

Modeling the temperature regime of the heat accumulator

Inomjon Nematov^{1*}, *Botir Khairiddinov*¹ and *Shakhriyor Ergashev*¹

¹Karshi Engineering-Economics Institute, 225, Ave. Mustakilik, Karshi, 180100, Uzbekistan

Abstract: In the article, a mathematical model of the temperature regime (charge and discharge) is developed based on the balance equation of the water tank heat accumulator. In the development of the mathematical model, the results of the temperature regime are presented, taking into account different volumes of the water tank accumulator (40, 60, 80, and 120 m³) and other water consumptions (2, 4, 10, and 15 m³/h). When creating the balance equation, solar energy and thermal energy from the biogas boiler were taken into account, and the heat storage efficiency of the water tank accumulator was calculated.

1 Introduction

Low-temperature heat constitutes a significant share of the world's energy consumption. 50% of the total energy consumption is spent on heating homes (maintaining the temperature at 18±2°C) in the countries located in the northern middle latitudes. It is not necessary to use high-temperature energy sources for heating, it is advisable to use them for technological purposes. It is advisable to use solar energy and heat accumulators together with the heat waste of various heat-technological devices for heating. Accumulators that store heat from several days to three months are needed for maximum efficient use of solar energy for heating [1-10].

In order to increase the efficiency of the water tank heat accumulator, the shape and size of the device, the type and thickness of surrounding heat storage materials, and the development of criteria for the use of hot water supply from the biogas boiler during chronically cloudy and cold days of the atmosphere are one of the important issues.

The amount of accumulated heat can be used for the necessary purposes, especially in greenhouses, houses, heliopoultry rooms, fruit and grape dryers, and shower devices under the influence of hot air transmitted from the solar air heating collector to the flat wall water tank heat accumulator. A water tank battery was designed to use heat from an additional bioenergy plant, and a cross-section of the experimental plant is shown in Figure 1.

*Corresponding author: strong.shakhrier@mail.ru

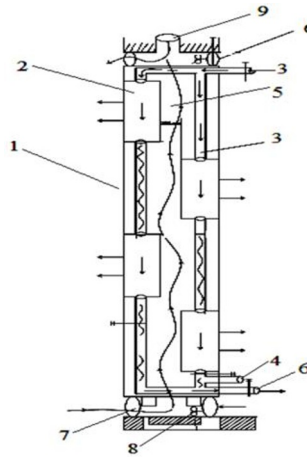


Fig. 1. Cross-section of the water tank accumulator experimental device. 1- flat wall with water tank heat accumulator set; 2- water tank heat accumulator; 3-hot water pipe from the biogas boiler; 4-tank accumulator water supply pipe; 5th runway; 6,8 fans; 7,9- inlet and outlet air collectors.

The air of the building where agricultural products are dried is ventilated through flat-walled water tank accumulators. The water heated in the biogas boiler device is transferred to the water tank accumulators through pipes and gives its heat to the accumulator. As a result, hot water from the biogas boiler is mixed with water in the heat accumulator, and an optimal temperature is created.

At the same time, water at $t_{h.ac.}$ temperature and $U_{h.ac.}$ consumption from the heat accumulator is transferred through a pipe to the biogas boiler or used for use in other household processes. Based on this system, the flow of hot water continues. Figure 2 shows the general working principle of a flat wall water tank heat accumulator.

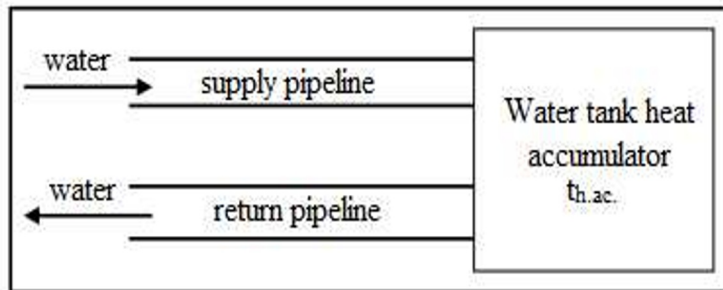


Fig. 2. Flow diagram of the heat carrier in the water tank heat accumulator.

