Heat exchange process intensification in solar collectors

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Abstract. The article discusses improvement of a flat solar collector with the heat exchange process intensifying aim, which improves the quality and the equipment efficiency in question. Based on the solar thermal plants’ calculation, taking into account the design features affecting the generated energy amount, a comparative analysis of the characteristics of traditional flat solar collector and solar collector of intensified heat exchange with an independent heating contour was carried out. The theoretical study results of the thermal energy accumulation processes by solar receiving devices of two types are presented.

Introduction
The urbanization development leads to significant increase in energy consumption. This trend creates a need for the resource-producing and power-generation technologies development, search for a more accessible and cost-effective methods of energy generation, existing equipment improvement, related to the field of alternative energy [1], which use leads to improved quality and efficiency indicators, contributes to preservation of basic natural resources and the ecosphere from pollution protection.

Analysis of publications
In many countries around the world, including Russia, solar heat supply is considered to be the most promising direction of the alternative energy development, in the unlimited potential and reliability view. Solar energy conversion into heat is characterized by a heat-accumulation effect, accompanied by a series of heat and mass transfer processes, of which radiation is fundamental and the most significant. The amount of solar energy absorbed by the absorbing panel is proportional to the solar hot water system heat output (HWS). The heat generation reduction occurs due to effects of the external factors causing the heat carrier cooling. Among the options for reducing heat loss the most effective are the system elements thermal protection enhancement and an increase in the solar collector radiant surface area. The literature sources analysis shows that in recent years there have been practically no theoretical and experimental studies aimed at studying intensification and optimization of the thermal energy accumulation process by the solar thermal plants’ solar collectors.

The problem solution was previously discussed in the article [2], wherein the flat solar collector technically perfected structural elements efficiency and economic feasibility analysis was carried out, as well as in the patent for utility model [3], the development purpose which is the heat transfer intensification in solar collectors.

Materials and methods of research
The actual side is the thermal energy accumulation process study in the operation of solar hot water systems. Purpose of the study is the heat exchange process intensification in solar
collectors. The problem definition is to optimize the solar collector operation, ensuring its efficient operation.

**Results and analysis**

The thermal energy absorption intensification concept implementation in the solar hot water systems operation is carried out by upgrading the absorbing panel of a flat solar collector by converting it into a heating element. This device is made of two thin-walled copper plates arranged parallel to one another and interconnected by means of locking the contour of the side walls and rod-like heat-conducting elements. Above is a ray-receiving panel with the formation of spherical segments; below is the base, Fig. 1-6. The decision to change the shape of the absorber is due to the desire, while maintaining the overall dimensions of the hull, to increase the area of the absorbing surface, the value of which is the main characteristic of the solar thermal installation.

![Figure 1. The SC (solar collector) cross-section](image1)

![Figure 2. The SC longitudinal section](image2)

![Figure 3. Heating Element](image3)
Let's consider the heat accumulation process during the warm season by solar domestic hot water systems at the example of a two-story cottage, with the number of residents - 4 people, located in Rostov region.
According to the data [4], the hot water consumption rate per person is $G_0 = 50$ L/day, let us determine the total flow of the heat carrier according to the formula

$$G = G_0 \cdot n \cdot 1.5.$$ (1)

where $G_0$ – is the water consumption rate per person, L/day;
$n$ – number of residents of one cottage;
1.5 – is the correction factor taking into account seasonal water consumption unevenness.

Total heat carrier consumption shall amount to $G = 300$ L/day, at temperatures in the supplying pipeline – $t_{w1} = 55^\circ$С and make-up pipeline – $t_{w2} = 15^\circ$С.

Let us make a comparative analysis of two solar hot water systems, operated in climatic conditions of Rostov region, with equivalence of all affecting factors, with different solar receiving equipment for solar hot water supply:
- flat solar collectors of the company Vaillant – VFK 150 V;
- solar collectors of the intensified heat exchange with an independent heating circuit.

Basic design characteristics of the used equipment are presented in Table 1.

| Solar collector | Standard efficiency factor, $\eta_0$, [%] | Coefficient of heat loss, $U$, [W/(m$^2 \cdot ^\circ$С)] | Coefficient of glass transparency, $\tau$, [%] | Coefficient of absorber absorption, $\alpha$, [%] | Coefficient of absorber radiation, $\varepsilon$, [%] | Case dimensions, $a \times b$, [mm] | Dimensions of absorber, $a_y \times b_y$, [mm] | Absorbing panel area, $A_t$, [m$^2$] |
|-----------------|----------------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|---------------------------------|--------------------------|
| VFK 150 V       | 83.3                                   | 2.33                            | 96                              | 95                              | 5                               | 2033 $\times$ 1233               | 1978 $\times$ 1075           | 2.35                     |
| SC of the intensified heat exchange with an independent heating circuit | 83.3                                   | 2.33                            | 96                              | 95                              | 5                               | 2033 $\times$ 1233               | 1978 $\times$ 1075           | 2.77                     |

Based on the data of the table, the surface area of absorbing panel with equivalent dimensions is significantly larger than that of the analog. As a result, in identical design conditions, a smaller number of considered devices will be required. As evidence let us use the procedure set forth in [5]. Let us calculate the absorbent surface required area for warm season, in order to determine the required number of solar collectors for the two types of equipment.

To determine heat production of HWS solar system let us carry out the calculation of the following values:
- required area of absorbing solar collector surface;
- solar collector efficiency coefficient;
- solar collector modified optical performance;
- required number of solar collectors

Let us take the amount of solar radiation received by the surface absorbers, taking into account the instantaneous coefficient of performance (COP) and the solar collector angle optimization [6] as
equivalent to the consuming circuit thermal load. The initial data are the intensity of solar radiation and the average daily temperature in the region, in accordance with NASA data [7]. The results of the calculation are summarized in table 2.

| Months    | Efficiency | A, [m²] | n (VFK 150 V), [pieces] | n (SC of intensified heat exchange with an independent heating circuit), [pieces] |
|-----------|------------|---------|-------------------------|--------------------------------------------------------------------------------|
| April     | 0.53       | 8.02    | 4                       | 3                                                                               |
| May       | 0.55       | 5.09    | 3                       | 2                                                                               |
| June      | 0.56       | 4.91    | 3                       | 2                                                                               |
| July      | 0.57       | 4.7     | 3                       | 2                                                                               |
| August    | 0.57       | 4.78    | 3                       | 2                                                                               |
| September | 0.56       | 7.07    | 4                       | 3                                                                               |

Based on the study, a graph of the solar collectors number linear dependence from the calendar month was constructed for two types of equipment, Figure 7.

According to the study, the number of collectors is determined based on individual needs. The use of such devices for operation during the cold period of the year is impractical because of the overestimation of the costs due to the increase in the required number of solar collectors.

**Summary**

The technical result of the flat solar collector improvement is the heat exchange process intensification, which leads to an increase in operating efficiency, and helps to reduce the operating costs; can be considered as an innovative direction in the solar power plants development. As part of the study, the authors will continue optimization of the absorbing panel spherical segments shapes in order to increase the receiving surface area, while maintaining the absorption coefficient value.

**References**

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