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Efficiency of solar collector combined with outer wall

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Abstract: The results of experimental research of the solar system with solar wall in the mode of circulation are presented. The results of researches of receipt of radiation on the solar wall are described. Graphical dependence of the heating temperature of the coolant at the inlet and outlet of solar wall are defined, as well as in the storage tank and to the amount of heat, that solar system got from time of irradiation of its by the heat source. It is shown that the solar collector combined with outer wall of building can works effectively in the system of solar heating.

***Index Terms*: solar collector, solar radiation, the amount of heat.**

I. INTRODUCTION

The aggravation of the energy and environmental problems, in particular energy shortages, global warming and the change in the level of traditional energy has led to a special relationship to alternative energy, bringing it from some promising exclusive destinations in to the required number of priority tasks. For the possibility of using solar installations it is necessary to analyze and compare the resources of renewable energy with existing irreplaceable. On Earth there are all preconditions for intensive use of large potential of unconventional energy, particularly solar. Therefore there is a need in the implementation of complex measures for the use of alternative energy sources. The solution to this problem requires significant changes in the global energy balance. The alternative of traditional energy is the use of unconventional renewable energy sources: Solar, wind, heat of industrial and sewage wastes, water, etc.

II. ANALYSIS OF RECENT RESEARCHES AND PUBLICATIONS

There are many different designs of solar collectors for domestic and industrial needs, however, have become common combined solar collectors [1]. It's developed energy efficient walling in the form of roofs and external walls of buildings (residential, public, administrative, etc), and also as elements of surfaces of industrial objects (freezing, cooling and drying chamber, etc). Such constructions allow utilize for needs of hot water, air conditioning and industrial heat the energy of solar radiation, heat outdoor air and exhaust air, as well as an opportunity to implement the functions of the ejection out of the excess heat and regulate heat accumulation [2]. It's widely used wall-mounted solar collectors, which simultaneously perform the function of walling [3].

Their efficiency is influenced by many factors: the incidence of radiation [4], clouds [5], speed and wind direction [6], latitude, etc [7]. Important is to study all factors that affect the solar collectors and to search for optimal designs and their operation modes, it is developed a number of research methods for this task [8]. Today no less important is the construction of energy-efficient houses that would not only effectively use the heat, but also to make it themselves [9-10].

III. THE STATEMENT OF THE PROBLEM

One of the most promising sources of alternative energy is Solar energy. However, solar heat systems with solar collectors that commercially available there are quite expensive and create additional mass load on the construction of buildings on which they are placed.

The consturctive combination of solar collector and building envelope will allow to reduce the cost of solar heating system, increase its efficiency and simplify the design. Therefore, today it is important to study the effectiveness of solar wall in the system of solar heating.

IV. THE MAIN MATERIAL

Experimental researches were carried out on the installation, which consisted of a solar wall, the storage tank, the

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radiation source and measuring instruments. Scheme of eexperimental installation is shown in Fig..1.

Solar wall as a solar collector works as follows. Solar beam hits the plaster 7 of solar wall, which functions as a heat-conducting layer. At this time, it is heating. Heat is transferred to the tubes of circulation 4. Insulating layer 2 ensures the reduction of heat loss. Placing a layer of heat reflective material 3 makes it possible to increase the efficiency of use of solar radiation, part of which is passed by the tube of circulation. A layer of heat reflecting material 3 reflects solar radiation in the opposite direction of the tube for the coolant 4, as a result it is absorbing more solar radiation which is falling on solar wall.