2 Materials and methods

Based on the calculation scheme in Fig. 3, we make the heat balance of the water tank heat accumulator and solve the differential equation representing the temperature change over time using the Runge Kutta method, considering several boundary conditions. The amount of heat accumulated in the water inside the heat accumulator is stored as heated water or changes per unit of time. Thus depends on the amount of hot water transmitted through the pipe from the biogas boiler under the influence of solar energy [11-13].

The heat supplied to the water tank heat accumulator from solar energy and the biogas boiler unit consists of heat $Q_{h.ac.}^0$, heat energy transmitted from the heat accumulator to the air in the room where the fruit and grapes are dried, $Q_{h.ac.}$ and heat lost through the walls of the heat accumulator Q_{loss} .

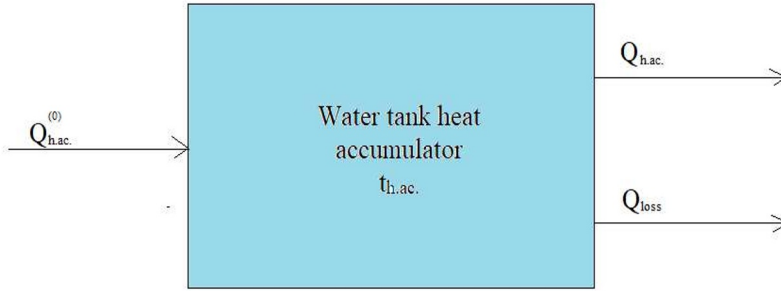


Fig. 3. Scheme of calculating the heat balance of the water tank heat accumulator.

3 Equations and mathematics

The heat balance of the water tank heat accumulator is expressed as follows:

$$\frac{d(V_{h.ac.} \cdot c_p t_{h.ac.})}{d\tau} = Q_{h.ac.}^0 - Q_{h.ac.} - Q_{loss} \quad (1)$$

Or

$$\frac{d(V_{h.ac.} \cdot c_p t_{h.ac.})}{d\tau} = v_{h.ac.} \cdot c_p t_{h.ac.}^o - v_{h.ac.} \cdot c_p t_{h.ac.} - K_{h.ac.} \cdot F_{h.ac.} (t_{h.ac.} - t_{in.}) \quad (2)$$

where $V_{h.ac.}$ and $t_{h.ac.}$ are the water tank heat accumulator volume (m^3) and temperature, $^{\circ}C$; c_p - volumetric heat capacity of water in the pressure process, $J / (m^3 \cdot ^{\circ}C)$; $v_{h.ac.}$ - hot water consumption from the biogas boiler, m^3/h ; $t_{h.ac.}^o$ - water tank temperature of hot water supplied to the heat accumulator from the biogas boiler, $^{\circ}C$; $K_{h.ac.}$ - heat transfer coefficient from the water tank heat accumulator to the fruit drying room $W / (m^2 \cdot ^{\circ}C)$; $F_{h.ac.}$ - water tank heat accumulator wall surface, m^2 ; $t_{in.}$ - the temperature of the fruit drying room, $^{\circ}C$.

Integrating equation (2), we write the expression that takes into account the change of the temperature of the water in the heat accumulator of the water tank over time based on boundary condition $\tau = 0, t_{h.ac.} = t_{in.}$ as follows.

$$t_{h.ac.} = \frac{\left[t_{in.} + \frac{v_{h.ac.} c_p t_{h.ac.}^0 + K_{h.ac.} F_{h.ac.} t_{in.}}{v_{h.ac.} c_p + K_{h.ac.} F_{h.ac.}} \times \left(\exp\left(\frac{v_{h.ac.} c_p + K_{h.ac.} F_{h.ac.}}{V_{h.ac.} c_p} \tau \right) - 1 \right) \right]}{\exp\left(\frac{v_{h.ac.} c_p + K_{h.ac.} F_{h.ac.}}{V_{h.ac.} c_p} \tau \right)} \quad (3)$$

The water tank heat accumulator works in three modes: accumulating heat (charging), spending heat (discharging), and storing heat in the volume of the heat accumulator. It is necessary to accept certain permitted conditions to show the status of heat storage and consumption mode in the heat accumulator and to perform calculations. In particular, the heat accumulator has very good heat storage properties. The average value of the temperature of the water or air heater in the mode of transmission through pipes from the helio collector is taken, and the temperature of the hot water transmitted from the bioenergetic boiler device is taken as unchanging and constant per unit of time.

