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METHOD FOR STUDYING THE TUBULAR SOLAR COLLECTOR TESTING IN A LABORATORY

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ABSTRACT

This paper considers the technique for studying the testing of tubular solar collector in a lab. Today, there are several ways methods of using solar collectors. When using the first method, the following values are measured: coolant flow, difference between the temperatures of the collector coolant fluid at the collector inlet and outlet and the density of the incident solar radiation flux. Here, all these values are measured simultaneously and under quasi-stationary mode. Much of the research is related to testing of collectors in field conditions using the instant method. At the end of the tests, the product of the total heat loss coefficient of the collector and efficiency coefficient of the absorption panel was determined. The heat output of the collector was also measured. As is seen from experimental methods of testing tubular solar collector, the tubular collector with an absorbing screen decreases from 0.8 to 0.17 when water is supplied at the inlet 20°C, 30°C, 40°C and 50°C, while the efficiency of the tubular collector with a reflector increases from 0.17 to 0.68 when water is supplied at the inlet 20°C, 30°C, 40°C, and then decreases to 0.4 at t1-50°C. It is obvious that the efficiency of heat absorption and transfer as a result of thermal conductivity is much higher than the capturing and reflection of sunlight by the absorbing pipe. However, both the cost and labor input involved in the manufacture of the above tubular collector with an absorbing screen is higher.

Keywords: *Tubular Solar Collectors, Heat Losses, Efficiency Factor, Optical Efficiency Product, Absorption Panel Efficiency Coefficient*

1. INTRODUCTION

The intensity of energy use is increasing year after year. In the energy sector, households and the service sector are the main end-users of energy in absolute terms. According to studies, energy consumption in homes in the EU is comparable with that in the transport sector, and twice more than that in the industrial sector [1-3]. In the current methodology for calculating heat energy consumption, climatic conditions of the region and building insulation are factored in. At the same time, it is recommended to take into account other important factors such as efficiency of use of renewable energy for heating and air-conditioning of rooms [4, 5].

Although all solar water-heating systems are based on the same technique –absorbing and converting solar energy into thermal energy, however, solar collectors and systems differ in various ways. The differences are important because they depend on the need for hot water in various processes and on serviceability of certain types of collector systems. The materials and components used in the solar water-heating systems vary depending on the expected operating temperature range [6, 7].

The simplest type is the unglazed solar collector. In low temperature systems, they tend to

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operate at lower temperatures, down to 10°C, above the ambient temperature, and are most often used to heat swimming pools. In the pool, water is colder than the air collector, and so insulating the collector would be counterproductive. The swimming pool water flows directly through solar collectors using a circulating pump running in the water filtration device. In heating systems with temperatures from 10°C to 50°C and above, solar collectors are used in combination with boilers and heated floors.

A typical sample of a solar collector consists of an absorbing panel (absorber) placed inside a closed glass casing. An adsorbed made in the form of a flat plate has flow channels. Fiberglass or polyurethane insulation material is stacked between the rear wall and the casing. At low temperature differences, heat loss through reflection and absorption of sunlight by the glass leads to lower efficiency. However, the glass is necessary to preserve heat at higher temperatures. Copper absorber made of copper tubes, welded to a flat plate, is often used. The absorber is coated with a selective absorber to reduce energy loss by radiation from the collector. Black nickel is often used – it has high absorptivity in the short-wavelength region of the spectrum of solar radiation, but low absorptivity in the long-wavelength thermal spectrum [8-10].

Vacuum tubular collectors are widely used in Europe and China. The main element in them is heat pipes that are placed inside an evacuated bulb. Solar energy, which is usually supplied by the flat longitudinal absorbing plate, is absorbed by the heat pipe. The heat pipe transfers heat to the heated water through the hot end. Structurally, the evacuated tube can consist of multiple evacuated glass tubes [11]. Here, the inner tube is filled with an intermediate liquid – water mixed with propylene glycol or antifreeze. The intermediate heat carrier transfers heat through the heat exchanger to the hot water supply system or room heating system. The vacuum inside the evacuated tubular collectors, as have been proven, can remain for more than 25 years [12]. The vacuum that is outside the tube considerably reduces heat convection and loss. Accordingly, compared with flat collectors, this effect is especially noticeable in cold conditions. However, this advantage is generally lost in warmer climates – except in those cases where it is necessary to obtain hot water, for example, for special technologies. To prevent overheating, which may arise when there is no water circulation or when there is high solar intensity, special design solutions (safety valves or expansion tanks) are used.

2. METHODS

The existing methods of testing solar collectors can be divided into two main groups: the method of determining the efficiency using instantaneous values of regimes and meteorological factors and calometric method. Each of them can be used to identify the basic characteristics of a collector. The ASHRAE and NBS methods are used in the US, BSE method in Germany, AFNOR method in France, and EIR method in Switzerland.