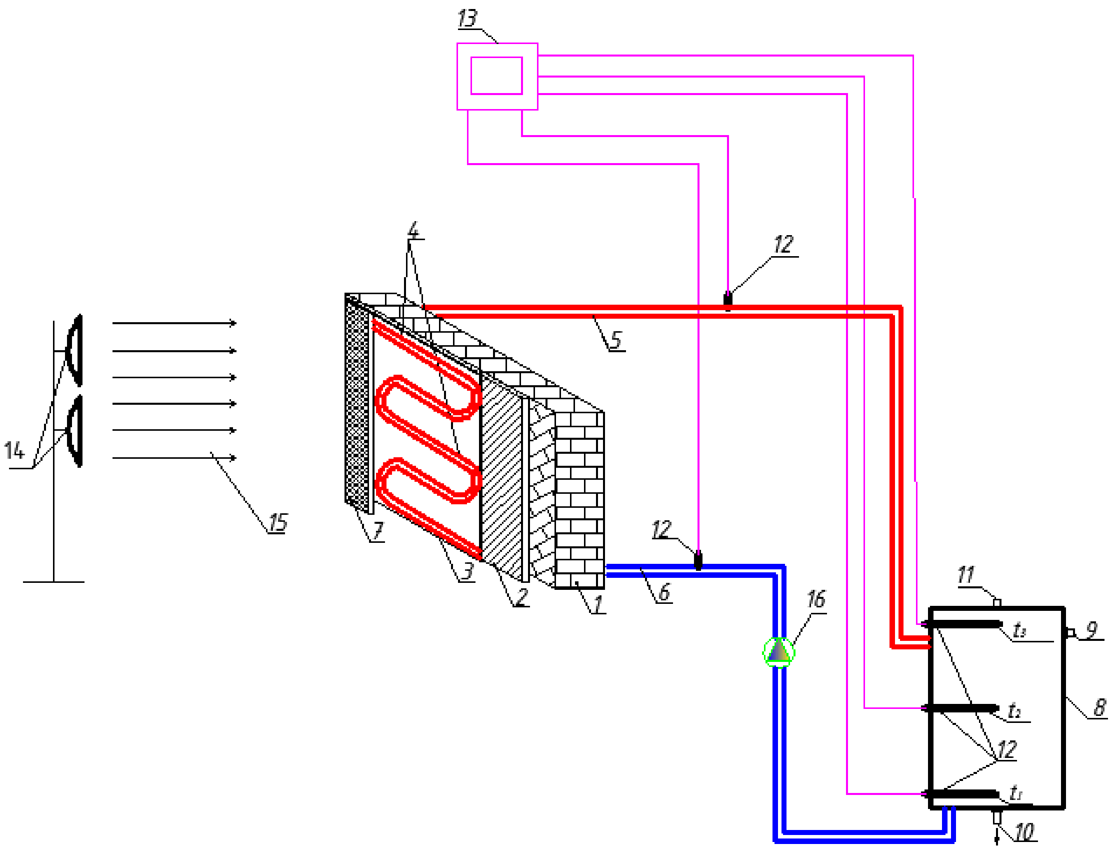

Fig (1) Scheme of the experimental setup

1. wall
2. insulating layer
3. heat-reflecting layer
4. tubes for coolant
5. return pipe
6. feed pipe
7. plaster
8. water-tank
9. tube feeding water to the consumer
10. drain pipe (supply cold water in a system)
11. air purger
12. resistance thermometers
13. digital thermometer
14. the emitter of thermal energy
15. heat flow
16. circulating pump

Due to the action of the circulation pump, and accordingly the differential pressure in the zone of the inlet and outlet pipes, creates a circulation of the coolant. The heated coolant through the feed conduit is provided to the storage tank of hot water. The heated water is fed through the pipe to the consumer. Chilled coolant through the reserve pipeline returns to solar wall, and heated.

During the experiment the temperature of the coolant at the inlet to solar wall, the temperature of the coolant at the outlet of solar wall, the temperature at three points of the storage tank, arranged vertically at equal distances from

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each other were measured.
We controlled that the experiment was not affected by other factors (solar energy through the window, hit the reflected radiation on solar wall, shading of soalr wall). As the experimental factors, we selected the following parameters:
- the distance above the tubes of the circulation, δ, m
- the coolant flow rate, G, kg/s.

