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The efficiency of using flat solar air collectors in a pyrolysis bioenergy device

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ABSTRACT: Nowadays, various methods of utilizing alternative energy sources are widely spread, and one of the most common methods is the use of solar energy. Two types of energy can be obtained from the sun: heat and electricity. Utilizing solar thermal energy for a drying chamber is quite efficient and economically cost-effective. In a low-power pyrolysis device, a drying chamber was used to standardize the moisture content of the selected raw material to the required level. The use of a flat solar air collector (FSAC) was proposed to heat the air supplied to the drying chamber, and this article presents the types of collectors, the technological scheme of the FSAC, and calculations of its main parameters.

I. INTRODUCTION

The use of solar collectors primarily involves converting solar energy into thermal energy, thereby reducing the need for electrical energy. Solar energy is an environmentally clean and renewable energy source, and its utilization minimizes additional costs. Therefore, the use of solar collectors is both ecologically and economically efficient. Collectors are an integral part of solar thermal devices. Solar collectors are a type of solar panel that helps capture solar radiation and convert it into thermal energy. The history of solar collectors dates back to the late 18th century and continues to be improved to this day [1].

In drying chambers, high temperatures are usually required to dry products. By using solar collectors in drying chambers, the air flow can be quickly heated, enabling efficient drying of products. At the same time, the temperature and humidity of the air can be controlled through specialized technologies and processes. The use of solar collectors in drying chambers, especially for drying food or agricultural products, helps achieve high-quality results. This method allows products to dry naturally, preserving their quality. [2].

II. MATERIALS AND METHODS

Nowadays, the following types of solar collectors are most commonly used to convert solar energy into thermal energy:

- Air solar collectors
- Flat solar collectors
- Vacuum solar collectors

One of the simplest forms of solar collectors is the air collector (Figure 2.1). The inner part of the collector is usually made of black material because black color absorbs sunlight well. Air collectors are primarily used to heat air and are utilized in building heating or ventilation systems, where the heat obtained from solar radiation is transferred through the air. Air collectors are cost-effective, and maintaining the device is relatively easy. The operation process of this device is quite simple: solar energy passing through the glass heats the environment that needs to be warmed [1].

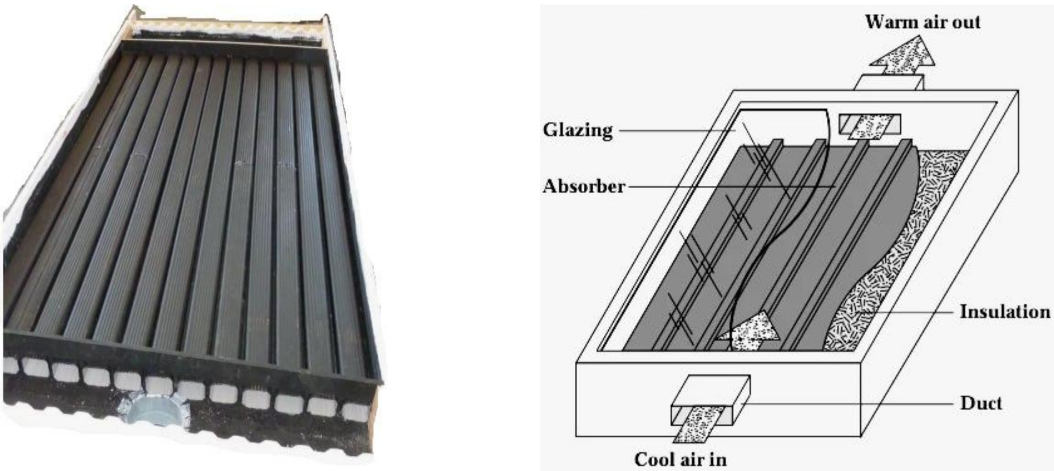

Fig 2.1. General appearance of the air collector.

Flat-plate collectors have a black surface that absorbs solar radiation. The material on this surface absorbs sunlight and converts it into heat. The top part of the collector is usually made of aluminum or copper. The heat, in turn, is transferred to water or an antifreeze mixture, which serves as the heat transfer fluid inside the collector. The glass part of the flat solar collector can be transparent or translucent. Specifically, iron oxides are added to the glass in very small amounts, which helps transmit the majority of the incoming light. Its operation is as follows: inside the collector, there are tubes that absorb heat. These tubes transfer the thermal energy to the heat transfer fluid. The back and sides of the collector are insulated to prevent heat loss. This helps maintain the high temperature of the fluid. The front side of the collector typically has a transparent material (such as glass or plastic), allowing sunlight to reach the collector's surface. Its walls also act as thermal insulation, minimizing heat loss in such a design (Figure 2.2) [3].

The reason for painting the solar energy-absorbing plate or absorber in black is to increase the amount of absorbed solar energy. This is because a perfectly black object absorbs the entire spectrum of radiation, regardless of the wavelength of the incoming radiation.