When using the first method, the following are measured: coolant flow, difference between the collector inlet and outlet coolant temperatures and the density of the incident solar radiation flux. Here, all these values are measured simultaneously and under quasi-stationary mode. Instantaneous efficiency is defined as:

$$\eta = Q_{пол.} \Big/ EF = G \cdot c_p \cdot (t_{out.} - t_{in.}) / EF_к, \quad (1)$$

where: G – water flow (m^3/h);
C_p – specific heat of water (J/kg·K);
t_{in} – water inlet temperature (°C);
t_{out} – water outlet temperature (°C);
E – solar radiation intensity (W/m^2);
F_k – collector area (m^2).

When using calometric method, one applies a system in which a change in the temperature of a certain amount of coolant over a long time interval with respect to energy radiation is measured.

Each method has its advantages and disadvantages. In the method of determining the efficiency using instantaneous values of regimes and meteorological factors, it is necessary to measure a large number of parameters, moreover, with high accuracy, independently and simultaneously. However, in temperate climate regions (above 500 north latitude), it is quite difficult to conduct instant tests at steady-state conditions due to instability of meteorological factors.

Comparative testing of different types of solar collectors can be given as an example of a calometric method. Based on this method, all collectors were tested under the same water flow specific temperature at the collector inlets. The tests were carried out based on the efficiency and average daily temperature of the heated water. Similar tests were carried out in Australia [13].

The most part of studies are related to testing of collectors in field conditions using instant method. Here, the field test results are presented in the form of dependence of efficiency on $\Delta t/E$.

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In the method recommended by the National Bureau of Standards (NBS) [14], the difference between the half-sum of the temperatures of the collector coolant fluid at the collector inlet and outlet and the outside air temperature is used as Δ t. Sometimes, the half-sum $\frac{1}{2}(t_{вх.} + t_{вых.})$ is replaced by the fluid inlet temperature, such as in the method of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) [80]. There will be a considerable dispersion in experimental points in any of these approaches. The following designations are introduced in order to reduce dispersion in the NBS technique: E_{min}=630 W/m^2, t_{max}=30°C; V_{max}^{BET} =3.5 m/s; θ_{max}=45^0.

The ASHRAE method used slightly different values of these parameters. The method by Cardiff University of Shanghai Institute of Mechanical Engineering [15] and a number of other methods are not very different from ASHRAE method, although each of them has their own approach and experimental conditions.

The method of experimental identification of the main characteristics of a solar collector allows to calculate the efficiency of that collector [16]. Among such characteristics are:

– Rate of heat removal from the collector F_R;

– Given absorption capacity $(\tau\alpha)_e$;

– Total loss coefficient U_L.

These parameters are determined at full-scale testing of the solar collector. This method was applied to the collectors of a solar house (Colorado State University) and showed that experimental data matched well with theoretical values.

Some authors [17] suggest testing the collectors in the laboratory with the help of a simulator. The main reason here is that NBS requirements with respect to meteorological factors for central European conditions are unsuitable. Therefore, it would take some weeks to obtain the curve $\eta = f(\Delta t / E)$.

3. TABLES AND FIGURES

Tests to determine the product of the total heat loss coefficient of the collector and efficiency coefficient of the absorbent panel were conducted in a laboratory in accordance with GOST 28310-89 and GOST R 51594–2000.

The schematic diagram is shown in Fig. 1. It includes the following elements: a solar collector 6, thermostat tank 1, which has an electric heater that heats to a predetermined water temperature.

Figure 1: Getting started with GU-500 with tubular solar collectors with an absorbing screens

Two types of collector were used for the test:

1. Tubular solar collector with a semi-cylindrical reflector;
2. Solar collector with absorbing screens with cellular coatings;

Heat insulated pipe 2 is used to supply the coolant (hot water) to the solar collector from the thermostat tank. Heat insulated pipe is connected to the stand pipes no more than 10 cm from the collector. The remaining branch pipes should be closed by caps. The contour of the stand is filled with water. Make sure there is no air in the contour. The valve is opened and water flow through the collector is set 25 kg (m^2·h).

Temperature sensor 4, 5 is installed at the solar collector inlet. Here, a mercury thermometer with measurement limits 0-100°C and scale interval of 0.1°C is used as the sensor;

Heat insulated pipe 2 used to supply the coolant from the solar collector to tank 1. Mercury thermometer 5 and valve 3 are installed in the pipeline. Here, mercury thermometer 5 is no more than 10 cm from the solar collector outlet. Water flow is measured by the gravimetric method.

The collector being tested is mounted on a special support at an angle of 30° to the horizon.

Test conditions:

– Water with temperature 40, 50, 60 and 70°C is fed at the collector inlet. Water temperature is changed from test to test;

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– Tests should be conducted in a stationary mode. Test conditions are considered stationary if the water temperature at the collector inlet and outlet and the ambient temperature do not change by more than 0.1°C for 10 minutes.

In the tests, the following are recorded 20 minutes after entering the stationary mode:

– Collector inlet and outlet water temperature;

– Ambient air temperature;

– Water flow through the collector.

To measure the temperatures, an infrared pyrometer C 300-3 "Photon" with recorder meter IC 203.3 (4) was used. Heat converters with temperature measuring range of -50 to 180°C were used as the HCX temperature sensor (Figure 45a).