4 Results and discussions

1. In the heat accumulator, the mode of collecting (charging) the heat transferred from the solar energy and bioenergy boiler device in water: The heat stored in the heat accumulator is assumed to be $Q_{h.ac.}^o > Q_{h.ac.}$, $t_{h.ac.}^0 > t_{h.ac.}$ under ideal conditions. In this case, the temperature of the water in the water tank heat accumulator rises. Using the expression (3), it can be seen that the heat varies depending on the temperature of the water in the

accumulator, parameters $V_{h.ac.}$ and $v_{h.ac.}$.

The graph in Fig. 4 shows the time-dependent change in the temperature of water in the heat accumulator. Initially, the temperature of the water in the heat accumulator is 20 °C, and the temperature of the water in the water tank with a volume of 60 m^3 rises to 95 °C for 2 days under the influence of solar energy, and the heated water transmitted from the biogas boiler device (Fig. 4a, (1) curve).

If the volume of water in the tank is 120 m^3 , heating will continue for 4 days (Fig. 4a, 4 curves). But when hot water consumption is 2,4,10, and 15 m^3/h and the initial temperature of the water in the tank is 20 °C, the more the hot water consumption increases, the more time it takes to change the water temperature in the tank decreases (Figure 4b).

If the volume of water in the tank is 120 m^3 , heating will continue for 4 days (Fig. 4a, 4 curves). But when hot water consumption is 2, 4, 10, and 15 $m^3/hour$ and the initial temperature of water in the tank is 20 °C, the more hot water consumption $v_{h.ac.}$ increases, the time it takes for the water temperature to change in the tank decreases (Figure 4 b).

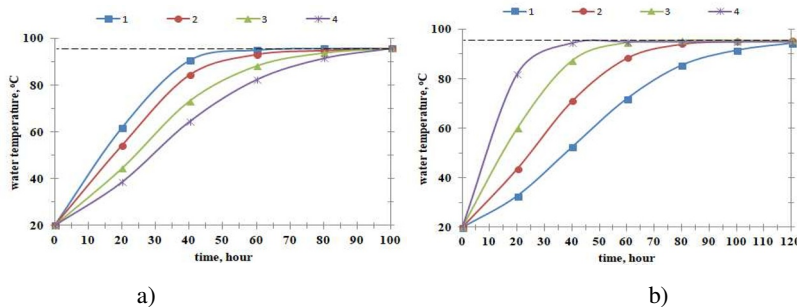


Figure 4. Time graph of the water temperature in the water tank heat accumulator.

The time variation of the temperature of the water tank accumulator when the volume of water in the water tank accumulator is $V_{h.ac.} = 40, 60, 80, 120 \text{ m}^3$ shown in curves 1-4 in Fig. 4a, and the variation of the temperature of the water tank accumulator in time when the hot water consumption is $v_{h.ac.} = 2, 4, 10, 15 \text{ m}^3 / \text{h}$ and temperature $t_{h.ac.}^0 = 95^\circ \text{C}$ shown in curves 1-4 in Fig. 4b expressed.

2. Discharge (discharge) mode of accumulated heat in the water tank heat accumulator:

The following condition $Q_{h.ac.}^o < Q_{h.ac.}$, $t_{h.ac.}^0 < t_{h.ac.}$ is taken into account. The heat storage tank is characterized by the difference in the dynamics of parameters depending on the size of the heat accumulator, and the amount spent on the consumer. The results of the theoretical studies is illustrated in Fig. 5a.

When the initial temperature of the water is $t_{h.ac.} = 95^\circ \text{C}$ constant, and the consumption of water transferred from the heat accumulator to the consumer through pipes per unit of time is $v_{h.ac.} = 2 \text{ m}^3 / \text{h}$, the temperature of the water consumed per unit of time from the heat accumulator decreases to 35°C , and in this process, the heat accumulator volume is equal to 40 m^3 for 2 days, when it is equal to 60 m^3 , 2, 5 days, 3.5 days for 80 m^3 , 4 days for 120 m^3 .

