Russian solar collectors for hot water supply of agricultural complexes and small private farms

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Abstract. This paper presents data on new designs of Russian solar collectors for hot water supply. Field tests of collector installations showed its high efficiency corresponding to the best foreign analogues. The main advantage of the collector is a low cost, which is achieved by using new methods of local processing. A new cost-effective production technology for a thin-walled heat-receiving panel allows you to produce channels of any shape. Based on the method of local deformation, the production technology of the panels made it possible to arrange their manufacture in Russia and reduce the weight of the panels and their cost by 30...45% compared with the best Japanese and German counterparts.

1. Introduction

The use of solar collectors is most effective in the southern regions of Russia, i.e. in climatic regions characterized by a stable arrival of solar radiation for a sufficiently long period, although in some cases their use is advantageous in the central and even northern regions in the summer. Solar water heaters are installed on a horizontal surface of the ground or roof, as well as on the sloping roof of a building. The working surfaces of solar collectors should be oriented to the south with a deviation from the south direction within 15°. The angle of inclination of the solar collector to the horizon during installation is fixed and its value is selected depending on the geographical latitude of the terrain and the expected duration of the operating season.

Bauman Moscow State Technical University created a new design of a flat solar collector, corresponding to the best German, American and Japanese collectors of this type. [1–3]. The solar collector is created with the use of modern aerospace technologies and equipment, which allowed reducing significantly production costs, as well as reducing the prime cost of a collector by one and a half to two times compared to similar collectors of foreign companies [4 – 6].

Based on these collectors, mobile and stationary hot water installations were designed, which can be used in the agro-industrial complex for hot water supply of livestock farms, greenhouses, etc.

2. Subject and methods of research

The main distinctive feature of the collector is the use of thin-sheeted stainless steel with thickness of 0.3...0.5 mm for the production of a stamp-welded heat-receiving panel of the collector. A new highly efficient technology of manufacturing heat-receiving panels by obtaining channels by the method of local forming on special equipment - local forming machines is protected by Russian Federation patents [1, 2]. This technology with high capacity to 2 m²/min allows obtaining channels of almost any
shape of 3 to 20 mm depth, depending on the thickness of the parent metal and the channel width. Herewith thin-sheeted materials with thickness up to 0.3 mm are used, which allows reducing the panel weight by 30...45% compared to similar stamped Japanese panels [1–3, 5, 6]. Figure 1 shows one of the options of a solar collector with a new panel.

Another distinctive feature of the new collector is the use of specially developed selective coating. The technology used in space stations «Almaz», developed at the JSC "MIC "NPO Mashinostroyenia", was adopted as the basis for this coating. The selective coating is applied by vacuum magnetron sputtering. Aluminum is the carrier layer, over which in the second vacuum chamber after the process of ion-plasma purification of the panel from the gas medium by plasma deposition is applied a three-layer selective coating: the first layer – silicon is precipitated from silicon-containing medium to create good adhesion of subsequent layers; the second layer - precipitates carbon from a carbon-containing medium, which provides a high absorption capacity: the third layer is an antireflective coating designed to reduce the reflection coefficient from the surface. Such coverage provided a high absorption coefficient with a low coefficient of self-radiation [7–10].

Tests of this coating under a special program of the impact of operational factors, including tests on humidity, heat and cold, cyclic temperature changes and impact tests of temperature conducted in a special laboratory of the Flight Research Institute (FRI named after Gromov), showed its high performance characteristics with guaranteed service life of more than 10 years.

Tests of various modifications of solar collectors were carried out in full-scale conditions (20 year-experience of operation in the conditions of the polygon of Moscow region) and in various independent specialized laboratories:

- in the laboratory of solar collectors testing of the Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS) in the Makhachkala city (Russia);
- in the laboratory of the Higher School in the Ulm city (Germany);
- in the laboratory of the Central Aerohydrodynamic Institute (TsAGI) in the Zhukovsky city (Russia).