At the end of the tests, the product of the total heat loss coefficient of the collector and efficiency coefficient of the absorption panel was determined by the formula:

$$F'xU_L = \frac{Gxc_p x(t_{вх} - t_{вых})}{Ax(\bar{t}_{ж} - t_{в})}$$

(2)

where U_L – total heat loss coefficient, W/(m^2·°C);

F' – efficiency coefficient of the absorbing panel;

G – water flow through the collector, kg/h;

A – area of the heat-receiving surface, m^2;

c_p –Heat capacity of water, W h/(kg·°C);

t_{in} – water inlet temperature of the collector, °C;

t_{out}– water outlet temperature of the collector, °C;

t_a – ambient air temperature of the test collector, °C;

$\bar{t}_{ж}$ – average temperature of the liquid equal to the half-sum of the water temperature at the collector inlet and outlet.

4. DETERMINING THE OPTICAL PRODUCT OF COLLECTOR EFFICIENCY $(\tau\alpha)$ AND EFFICIENCY COEFFICIENT OF ABSORBING PANEL F'

Tests were carried out in field conditions at the above-mentioned laboratory setting in accordance with GOST 28310-89 and GOST R 51594-2000.

Test conditions

The tests should be carried out under a clear, cloudless sky and density of total solar radiation flux of at least 600 W/m2. The temperature of the ambient air has to be not below 15°C.

Wind speed during collector testing should not exceed 5 m/s. The wind speed should be measured near the collector at a height corresponding to half the height of the collector.

Tests are carried out at a water flow rate of 25 kg/(m2 h) through the collector and collector inlet water temperature of 20, 30, 40 and 50°C. Water temperature is changed from test to test. Thus, at least 4 tests should be carried out.

The tests should last for at least 2 hours.

The following additional devices are used in the testing process:

– Pyranometer M-80 paired with the secondary device;

– Cup anemometer.

The following are recorded at the same time during tests:

– Total solar radiation flux density in the collector plane;

– Ambient temperature;

– Collector inlet water temperature;

– Collector outlet water temperature;

– Water flow through the collector.

5. RESULTS

The test results (Fig. 2) are used to determine the heat output of the collector (Q_k) by the formula:

$$Q_к = \frac{G \cdot c_p}{A}(t_{вых} - t_{вх}) \cdot \tau_0 \quad (3)$$

and complex $\frac{1}{E}\left(\frac{t_{вх} + t_{вых}}{2} - t_в\right)$,

where E is the total solar radiation flux density in the collector plane, W/m^2;

τ_0 – test duration, h.

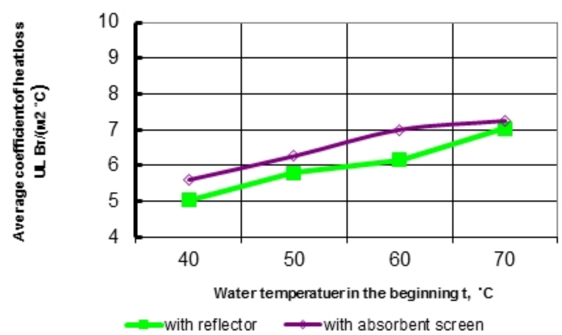

Figure 2: Dependence of heat loss $F' \cdot U_L$ on water inlet temperature

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The calculation results (Fig. 3) are used to plot the dependence of $Q_к/(Ex\tau_0)$ on $\frac{1}{E}\left(\frac{t_{вх}+t_{вых}}{2}-t_в\right)$, Intersection of the plotted dependence with the y-axis gives the required collector value $F'x(\tau x\alpha)$.

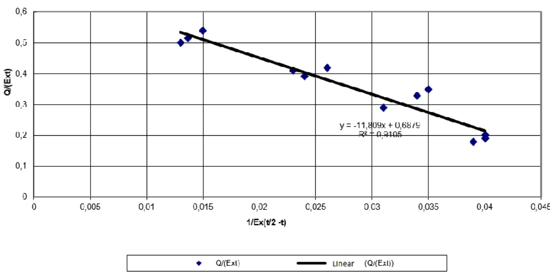

Figure 3: Dependence of Q/(E·t) on complex 1/E· (t/2− t̄) of tubular solar collector with a semi-cylindrical reflector

Calculation error $F'x(\tau x\alpha)$ must not exceed ± 10 %.

6. CONCLUSION

As has been shown, the efficiency of a tubular collector with an absorbing screen decreases from 0.8 to 0.17 when water is supplied at the inlet 20°C, 30°C, 40°C and 50°C, while the efficiency of the tubular collector with a reflector increases from 0.17 to 0.68 when water is supplied at the inlet 20°C, 30°C, 40°C, and then decreases to 0.4 at t1-50°C. It is obvious that the efficiency of heat absorption and transfer as a result of thermal conductivity is much higher than the capturing and reflection of sunlight by the absorbing pipe. However, both the cost and labor input involved in the manufacture of the above tubular collector (with an absorbing screen) is higher.

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