Increasing energy efficiency combined device solar dryer-water heater with heat accumulator

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Abstract. In the article, the authors proposed a combined device of a solar dryer-water heater with a heat accumulator (CDSDWHHA) for drying agricultural products using solar energy. As a research object - a connected device of a solar dryer-water heater with a heat accumulator, a drying drum installation, and an additional combined solar water-air heating collector for simultaneous heating of water and air was installed. Drying agricultural products is a technological process that requires a large consumption of thermal energy and fuel-energy resources. The results of the conducted analysis showed that electric heating devices are often used to operate such a system, which are always expensive and not economically acceptable. In this paper, in order to reduce the traditional energy consumption for drying agricultural products, a combined device of solar dryer-water heater with heat accumulator is proposed and experiments were conducted in the meteorological climate of Karshi city. As a result of experimental studies shows the heat load compensation and energy efficiency of the solar water-air heating collector drying device with a heat accumulator in the “water + air” heating mode. The installation efficiency was found to be in the range of 0.66 - 0.72.

1 Introduction

Currently, in the Republic of Uzbekistan, energy saving and saving of traditional energy resources, production of new modern energy-saving technologies, and in the heat and hot water supply systems of various structures, households, and social facilities in the Republic of Uzbekistan great attention being paid to the issues of introduction to economic sectors and social sphere sectors. The use of renewable and alternative energy sources is rapidly developing in economic sectors and social sector sectors, autonomous energy supply systems [1,2].

The rational use of fuel and energy resources, especially natural energy reserves, is one of the global problems, and its successful solution will be crucial not only for the further development of the world community but also for our country, as well as for the preservation of its living environment. Undoubtedly, one of the promising ways to solve this problem is the use of new energy-saving energy devices using renewable and alternative energy sources and secondary energy resources. The depletion of traditional

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natural fossil fuel reserves and the environmental consequences of burning them has led to a significant increase in interest in these technologies in recent years in almost all developed countries [3-6].

Increasing the efficiency of using energy resources and introducing energy-saving technologies that ensure the preservation of the energy independence of the country and its export potential is the main priority in the development of the economy-sociality of Uzbekistan. The government of our state has set the tasks of uninterrupted power supply to industrial facilities, transport, and rural settlements, the implementation of measures to accelerate the development of industrial production and construction in the countryside, the creation of compact enterprises for the cultivation, storage, and processing of agricultural products, equipped with modern equipment and technologies [7-10].

World experience shows that the use of renewable and alternative energy sources can strengthen the country's energy security, reduce energy consumption at the expense of the gross domestic product, preserve the country’s natural energy resources, maintain environmental stability, develop the lifestyle of the population, prevent environmental disasters and climate change. takes, at the same time helps reduce greenhouse gases, etc. [11-12].

In recent years, the use of renewable and alternative energy sources in the world, primarily solar energy with high potential, in heat and hot water supply systems has increased significantly. It envisages a high level of expansion of the use of solar energy potential in the national energy programs of all developed countries. The main reason for this is to increase energy security, accelerate the process of decarbonization, digitization, reduce the energy capacity of the gross domestic product, and prevent environmental disasters, climate warming, and the increase of greenhouse gases caused by the large-scale use of natural hydrocarbon fuels [13-14].

According to the measured data, the density of solar radiation in the conditions of Karshi on clear noon reaches up to 1 kW/m^2, and on average per year (taking into account nights and cloudy days) is about 200-250 W/m^2, which nevertheless corresponds to the annual income per 1 m^2 of the earth’s surface of energy equivalent to 150÷250 kg of standard fuel (1 kg of standard fuel = 7000 kcal or 29310 kJ of heat).

2 Materials and methods

Combined device of a solar dryer-water heater with a heat accumulator (CDSDWHHA) consists of a drum dryer with a loading chamber, an electric motor, mounted on roller supports moving with a reducer, mesh racks and fixed vane mixers are placed inside, with a direct louver and fan, and an air duct with an electric heater installed. connected, transparent glass heat storage solar water-air heating collector fixed on the support, consisting of air channel, water pipe and expansion tank at the top, water pipe connected to the cleaning tank through a valve, receiving hopper drum dryer for collecting dried fruits and vegetables installed at the bottom. In order to increase the resource efficiency of the device, a solar photovoltaic battery is installed on the back of the device.