This article presents the results of experimental researches of solar wall in the solar heating system when the diameter of tubes of the circulation d = 0,010 m, the distance between tubes of the circulation is l = 0,01 m. The thickness of plaster on top of tube of the circulation was set at 0.02 m. The flow rate of the coolant in the circulation loop comprised of 0,0125 kg/s per 1 m^2 of solar collector. The researches were carried out at the intensity of the heat flow of 300 W/m^2, which corresponds to the average value intensity of solar radiation during the day. All researches were conducted in laboratory conditions.

The results of experimental measurements of the temperature of the coolant at the inlet and outlet of solar wall, and average air temperature near the experimental setup is presented in graphical form in Fig (.2).

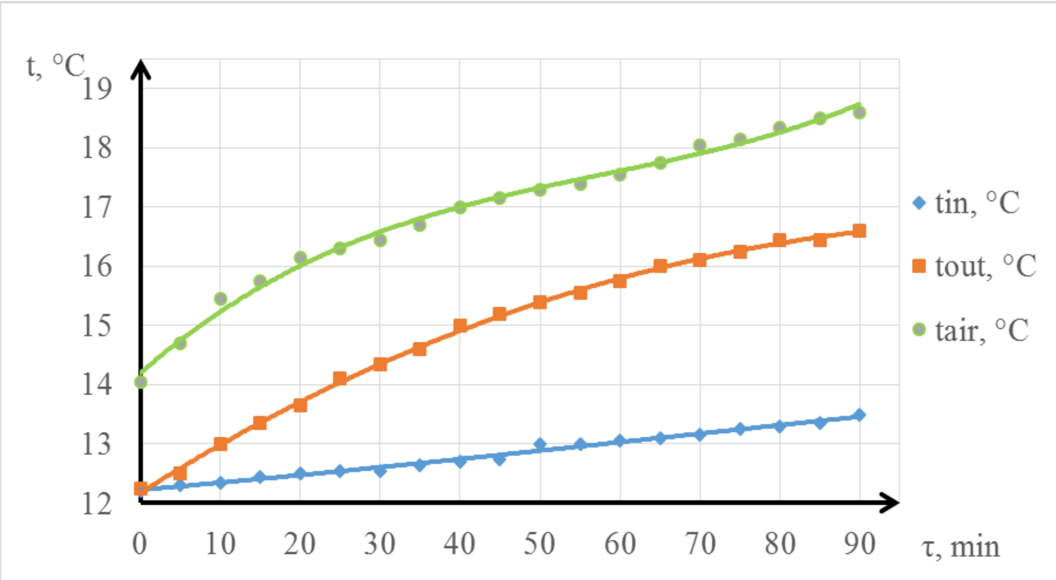

Fig (.2) The results of experimental researches of solar wall

t_{in} the water temperature at the inlet to solar wall,°C
t_{out} the water temperature at the outlet of solar wall, °C
t_{air} average air temperature near the experimental setup, °C

After analyzing the graph depicted in Fig (4.2), it is possible to see a gradual increase of water temperature in solar installation throughout the experiment. The water temperature at the outlet of solar wall reaches a value of 16.6 °C, that is for 90 minutes of irradiation by heat flow of intensity of 300 W/m^2 the temperature of the coolant at the outlet increased by 36 %.

According to temperature changes at the inlet and outlet of solar wall, it is advisable to analyze how changing the coefficient. The efficiency of the solar collector, η_{sc} is determined by the equation:

$$\eta_{sc} = \frac{Q_{sc}}{I} 100\%, \qquad (1)$$

Where:
$Q_{ск}$ – specific instant heat capacity of solar collector, W/m^2; I – the intensity of the radiation source to the surface of the heat absorber of the solar collector, W/m^2.

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Specific instant heat capacity of solar collector was calculated as follows:

$$Q_{sc} = \frac{G \cdot c \cdot (t_{out} - t_{in})}{F_{sc}}, \quad (2)$$

Where:
G – the specific flow rate of coolant, kg/(s•m^2); *c* – specific heat of coolant, J/(kg•K); t_{in}, t_{out} – the temperature of the coolant at the inlet and outlet of the solar collector, K; $F_{ск}$ - the area of solar wall, m^2.

