Experimental data SC based on the aluminum HPs with non-selective coating “anodized (black)” were obtained in the range of total solar irradiation

values of 750 W/m^2 to 950 W/m^2 .

Analyzing the experimental data, the authors could say that efficiency of flat SC with aluminum HPs is not worse than that of well known evacuated tube SC, and for small X values (for low temperature values of heat absorbing surface and water in the storage tank) are even better. But that is true only for the summer period of the year.

Efficiency of the presented SC model is not worse than of well-known flat SCs designs with non-selective coating as it is evident from the test results, depicted in Fig. 4.

Although, the use of selective coating on the heat absorber surface of the SC is important for the temperature level higher than 55°C and low values of solar irradiation. So, as a rule, seasonal solar plants operate when X values are less than 0.05. In this case, the designed SC based on HPs (Fig. 3) is not much inferior to the collectors with selective coating, and the difference in efficiency is below 10% at X less than 0.05.

3.3 Optical Performances of the Developed Coatings

Preliminary results are showing in Table 1 on the optical performances of the developed coatings with the colors (Fig. 2).

It was revealed by the test results that the coatings have a relatively high absorption factor (A_s). But the emissivity (ϵ) for colored coatings No. 1-5 (Table 1) is also high, which does not meet the requirement to the high selectivity. For the selective coating emissivity (ϵ) should be minimal.

On the other hand, if the authors compare the optical coefficients of the colored coating with

Table 1 Measurement results on the optical performances of the experimental coatings.

No.	Color	Absorption factor (A_s)	Emissivity (ϵ)	Technology
1	Black	0.89	0.52	Sol-gel
2	Brown	0.86	0.58	Sol-gel
3	Purple	0.76	0.72	Sol-gel
4	Green	0.75	0.69	Sol-gel
5	Red	0.73	0.70	Sol-gel
6	Black	0.94	0.95	Anodizing

“anodized (black)” coating, which is used on the experimental sample of the SC (Fig. 1), their values do not differ significantly. Therefore, it can be stated that efficiency value of SC with applied colored coating would be near to the one of the developed specimen (Fig. 4).

Any changes into the structure of coatings surfaces were not detected after lifetime tests.

So, coatings No. 1 and No. 2 could be applying for aluminum alloy today. But obviously, at this stage it is necessary to continue research of colored coatings creation, first of all with No. 3, No. 4 and No. 5. The authors' goal is the achievement emissivity (ϵ) of colored coatings around 0.1-0.3. Now the authors get multilayer coatings by the using of sol-gel method. They are changing a concentration of components, a temperature of formation of coatings, using different functional groups, organic and inorganic supplements. In their opinion, it is possible significantly to improve optical characteristics of colored coatings by the application such methods.

4. Conclusions

In this research, the successful application of aluminum HPs to various kinds of SCs was proved. Aluminum HPs could be used as elements of SCs and serve for efficient heat absorption and transfer to the coolant, which circulates in the solar heating system.

Expediency of aluminum alloy HPs usage in SC's design was verified by operation and tests on the produced prototype of flat SC and full-scale solar heating plant.

Low hydraulic resistance of solar heat collectors with aluminum HPs allows to use successfully many SCs in one system or PV controlled circulation pumps. Also, high modularity and scalability of SCs is obtained due to using of separate HPs sections. Designs of various shape and size could be assembled from the finned aluminum alloy made HPs. The described solar heating plants could be integrated into building constructions. Moreover, repairing or

upgrading of the whole system, does not require draining the coolant out of the solar system loop, stopping it or refilling.

Works on the efficiency increase of colored coatings for solar SCs' absorbers are being continued.

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