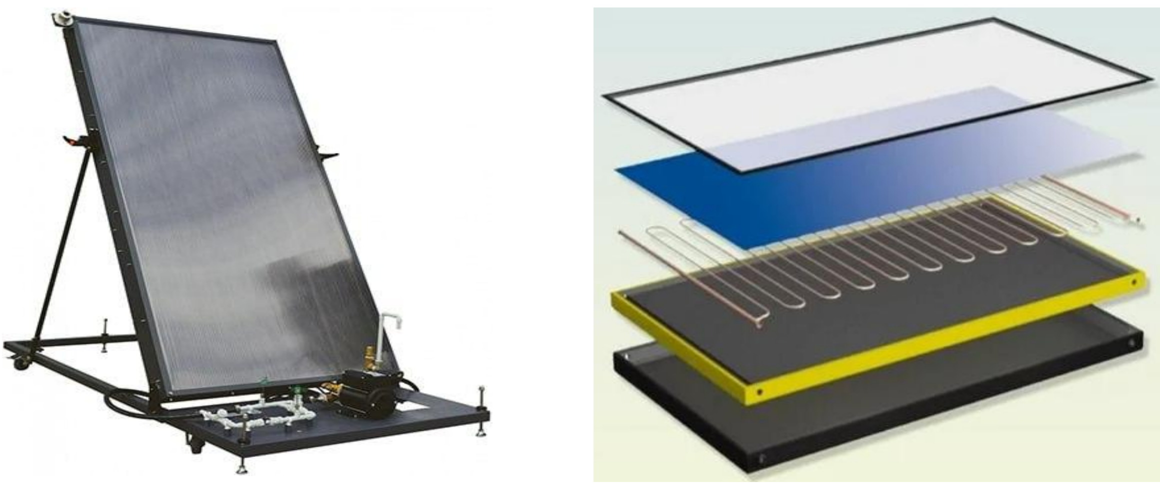

Fig 2.2. General and schematic view of a flat solar collector.

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The solar energy that passes through the glass and reaches the absorber plate is then transferred to the heat transfer fluid in order to continue the process of converting it into thermal energy. In this process, the air or liquid moving through the pipes serves as the heat transfer medium. Unfortunately, the darkened surface can also reflect up to 10% of the solar radiation. To mitigate this issue, a special coating is applied to the absorber plate. This coating lasts longer compared to a surface painted with ordinary paint and helps to increase the efficiency of the collector [4].

A vacuum tube solar collector consists of a collection of cylindrical tubes, made of selective absorbers, placed on a reflector seat and wrapped in a transparent glass cylinder. They primarily collect solar radiation, retain the absorbed energy as heat, and transfer it through a fluid (typically water or antifreeze). Compared to flat plate collectors, vacuum collectors are much more efficient at capturing heat, as their internal tubes are in a vacuum state, which helps reduce heat loss.

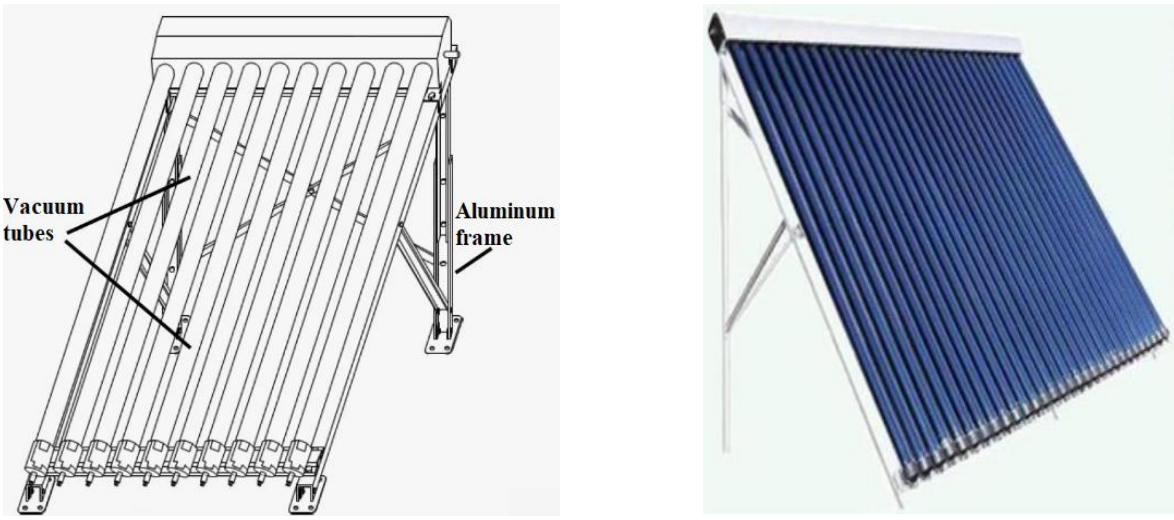

Fig 2.3. The general appearance of vacuum solar collectors

Considering the need to supply the drying chamber with hot air flow and based on the above information, a flat-plate solar collector was selected. In the system, the heat transfer medium is air, thus the selected system is called a flat-plate solar air collector (FPSAC), and its technological schematic is proposed (Figure 2.3) [5].

