ISSN: 2350-0328

International Journal of AdvancedResearch in Science, Engineering and Technology

Vol. 10, Issue 8, August 2023

# Mathematical modeling of the heat accumulation system in a hot water collector using solar energy

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**ABSTRACT:** The article aims to solve the problem of researching the system of mathematical modeling of heat stratification in determining the mode of operation of a double-circuit flat solar water heater and useful recommendations. An experimental module was developed by sufficiently equipping the solar water heating collector with special devices. The main concept of the given problem is characterized by the optimization of the stratified heat accumulation mode in the device and the research of the parameters in the heat exchanger devices (coil in the tank). The process of heat accumulation and heat exchange was analyzed by comparing the results obtained with experimental devices and theoretical studies. A special mathematical model was created to model the thermal energy transferred to the stratified capacity. A system of mathematical equations has been developed to solve the heat storage and energy exchange system based on a computer program. Numerical and experimental studies were carried out to thoroughly test the process of double-circuit solar water heating and hot water collection, and the results were compared and analyzed.

**KEYWORDS**: solar energy, heat accumulator, coil, heat exchange, heat transfer coefficient, heat exchange efficiency coefficient.

## I.INTRODUCTION

In our republic, a wide range of effective studies have been conducted on the wide implementation of the system of hot water extraction devices using solar energy. The use of solar energy in various sectors of the national economy in all regions of our country, the duration of the sun's radiation is 2800-3200 hours per year, and the maximum power of radiation energy falling on each square meter of the surface, placed vertically in relation to the sun's rays, reaches 1 kW. During the year, the total amount of solar energy falling on the horizontal surface of 1m$^2$ is 5900-6300 MJ (or 1640-1750 kWh), which is equivalent to the thermal energy released when burning 200-215 kg of conventional fuel.

The annual technical energy of solar energy is equal to the amount of 290 million tons of conditional fuel, which is 4 times more than the total amount of primary energy resources used for domestic needs during this year [1].

A device consisting of a thermally stratified hot water storage capacity for the use of double-circuit solar energy was developed for use in the communal household sector. The water temperature in the upper part of the water storage capacity is higher than in the lower part due to hot water accumulation, and heated water is delivered to the consumer.

The hot water in the double-circuit solar water heating collector consists of the working fluid that enters the storage capacity, and the UWC of the device is determined by the difference in the temperatures of the solar collector and the supplied cold water from the bottom of the heat storage tank. It is most important to maintain thermal stratification in a device based on such a system [1]. The storage capacity of hot water requires the use of various mechanisms to prevent thermal stratification in the accumulator. The first mechanism is the effect of convective movement with forced flow through the hot water storage capacity. It is characterized by the formation of a moderate mixture in the process of heat accumulation under the influence of the flow of working fluid entering and leaving the battery capacity with hot water.

The second mechanism is that relatively cold water from the solar collector falls into the hot water in the upper layer of the water heat storage battery and a mixed water layer is formed. It depends on the days when the weather is cloudy and the current consumed by the collector circuit [2].

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## II. MATERIALS AND METHODS.

Effective use of the solar water heating collector in all months of the year and prevention of freezing of the working liquid for storage in the hot water accumulator are important issues.

A water heating device using solar energy was developed in a heat accumulator consisting of a water tank with a heat exchanger equipped with small twisted (coil) d=15 mm pipes (Fig. 1).

Studies show that the methods of efficient use of solar energy require the placement of twisted pipes in the water tank accumulator in two or three parts in order to improve thermal stratification. They are placed at different heights of the water tank accumulator. The water tank provides the temperature regime due to intensive heat exchange at the top of the accumulator, and the water tank transfers the heat from the heat accumulator to the working fluid. Temperature stratification depends on the liquid consumption from the solar collector [3,4]. The high consumption of water in the water heating collector using solar energy causes the temperature of the working fluid to rise, as a result of which the upper and lower water layers are not efficiently transferred from the water accumulator in the system to the consumer. Also, due to the small temperature difference between the fluid entering and leaving the solar collector, the cold convective flow increases in the upper part of the heat accumulator capacity, and the temperature in the upper water layer is also lower. On the other hand, when the liquid circulation consumption in the circuit of the solar water heating collector is small and the temperature difference between the inlet and outlet of the liquid is large, the hot water is at a high temperature and occurs in the upper layer of the water tank accumulator [5,6].