It is to create a combined device of a solar dryer-water heater with a heat accumulator for high-quality drying of agricultural products and fruits and vegetables, to increase its energy efficiency and resource saving.

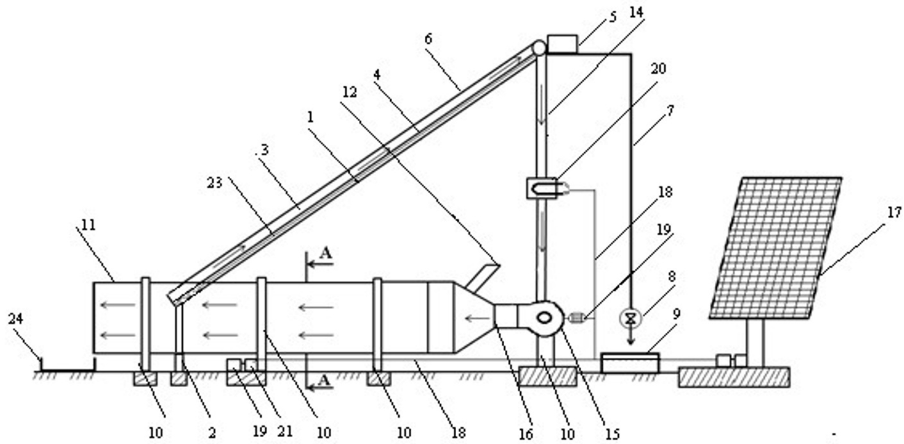

Figure 1. Combined device of a solar dryer-water heater with a heat accumulator.

The combined heat accumulator helio dryer-water heater device is composed of the heat accumulator solar water-air heating collector (1), base (2), air channel (3), water pipe (4), expansion tank (5), transparent glass. (6), hot water pipe (7), valve (8), cleaning tank (9), roller support (10), drum dryer (11), loading chamber (12), mesh racks (13), air pipe (14), fan (15), hatch (16), solar photovoltaic battery (17), cable (18), electric motor (19), electric heater (20), reducer (21), fixed wing mixers (22), oil heat accumulator (23) receiving hopper (24).

Figure 2. Combined device of a solar dryer-water heater with a heat accumulator.

Combined device of a solar dryer-water heater with a heat accumulator is composed of heat storage solar water-air heating collector, support, air channel, water pipe, expansion tank, transparent glass, hot water pipe, valve, cleaning tank, roller support, drum dryer. A comparative analysis of the proposed device with existing prototypes of the technical solution in the countries of the world revealed the following specific features:

- Unlike the prototype, in order to increase the energy efficiency of the combined device of a solar dryer-water heater with a heat accumulator, the device is equipped with a heat accumulator solar water-air heating collector and is placed parallel to the drum dryer, simultaneously accumulating heat and heating water and air at a high temperature.

- Combined device of a solar dryer-water heater with a heat accumulator is additionally equipped with a solar photovoltaic battery and is installed on the back of the device, increasing the resource efficiency of the device.

This allows us to conclude that the claimed device meets the “novelty” criterion.

The proposed solution is explained with drawings. Also, figures 1 and 2 show drawings of a combined device of a solar dryer-water heater with a heat accumulator.

The technical result is achieved through:

Combined heat accumulator helio dryer-water heater device works in the following order.

A solar water-air heating collector (1) with a heat accumulator is mounted on a support (2), and air enters from the inlet of the air channel (3). Water moves through the expansion tank (5) at natural pressure along the water pipe (4). Sunlight passes through the transparent window (6) and heats the air and water in the temperature range of 10℃ to 25℃ to 65℃ to 85℃ moving along the air channel (3) and water pipe (4). Heated water and air move upward due to natural convection. Water heated from 65℃ to 85℃ is poured into the cleaning tank (9) through the hot water pipe (7) using the valve (8). In the cleaning tank (9), the fruits and vegetables are pre-washed and cleaned before drying and are placed on mesh racks (13) through the loading chamber (12) of the drum dryer (11) mounted on roller supports (10) for drying. The heat required for high-quality drying of fruits and vegetables is the air heated from 65℃ to 85℃ from the temperature range of 10℃ to 25℃ moving in the solar water-air heating collector (1) with heat accumulator, passing through the air pipe (14) and fan (15) and the air consumption is adjusted with the damper (16). In order to increase the resource efficiency of the combined heat storage helio dryer-water heater device, a solar photovoltaic battery (17) is installed on the back of the device.) to ensure its operation, the built-in electric motor (19) provides continuous electricity. In order to keep the air temperature stable in cloudy and dark time, an electric heater (20) is installed in the air pipe (14) and it heats the air from 65℃ to 85℃ through the cable (18) due to the electricity produced in the solar photoelectric battery (17). and ensures process continuity. The fruits and vegetables placed on the mesh racks (13) dry well under the influence of hot air transferred to the drum dryer (11) by means of a fan (15). The electric motor (19) is connected to the cable (18) and rotates the drum dryer (11) on the basis of the reducer (21) attached to the drum dryer (11) every half an hour. As a result, fixed vane agitators (22) attached to the drum dryer (11) mix the fruits and vegetables. In order to increase the efficiency of the solar water-air heating collector with heat storage, an oil heat accumulator (23) is installed in the lower part of the solar water-air heating collector (1), and because the heat capacity of oil is higher than the heat capacity of air, it accumulates heat and becomes an additional source of energy. serves as a result of increasing the efficiency of the device.