In Fig (4.3) we show the dependence of the instantaneous thermal power of solar wall of irradiation time, calculated by dependence (2).

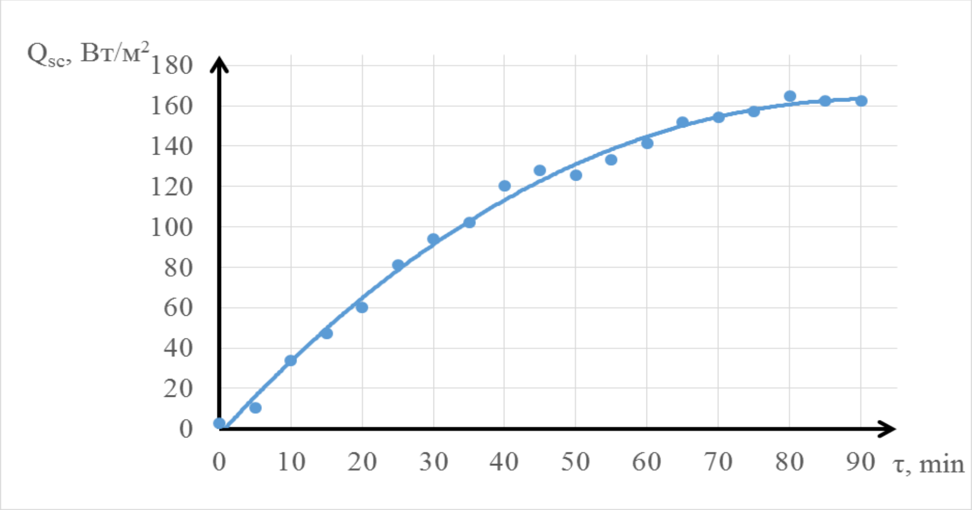

Fig (.3) The change of the specific instantaneous thermal power $Q_{ск}$, W/m^2 of solar wall depending on the irradiation time τ, min.

From Fig (.3) we can see that the specific instant heat capacity of solar wall increases sharply from the beginning of the experiment up to 75th minute and is 157 W/m^2, and then is on the level from 162 to 165 W/m^2. According to the data of Fig (4.3) by using dependence (1) we got the change in efficiency of solar wall, η_{sc} during experiment Fig (4).

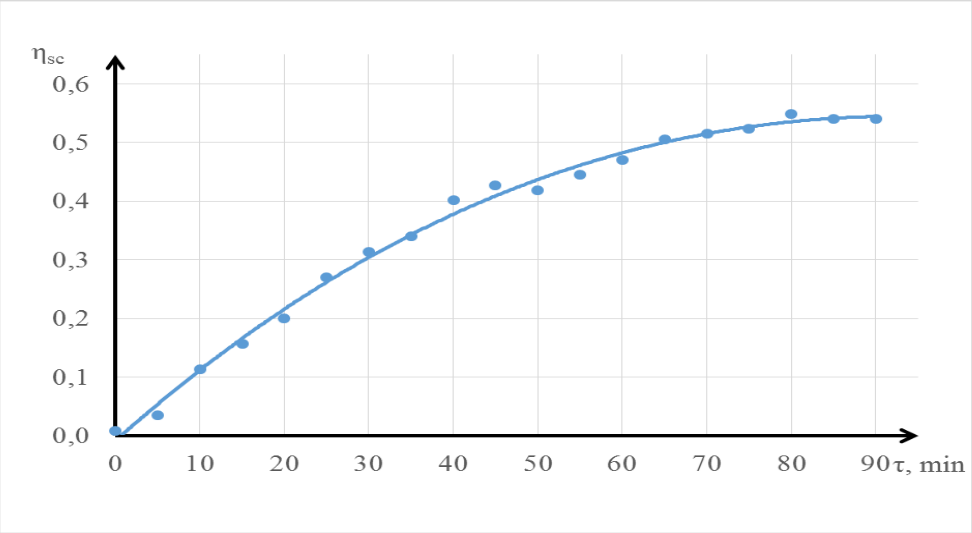

Fig .4) The change in the coefficient of efficiency of solar wall η_{rc} depending on the irradiation time τ, min