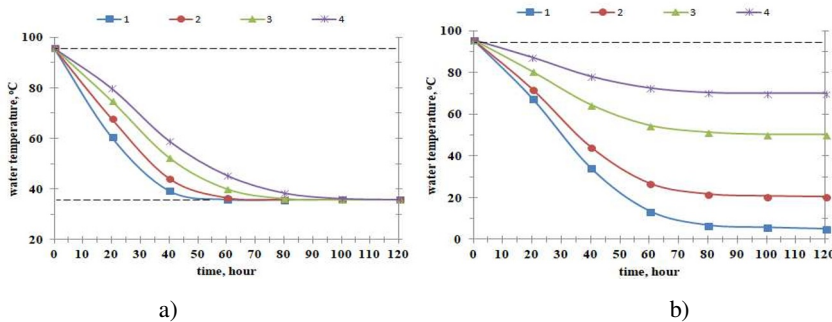


Fig. 5. Variation of water temperature over time in the mode of spending (discharging) the accumulated heat in the water tank heat accumulator

In Fig. 5a, when the consumption of the heat carrier in the pipe of the heat accumulator is $v_{h.ac.} = 2 \text{ m}^3 / \text{h}$, and the temperature is $t_{h.ac.}^0 = 35^\circ \text{C}$, curves 1-4 represent the time change of the temperatures of the water tank accumulator of size $V_{h.ac.} = 40, 60, 80, 120 \text{ m}^3$, respectively; in Figure 5b, curves 1-4 represent the time variation of the temperature of the heat accumulator with a volume of 120 m^3 , when the consumption of the heat carrier in the pipe is $v_{h.ac.} = 2 \text{ m}^3 / \text{h}$, and the temperature of the heat carrier is $t_{h.ac.}^0 = 5, 20, 50, 70^\circ \text{C}$, respectively.

From the heat accumulated in the heat accumulator, the internal air temperature ($t_{in.}$) in the room intended for drying agricultural products is maintained in the state required by the regulation during the day, and the efficiency criterion is evaluated. In this case, the heat balance equation of the water tank heat accumulator is expressed as follows [11-18]:

$$\frac{d(V_{h.ac.} c_p t_{h.ac.})}{d\tau} = -K_{h.ac.} F_{h.ac.} (t_{h.ac.} - t_{in.}) \quad (4)$$

Here, the change in water temperature in the water tank heat accumulator is explained as follows, similar to the formula (3):

$$t_{h.ac.} = t_{in.} + \exp\left(\frac{K_{h.ac.} F_{h.ac.}}{V_{h.ac.} c_p} \tau\right) \times (t_{h.ac.(0)} - t_{in.(0)}) \quad (5)$$

The decrease in the temperature of hot water in the heat accumulator depends on the heat transfer coefficient $K_{h.ac.}$ between the accumulator and the indoor air of the building.

To ensure the uninterrupted operation of the solar water heating device throughout the day, the establishment of a heat accumulator and the system using different bioenergy will ensure the production of hot water in the system. But as a result of the difference between the hot water temperature and the ambient temperature in the device with hot water accumulation, the thermal efficiency of the device decreases due to the occurrence of a certain amount of heat consumption [18-22].

Several scientific studies have also been conducted on the development of the optimally combined construction of a flat two-circuit water heating device and its heat accumulator using solar and bioenergy in business farms [14,15,16]. To solve this problem, a hot water storage battery device with a flat double contour and a volume of 120 m³ surrounded by a local heat-retaining material (a coating made of reed cuttings with a thickness of 0.1 m) was prepared and tested at the subsidiary of “Muborakneftgaz” LLC (limited liability company) [16]. On January 24, 2017, on sunny days, when the outside temperature is -5-7 °C, the results of a scientific study on the temperature change of the hot water storage tank using solar and bioenergy are presented in Figure 6.