Depending on the type of fruits and vegetables, the drying process takes one or two days. After the drying process is finished, the dried fruits and vegetables are dropped into the receiving hopper (24) and the process is continued.

The geometric and technical parameters of the CDSDWHHA are shown in table 1.

Table 1. Design parameters of the experimental setup.

Named installation items	Technical parameters
Drum diameters	d=1 *m*
Drum length	L=5*m*
Drum speed	n=10-11 *rpm*
Paddle nozzles in the drum	Number - 6 pieces, width 0.2 *m*
Drum residence time	7-9 *min*
Drum drive	Electric motor N= 2.2 *kW*,
Radial fan	Ts4-50 No. 5; N = 0-75 kW, n = 930 *rpm*

3 Results

The installation operates in two modes:

- Fuel-solar mode - in the presence of insolation, a mode with the use of solar radiation energy.
- Fuel mode - in the absence of insolation, traditional mode.

Drum dryers are heat exchangers operating according to the scheme of a direct flow of heat carrier and drying material, in which the through circulation of the drying agent through the all-fluid layer of the material is carried out with its active mixing. Cocurrent flow is more favorable for drying thermolabile materials than counterflow, since at high temperatures of the drying agent with intensive evaporation of surface moisture, the drying agent is quickly cooled and thus overheating of the material is not allowed [10-15].

The heat balance of the drying process can be represented as follows:

In fuel mode:

$$Q_b = Q_{h.m.} + Q_{h.l.} + Q_{h.o.} \tag{1}$$

In fuel-solar mode,

$$Q_b = Q_{h.m.} + Q_{h.l.} + Q_{h.o.} + Q_{\mathrm{CSWAC}} \tag{2}$$

Here, $Q_b, Q_{h.o.}$ the heat absorbed into the drum and leaving the drum with the drying agent, W, $Q_{h.m.}$ is the heat transferred by the drying agent to heat the material, W; $Q_{h.l.}$ - $Q_{h.l.}$ - heat loss in the drum, W ; Q_{CSWAC} - heat, to the combined solar water-air collector, W.

Heat absorbed into the drum with drying agent:

$$Q_b = G_m \cdot C_p \left(t_{d.a.t.} - t_{en.t.} \right) \cdot \tau, W \tag{3}$$

Where, G_m -mass flow rate of the drying agent entering the drum, kg/s; C_p - specific heat of the drying agent entering the drum, DJ / kgK; $t_{d.a.t.}$ - temperature of the drying agent entering the drum, ºC. $t_{en.t.}$ – outside air temperature, ºC; τ -time, sec.

The heat leaving the drum with the drying agent [16],

$$Q_{h.o.} = G_{h.o.} \cdot C_p \left(t_{h.o..} - t_{en.t.} \right) \cdot \tau, W \tag{4}$$

The heat transferred by the drying agent to heat the material,

$$Q_{h.m.} = Q_{d.m.} - Q_{d.d.m.} \tag{5}$$

The heat introduced by the drying material into the drum,

$$Q_{d.m.} = G_{d.m.} \cdot C_p \cdot t_{d.m.} \cdot \tau, W \tag{6}$$

$G_{d.m.}$ -mass consumption of drying material entering the drum, kg/s; C_p -specific heat of the drying material entering the drum, DJ/kgK ; $t_{d.m.}$ - temperature of the drying agent entering the drum, ºC.