On the graph Fig (4.4) we observe an increase in the value of the coefficient of efficiency up to 80th minute (according to the specific instant heat capacity), which is 0.55, and further significant changes are not observed and

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it remains at the same level.

Based on the data of Fig (4.4) we got analytical dependence of the coefficient of efficiency of solar wall $\eta_{ск}$ of irradiation time τ.

$$\eta_{sc} = 1E\text{-}07(\tau/60)^3 - 9E\text{-}05(\tau/60)^2 + 0{,}0129(\tau/60) - 0{,}0089 \qquad (3)$$

Where:
η_{sc} – the coefficient of efficiency of solar collector; τ – the duration of the radiation on solar wall, s.

It is also advisable to analyze the effectiveness of this system of solar heat supply for the amount of energy that the storage tank got. And also in Fig (.5) we show the variation of the water temperature in the storage tank during the experiment.

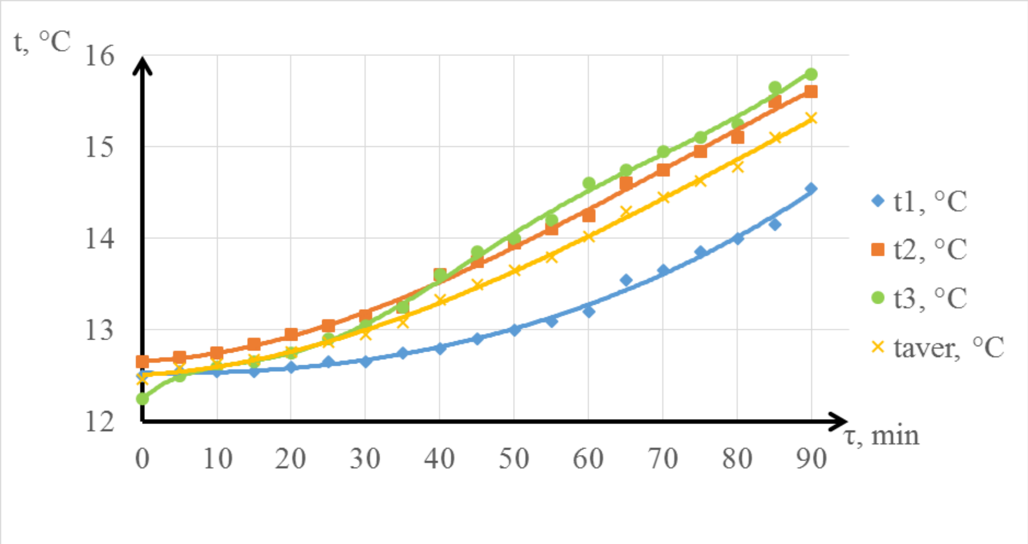

Fig (.5) The change of the water temperature in the storage tank

$t_{.1}$, $t_{.2}$, $t_{.3}$ – the water temperature along the height of the storage tank (see Fig (1)), °C

t_{aver}– the average water temperature in the storage tank, °C

On Fig (5) we see that the gradual heating of the water in the storage tank occurs throughout the experiment at all levels (tбак.1, tбак.2, tбак.3) and even on the interval from the 80th to the 90th minute, despite the fact that the specific heat capacity here did not grow (Fig 3)).

It is also important to analyze how much heat received by the system during the experiment, with average temperature in the storage tank with 1 m^2 of solar wall.