Full-scale tests were carried out on the installations of the following types:

- one collector (type A) + 70 liter tank without heat exchanger;
- two collectors (type B) + 110 liter tank with a heat exchanger;
- two collectors (type A) + 110 liter tank without heat exchanger;
- four collectors (type B) + 200 liter tank with a heat exchanger;
- four collectors (type B) + 300 liter tank with a heat exchanger.
During the test, the coolant flow rate, the coolant temperature at the inlet and outlet from the collector, the temperature of the water in the tank at three levels, the ambient temperature, and the wind speed were measured. Figure 2 shows the results of testing the third type installation with two collectors and a water storage tank for 110 liters of water obtained on April 15, 2014 and June 30, 2014 under clear weather and wind speed of about 3.5 m/s.

The following tests were carried out in Makhachkala city (JIHT RAS) and in Zhukovsky city (TsAGI) at the stands with artificial (simulated) sun, according to the method developed by the Joint Institute for High Temperatures of the Russian Academy of Sciences (JIHT RAS):

- tightness control;
- water resistance;
- thermal tests (time constant and efficiency curve);
- hydraulic tests (determination of hydraulic resistance);
- test for limiting heating;
- test for internal heat stroke;
- test for external heat stroke;
- test for internal pressure.

All modifications of collectors have successfully passed all test stages. The latest models have good performance on all the parameters and are not inferior to the best Japanese collectors of this class [11].

Figure 3 shows the experimental mobile all-season installation of hot water.
Relatively low cost of the collector "Rainbow" is to be mentioned aside; it enables to sell them at a price not more than 100 euros per 1 m$^2$. These prices are significantly lower than international prices for solar collectors of this type. For Russian consumers, such prices are very high, as the price of energy resource is still low and it is more profitable for a consumer to use traditional types of heaters.

Taking into consideration this particularly of Russian market, we have developed a new design of a plane collapsible solar collector with a heat receiving panel area of 2 m$^2$, which has a lower cost price.

The cost price reduced due to materials saving and reduced labor input. Figure 4(a) shows photos of this collector and the figure 4(b) shows heat receiving panel.

![Figure 4. Photos of the heat receiving panel of 2 m$^2$ (a) and a plane solar collector (b).](image)

Figure 5 shows the thermal characteristics of the solar collector "Rainbow 2".

![Figure 5. Thermal characteristic of solar collector with an effective area of 2 m$^2$.](image)

The efficiency of using solar energy $\eta$ depends on the indicator $T^* = (T_s - T_a) / I$, where $T_s$ – the average water temperature in the collector, °K; $T_a$ – ambient temperature, °K; $I$ – density of solar radiation, W/(m$^2$) [3, 12].

The main technical characteristics of the collector "Rainbow 2" are given in the table 1.
Table 1. Technical characteristics of the solar collector "Rainbow 2”.

| Type of collector | Plane |
|-------------------|-------|
| Heat exchanger material | Steel 12X18H10T |
| Wall thickness of heat exchanger, mm | 0.3…0.4 |
| Absorption capacity | 0.94 |
| Degree of blackness | 0.13…0.14 |
| Unit thermal loss, W/(m²) | 4.4 |
| Optical efficiency | 0.84 |
| Productivity of the collector of area 2 m², liters/day | up to 200 |
| Heating water temperature, °C | up to 90 |
| Working pressure in the system, MPa | up to 0.6 |
| Weight, kg | 42.2 |
| Service life, years | 15 |
| Dimensions, mm | 1990x1130 |
| Usable area of the collector, m² | 2 |
| Efficiency (DIN 4757-4-1982, Germany), % | 55 |

3. Conclusion

Great prospects are opening up due to the low cost of the collector "Rainbow 2" for application of plane collectors in hot water supply and heating devices, where large areas of collector panels are required. Solar pilot water heating plants, which convincingly showed their rather high efficiency, were created and successfully tested. Creation, production and widespread use of these facilities will significantly reduce energy costs for hot water supply and reduce the cost of agricultural products and improve the environmental situation by reducing harmful emissions into the Earth’s atmosphere [13, 14].

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