The heat carried away from the drum by the drying material [17],

$$Q_{d.d.m.}=G_{d.d.m.}\cdot C_p\cdot t_{d.d.m.}\cdot\tau, W \quad (7)$$

Heat loss through the cylindrical side surface of the drum from equation (1),

$$Q_{h.l.}=K\left(t_{d.m.}-t_{en.t.}\right)S_b\cdot\tau, W; S_b=\pi d_d L_b \quad (8)$$

K - heat transfer coefficient through the drum wall, W / m ^{2} K ; $t_{d.m.}$ - average mass temperature of the drying agent, drying agent in the drum, ºC; S_b - side surface of the drum, m ^{2}, d_d, L_b - diameter and length of the drum, m .

Heat introduced by combined solar water-air collectors.

For water:

$$Q_{CSWAC}=G_w\cdot C_{pw}\left(t_2-t_1\right)\cdot 10^3, W \quad (9)$$

For air:

$$Q_{CSWAC}=G_{air}\cdot\rho_{air}C_{pair}\left(t_2-t_1\right)\cdot 10^3, W \quad (10)$$

Where, G_w , G_{air} - mass flow rate of water and air, kg/sek and m^3/s; $c_{рв}$ C_{pw} - is the specific heat capacity of water, $C_{pw}=4,19\,kDj/kg^{\circ}C$ $c_{рв}=4{,}19$ кДж/(кг·°С); t_1,t_2,– temperature of water and air at the inlet and outlet of CSWAC, ºC; $c_{рвоз}$ C_{pair} is the heat capacity of air, equal to $C_{pair}=1,07\,kDj/kg^{\circ}C$ $c_{рвоз}=1{,}07$ кДж/(кг·°С); $\rho_{воз}$ ρ_{air} - air density, kg/m^3.

Annual amount of total SR in the natural climate of Karshi city is $4350\div5500\,MDj/m^2$ $4320-5000$ МДж/м^2. The analysis of the climate characteristics data of the local area shows that the radiation and TBP of Karshi city allow efficient use of solar collectors for drum dryers with CSWAC.

Experiments were carried out during the next season of operation of the drum dryer with CSWAC. As a result of experimental data processing, the main thermal characteristics of CSWAC were determined (table 2).

Table 2. Results of an experimental study of CSWAC in the water + air heating mode (August, 2022).

Local time	Outlet water temperature t_1	outlet air temperature, t_2 ºC	The heat received by the water $Q_{кол}$	Heat received by the air $Q_{кол}$	The heat received by the collector $Q_{кол}$	The intensity of the total SR flow to the collector area, $Q_р$	CSWAC efficiency, η

	t_1, °C		Q_{CSWAC}, Вт W	Q_{CSWAC}, Вт W	Q_{CSWAC}, Вт W	Q_{rad}, Вт W	η
9:00	26	23	126	44	170	97 2	0.17
10:00	35	28	315	116	431	115 5	0.37
11:00	39	37	399	248	647	120 8	0.53
12:00	43	39	483	277	760	135 2	0.72
13:00	46	43	546	336	882	1420	0.62
14:00	47	44	567	350	917	1468	0.62
15:00	49	45	609	365	974	145 5	0.66
16:00	42	39	462	277	739	14 12	0.52
17:00	35	33	315	190	505	135 6	0.37
18:00	29	28	399	116	425	110 4	0.38

4 Conclusions

Based on the research results, the following conclusions can be drawn:

It was found that in the developed CSWAC, in the “water + air” heating mode, the temperature of heat carriers at the outlet reaches 43...45 ºC (air) and 43...49 ºC (water), respectively. With CSWAC, it is acceptable for a drum dryer.

Experimental studies have shown the excess efficiency of CSWAC in the “water + air” heating mode compared to similar water and air collectors. The average daily efficiency of the developed CSWAC in the “water + air” heating mode is $\bar{\eta}^{\text{КСК}}_{\text{ср}} = 0{,}57$ η=72%.

Experimental results show that an increase in air flow from 0.05 m^3/sec to 0.1 m^2 doubles the average daily energy efficiency.

The developed combined system meets the requirements and has sufficiently high energy efficiency.

It was determined based on the experimental results that the heat energy required for drying fruits and vegetables in a drying device can be covered by CSWAC and a solar photoelectric plant.

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