The thermal energy that was accumulated in the storage tank was determined by the equation:

$$Q_{st} = m \cdot c \cdot (t_{fin} - t_{init}), \qquad (4)$$

Where:
m – the mass of the coolant in the storage tank, kg; *c* – specific heat capacity of the coolant, J/(kg•K); t_{init}, t_{fin} – respectively the initial and final temperatures of the coolant in the storage tank, K.
On Fig (6) you can see the variable nature of the energy which is accumulated in the storage tank during the experiment. It should be noted that the average value of the received energy by the storage tank with 1 m^2 of solar wall was 49.7 kJ and ranged from 10 to 75 kJ.

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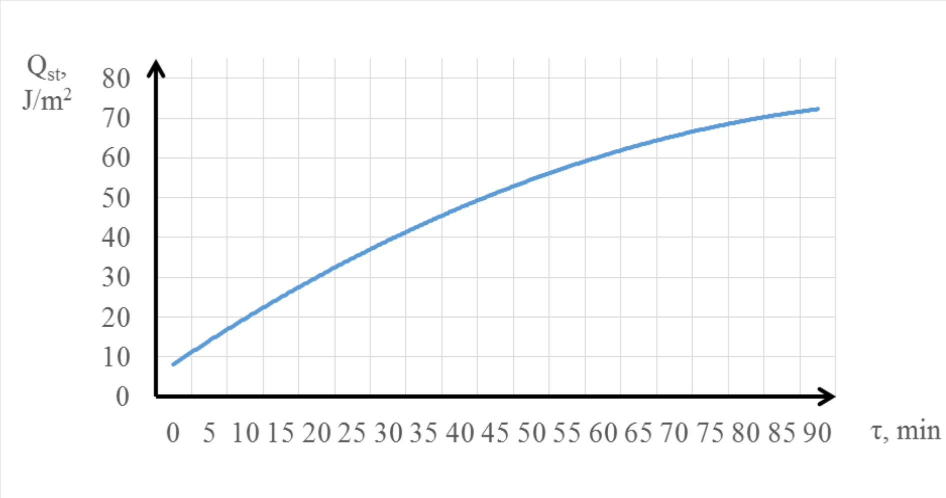

Fig (6) The amount of heat energy, that acumulated in the storage tank with 1 m^2 of solar wall every 5 minutes during the experiment

Whereas the received coefficient of efficiency of solar wall does not take into account heat loss through pipelines, storage tank and other factors, so it is advisable to analyze it for the quantity of heat that the storage tank has accumulated during the experiment.

$$Q_{ac} = c \cdot m \cdot (t_{aver.1} - t_{aver.2}), \quad (5)$$

Where:

c – specific heat capacity of the coolant, J/(kg•K); *m* – the mass of the coolant, kg; $t_{cp,1}$, $t_{cp,2}$ – the average temperatures of the coolant in the storage tank, K.

$$Q_{rad} = F_{sc} \cdot I \cdot \Delta\tau, \quad (6)$$

Where:

F_{sc}– the area of the heat absorber of the solar collector, m^2; *I* – the intensity of the radiation source to the surface of the heat absorber of the solar collector, W/m^2; $\Delta\tau$ – period of time, s.

The correlation of the accumulated heat by the storage tank and the amount of radiation energy that the surface of solar wall received is presented in Table 1.

Table 1. The amount of accumulated heat by the storage tank during the experiment

The irradiation time T, min	The amount of accumulated heat by the storage tank Q_{ac}, kJ/m^2	The amount of radiant energy received by solar wall Q_{rad}, kJ/m^2
10	52	180
20	94	360
30	152	540
40	272	720
50	372	900
60	487	1080
70	623	1260
80	727	1440
90	895	1620

We got based on the data of Table 1 dependence of the amount of heat received by the solar heat supply system on the basis of solar wall of irradiation time:

$$Q_{ccm} = -3E\text{-}14(\tau/60)^3 - 9E\text{-}13(\tau/60)^2 + 90(\tau/60) - 90, \quad (7)$$

Where:

Q_{ac} – the amount of heat that accumulated by the storage tank, kJ; τ – the irradiation time, min.