In order to heat water using solar energy and maintain a useful stratification process from the capacity of the heat accumulator, the characteristics of various types of constructions and the mode of operation in various meteorological conditions were carried out by conducting a large number of experiments and researches with a number of methods. For this, the capacity of the hot water tank accumulator and the parameters related to the characteristics of the heat exchanger in the accumulator consisting of twisted pipes (coil) placed in it and their condition, water consumption in the circuit of the solar water heating collector, the consumer to which hot water is transferred, etc. are determined. Experiments have been carried out to evaluate the efficiency level of the multi-layer hot water accumulator capacity in the process of circulating through the solar water heating collector in many models, laboratory devices. In many published studies, the amount of direct and scattered energy falling on the solar water heating collector, the studies on the reflection of light energy of the clear surface were analyzed, and the heat and mass exchange processes in the heat accumulator were studied separately in the heat exchanger consisting of twisted pipes [7,8 ].

Experimental research flat solar water heater collector device in the laboratory “Effective use of alternative energy sources in production” of Kashkadarya scientific-experimental station of academician M.Mirzayev scientific and technical institute of horticulture, viticulture and winemaking in the Republic.conducted in the modeled version of the battery water heating system. In order to make maximum and effective use of the direct and scattered radiation of sunlight, the angle of inclination and azimuth of the solar collector relative to the horizon; management of some working parameters (fluid consumption); All the most important parameters affecting the contour system of the heat exchanger consisting of twisted pipes (coil) placed in the capacity of the water tank with a heat accumulator in the collector designed to convert solar energy into heat energy were measured with the measuring instruments of the modern system and the obtained results were analyzed . The state of accumulation of water heated in the collector of the system consisting of a twisted pipe (coil) in the capacity of the water heat accumulator under the influence of solar energy is presented in Fig. 1.

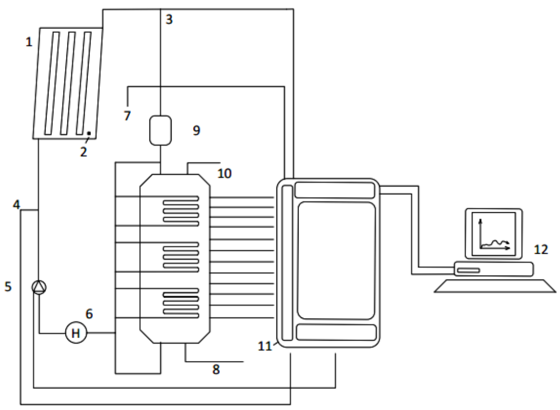


**Figure 1.The principle scheme of the experimental test device.**

1-flat water heating collector made of composite material; 2.a device that ensures the rotation of the flat water heating collector in relation to the sun's rays; 3-hot water transfer pipe; 4-flat solar collector cold water supply system; 5. A pump that controls the supply of cold water to the flat solar water heating collector; 6- H - a device for measuring water temperature and pressure in the layers of the heat accumulator winding (coil) pipe; 7- device for controlling the temperature change of water layers in the heat accumulator; 8- outgoing water; 9-expansion tank; 10-consumer transmission pipeline; 11-system for recording the connection between the temperatures of the solar water heating collector and the heat accumulator water layers; 12 - a computer providing recording of results.

The hot water storage device, which is transferred from the solar water heating collector to the water tank accumulator and stored in it, is made of stainless steel material in a cylindrical shape, with a length of 1.7 m and an inner diameter of 0.015 m., the volume of the tank is equal to 160 liters, and it is adapted for use in 3-room model houses. The first nozzle for water transfer is installed in the upper part of the tank. The second nozzle is located at the bottom of the water tank and is adapted to release cold water in the water supply line. The water tank and pipes attached to the house are insulated from heat. As a result, three copper pipes (coil) are placed according to the height of the water heat accumulator capacity. So, a system of one-, two- or three-screw pipes installed in different parts of the heat capacity of the water tank accumulator works. All observed parameters are recorded on the monitor using an automatic system. This system is equipped with a special electronic module, which records numerical signals through sensors for data obtained from similar changes, and converts the numerical data in the module and transmits it to the computer system and analyzes it. Long-term analyzes were carried out to prepare the system for economic efficiency and statistical calculation.