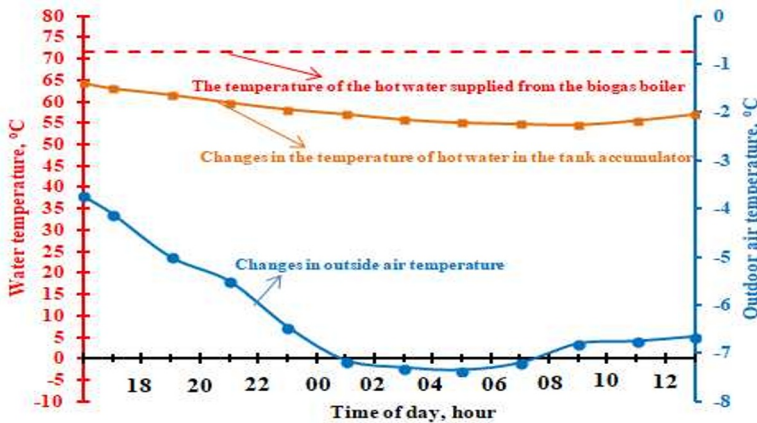


Fig. 6. Results of a pilot study conducted on a solar and bioenergy-heated water tank battery pilot plant.

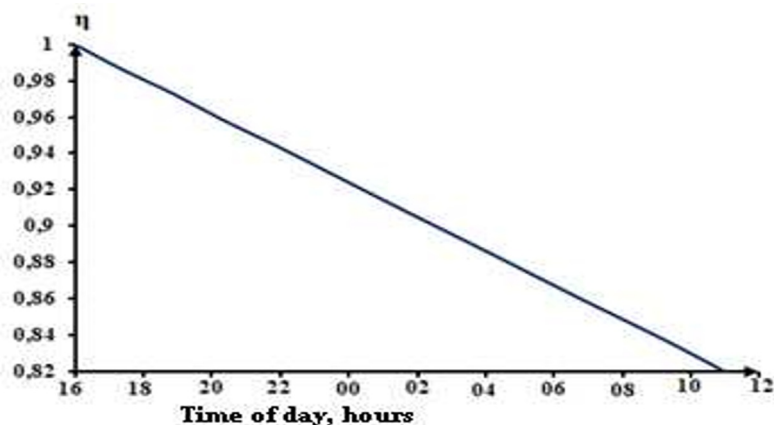


Fig. 7. Variation of the heat storage efficiency of the water tank heat accumulator by time of day.

The analysis of the obtained results shows that the temperature of hot water in the hot water storage tank-accumulator drops to 54.7 °C for 20 hours until 900 in the morning of the next day, which reduces the heat storage efficiency of the tank-accumulator by 19.5%. In this case, as soon as the automatic control device is activated, this situation is eliminated due to the hot water supplied from the biogas boiler. It was found that the results obtained from the numerical calculation of the efficiency of hot water storage of the investigated device in the auxiliary farm of “Muborakneftgaz” LLC - tested two-circuit flat solar water heating collector - hot water storage tank - accumulator with local heat preservation coating is in good agreement with the data obtained from the experiment. The heat storage efficiency of the water tank heat accumulator was calculated and the calculation results are presented in Figure 7.

5 Conclusions

In the water tank accumulator for hot water storage, the temperature of hot water during the day is 60 °C, and taking into account the decrease of 52 °C in the next 6 hours of the day, the automatic control device adds hot water with a temperature of 70 °C to the heat carrier supplied to the biogas boiler. The conducted studies show that on cloudy and cold days of the winter season, the thermal efficiency of the device increases to 50-56% because the hot water transferred from the biogas boiler device is stored in the tank-accumulator and sent for consumption.

Using the mathematical modeling system of the water tank heat accumulator, the process of its operation in different modes was modeled.

The mathematical model used in practice can predict the water temperature change in the water tank heat accumulator and relate to the energy obtained from additional heat sources.

In the course of further research for water tank accumulators from the proposed thermal accumulator model, it will be possible to create modes of drying of products such as fruit and grapes in dryers during the day and to improve the efficiency criteria of devices in heating greenhouses in communal, technological and agricultural systems.

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