As during receiving radiation energy by the solar wall, heat losses occur in the environment,that's why it is useful to analyze how much heat has been accumulated in the storage tank during the experiment. The efficiency of solar energy systems, η_{ses} is defined similarly to the efficiency of the solar collector for the amount of energy obtained by the storage tank $Q_{отр}$:

$$\eta_{ses} = \frac{Q_{ac}}{Q_{rad}} 100\% , \tag{8}$$

Where:

Q_{ac} – the amount of heat that were received by the storage tank during the period of time $\Delta\tau$, s, was determined experimentally; Q_{rad} – the amount of radiant heat that were received by the surface of the heat absorber of the solar collector during the same period of time $\Delta\tau$, s.

In Fig (7) is shown the variable coefficient of efficiency of solar heat systems with solar wall during the experiment.

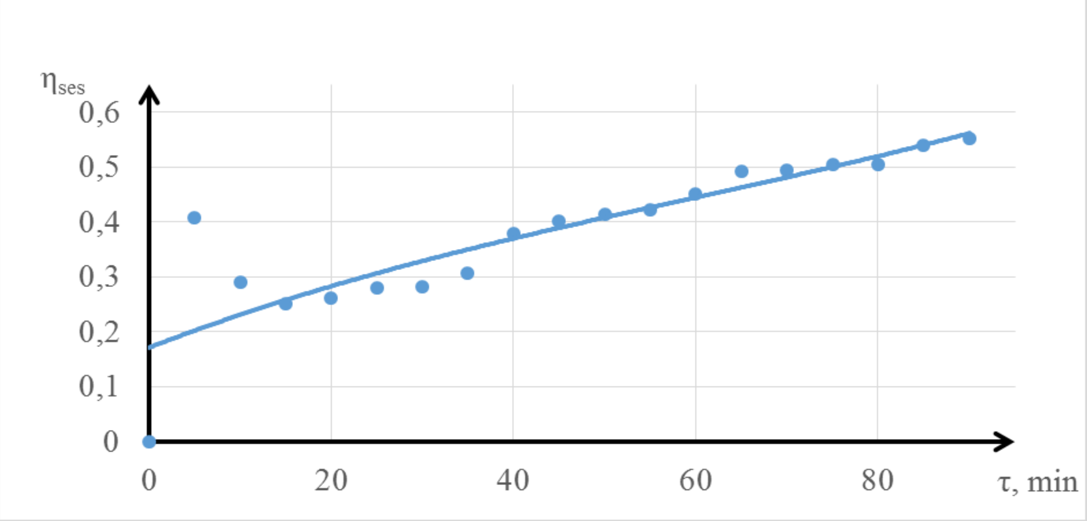

Fig (7) The change of the coefficient of efficiency of solar energy systems based on solar wall during the experiment

From the graph Fig (7), we can see that the coefficient of efficiency of solar heat systems with solar wall, from the beginning of irradiation to 20th minute is somewhat reduced from 0,41 to 0.25, and then sharply increase to 90th minute and is 0.55, then, is about on the same level.

V. CONCLUSION

The researches confirm the effectiveness of the use of solar wall in the solar heat supply systems. The analysis of research results shows that the average coefficient of efficiency of solar wall when the diameter of the tubes of the circulation d = 0,010 m, the distance between the tubes of the circulation is l = 0.01 m, the thickness of the plaster over the tubes of the circulation on the level 0.02 m, flow rate of the coolant in the circulation loop of 0.0125 kg/s per 1 m^2 of solar collector, and the intensity of the heat flow of 300 W/m^2 is 0.38, and the whole system is 0.4. The amount of heat that were received by the solar system during the experiment (90 minutes) with 1 m^2 of solar wall is 895 kJ, and the average specific instantaneous thermal power of the solar wall was equal to 112 W/m^2, that shows the prospects of using solar walls in the solar heat supply systems and the need for further research.

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