## III. RESULTS

The first mechanism of heat mass exchange uses hot water, hot water is spent on the upper sector of the heat accumulator tank. The volume of consumed hot water is compensated by cold water supplied from the lower sector. This water mixes with water in these sectors. A part of this water rises from the lower sector 1 and mixes with the next higher sector 2, and this process continues to the other upper sectors as well. The temperature change in the water tank accumulator, i.e., the process of temperature decrease in the sectors, can be calculated by the following expression [9]:

$$T_{i.n} = \left[(v_i - \Delta v)T_{i.n-1} + \Delta v T_{i-1,n-1}\right]/V_i \quad (1)$$

here, *i.n* – sector number and pitch; *V* – volume; *T* – water temperature; $\Delta v - n -$ the amount of water consumed from the thermal accumulator water tank in a time step.

The temperature of the water in the lower sector of the battery capacity of the water tank $T_{i-1,n-1}$for this is the temperature of the fresh water delivered$T_{i.n-1}$ – sequential transition occurs in the process of modeling. A graph describing the distribution of daily hot water and the amount delivered to the consumer has been developed. The second process in the heat accumulator of the water tank is that hot water (charge) is supplied to the water in the tank in which the elements are placed. The increase in water temperature depends on the temperature of the water coming out of the solar water heating collector and the consumption of the working fluid. Therefore, the process of determining the temperature rise had to be carried out repeatedly between steps per unit of time.

The energy balance by sectors leads to temperature changes, and the process is calculated by the following mathematical equation [9,10]:

$$T_{i.n} = T_{i.n} + \frac{K_{i.ser} \cdot F_{i.ser}}{\rho v_i c_p}(T_f - T_{i-1})\Delta\tau \quad (2)$$

here: $T_{i.n}$ – the heat consumption (discharge) in the heat accumulator, i - sector and n - the process after the heat consumption (discharge) in the heat accumulator is completed in a time unit step; $T_f$ – average liquid temperature and i - elements of twisted pipes (coil); $\Delta\tau$ –time interval step in the process of accumulating heat in the accumulator; $K_{i.ser} \cdot F_{i.ser}$ – heat transfer coefficient and heat exchange surface through elements of twisted pipes for the i -th sector; $\rho$ and $c_p$ – density and specific heat capacity of water in heat accumulator capacity.

Heat transfer coefficient $K_{i.ser}$ – It is determined by the convective heat transfer coefficient divided by two sides of the twisted pipe (coil). The heat from the outer surface of the spiral pipes is transferred to the water in the heat accumulator due to natural convection. Convective heat transfer coefficient $h_{fr}$, using the free arcuate layer, we get from the following equation [10].

$$h_{fr} = \frac{Nu_{fr}\lambda_s}{d_0}, \quad [w/m^2K] \quad (3)$$

here: $Nu_{fr}$ – Nusselt number; $\lambda_s$ -heat transfer coefficient of water in the hydro accumulator; $d_0$ – The outer diameter of the twisted pipes. To calculate the Nusselt number, we use the following criterion equation [11]:

$$Nu_{fr} = 0{,}394Gr^{0,2}Pr^{0,25} \quad (4)$$

here: $Pr$– Prandtl number; $Gr = \frac{\beta g d_0^3 (T_s - T_{asim})}{\nu^2}$ - Grashof number; β – coefficient of thermal expansion; $g$ – free fall acceleration; $T_s$ – the temperature of the wall of the system made of twisted pipes; $T_{asim}$ – the temperature of the water in the hydro accumulator; ν -coefficient of kinematic viscosity of the liquid.

The working fluid flowing through the spiral pipes placed in the heat accumulator capacity gives its heat to the wall of the spiral pipes under the influence of forced convection. In this case, the forced convection coefficient $(h_f)$ is expressed as follows [12].

$$h_f = \frac{Nu_f \lambda_s}{d_i}, \quad [w/m^2 k] \quad (5)$$

The Nusselt number is expressed as follows:

$$Nu_f = 2{,}1 \cdot 10^{-2} \cdot Re_f^{0,8} Pr^{0,43} (\frac{Pr_f}{Pr_s})^{0,25} \quad (6)$$

here: $Re_f$ – Reynolds number for the working fluid. The following expressions of this equation relate to the Pr-Prandtel number, and for the liquid temperature, the temperature at the wall of the twisted pipes is calculated. Convective heat transfer coefficients $h_f$ $and$ $h_{fr}$ of spiral pipe elements are added to the general heat transfer coefficient $K_{i.ser}$ for spiral pipe elements and calculated from the following equation for spiral pipe elements:

$$K_{i.ser} = \frac{1}{\frac{1}{h_f} + \frac{\delta_s}{\lambda_s} + \frac{1}{h_f r}}, \quad [w/m^2 k] \quad (7)$$

At the first stage, the outlet temperature and parameters of the working fluid coming out of the elements of the twisted pipes are determined:

$$T_{i.out} = T_{i.in} - \varepsilon(T_{i.in}) + T_{i.ac} \quad (8)$$

here: $\varepsilon$ – heat exchange efficiency coefficient for coiled pipe elements; $T_{i.in}$ – the temperature of the water entering the coil elements. The average value of liquid temperature in twisted pipes can be calculated as follows:

$$T_{av.i} = \frac{T_{i.in} + T_{i.out}}{2}. \quad (9)$$

It is used to determine the parameters of the working fluid and the temperature in the winding pipes. To calculate the Grashof number, it is necessary to know the temperature at the walls of the twisted pipes. This temperature depends on the coefficients $h_f$and $h_{fr}$, and is close to the temperature of the working body, and the coefficients $h_f > h_{fr}$ are required in this process. Effective results of theoretical studies show that intensive heat accumulation in the water tank heat accumulator is achieved depending on the maximum solar radiation falling on the solar water heating collector and the ambient temperature. To increase the accuracy of the results obtained for these processes, two-dimensional Nave-Stokes hydrodynamic model equation is used [13-17].

The results of the research on the improvement of the mathematical modeling system of the solar water heating collector are presented in many published articles. The temperature of the working fluid leaving the solar water heating collector can be determined using the following equation.

$$T_{sol.out} = \frac{F_R}{mc_p}[q_s(\tau \cdot \alpha)_e - U_2(T_{sol.in} - T_a)] \quad (10)$$

here: $F_R$ – surface of the solar collector; $m$ – working fluid mass consumption; $(\tau \cdot \alpha)_e$ – efficiency coefficient of the clear surface of the solar water heating collector; $T_a$ – ambient temperature.

The results of theoretical calculation and experimental research are presented in Fig. 2.

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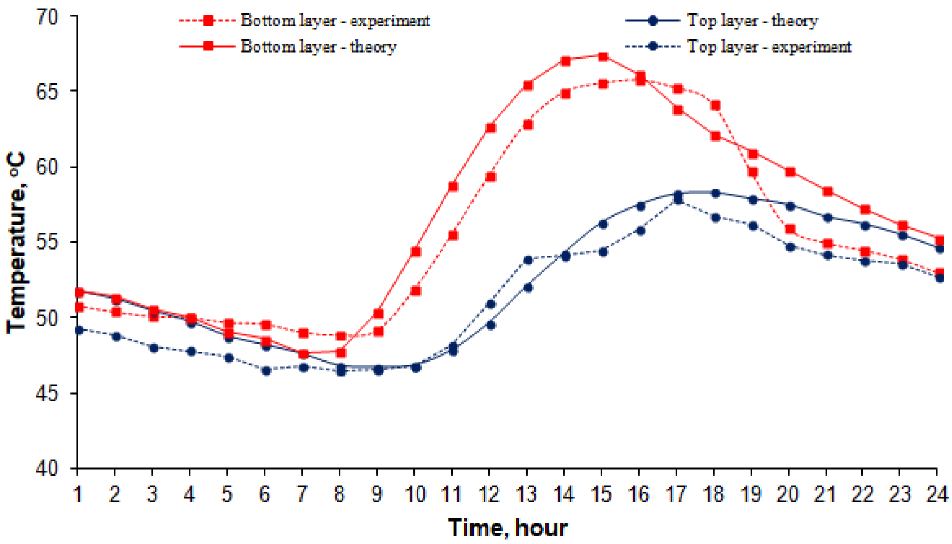


Figure 2. Graph of temperature changes in the upper and lower layers of the heat accumulator capacity of the water tank as a function of time.

## IV. CONCLUSION

The temperature of the water entering the solar water heating collector $T_{sol.in}$ was determined by the temperature of the working fluid coming out of the lower sector of the spiral pipes. The mathematical model helps to expand the field of research for the accumulation of hot water from the solar water heating collector, and useful recommendations were made on the parameters, modes, and construction efficiency of the device.

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