III. RESULTS

For drying the products loaded into the drying chamber, a FSAC with an area of 4 m² was chosen. Taking into account the movement of the sun throughout the day, the collector was mounted on a base with a special bearing, allowing the base to rotate at an angle of 360° and the collector to tilt on both sides using special bearings. A list of the required main parameters for the FSAC was created (table 3.1) [6].

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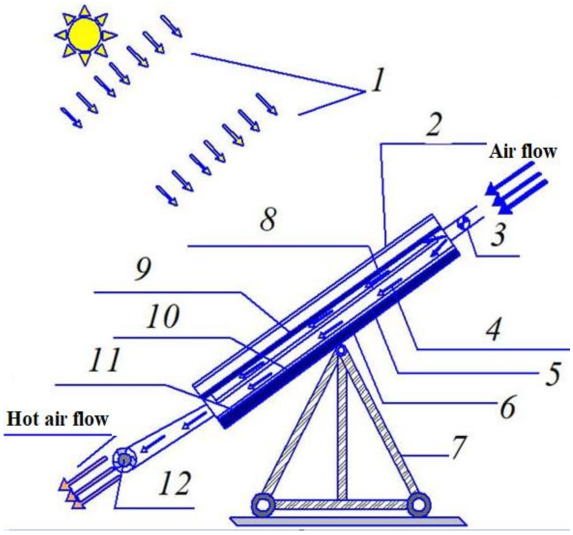

Fig.3.1 Technological diagram of the flat solar air collector.

1 - Solar radiation rays; 2 - Transparent cover; 3 - Vent; 4 - Ribbed tube and air to be heated under the absorber coating; 5 - Insulating material; 6 - Outer panel; 7 - Base; 8 - Entry of hot air into the ribbed tube; 9 - Absorber coating; 10 - Ribbed tube; 11 - Bottom panel; 12 - Ventilation.

The heat balance equation for the solar air collector (FPSAC) was calculated using the process parameters:

$$Q_{s.a.c} = G_a \cdot C_a(t_2 - t_1) \quad (1)$$

In this case, G_a represents the heat consumption of the air flow through the solar air collector, in kg/s;
$Q_{s.a.c} = G_a \cdot C_a \cdot (t_2 - t_1) = G_a \cdot \rho \cdot C_a \cdot (t_2 - t_1) = 0{,}05 \cdot 1{,}29 \cdot 1{,}05 \cdot (50 - 20) = 2{,}0$ kWt.
C_a - Specific heat capacity of air, $C_a \approx 1{,}05, \frac{Kj}{kg \cdot ℃}$;
t_1 − the temperature of the air at the inlet of the solar air collector, $t_1 = 20 \div 30$, ℃;
t_2 − the temperature of the heated air at the outlet of the solar air collector, ℃;
ρ_a − the density of the air, $\rho_a = 1{,}29, \frac{kg}{m^3}$;

Alternatively, the amount of heat obtained for heating the air from the solar air collector can be determined as follows, Vt.

$$Q_{s.a.c} = q_r \cdot \eta_c \cdot F_{cl}, \ kWt; \quad (2)$$

q_r − the solar radiation intensity, $q_r \approx 800 \ \frac{Vt}{m^2}$, ($q_r = 800 \div 1000 \ \frac{Wt}{m^2}$),
η_c – the coefficient of performance of the flat-plate solar air collector, $\eta_k \approx 0{,}5 \div 0{,}6$;
F_c − the area of the collector, m^2;
(3) The area of the collector is determined using the above formula;

$$F_c = \frac{Q_{s.a.c}}{q_r \cdot \eta_c} = \frac{2}{0{,}8 \cdot 0{,}6} \approx 4{,}0 \ m^2; \quad (3)$$

The heat absorption capacity of the air collector depends on the absorption of solar radiation and is expressed as follows: $Q = \alpha \cdot q_r \cdot F_{kol} = 0{,}9 \cdot 800 \cdot 4 = 2{,}88$ kWt; (4)

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Table 3.1 The main indicators of the flat-plate solar air collector.

№	Parameters	Symbol	Unit	Quantity
1	Heat consumption of air flow through the solar air collector	G_a	$\frac{kg}{h}$	0,05
2	Specific heat capacity of air	C_a	$\frac{kj}{kg \cdot ℃}$	1,05
3	Inlet air temperature to the solar air collector	t_1	℃	20÷30
4	Outlet temperature of the heated air in the solar air collector	t_2	℃	50
5	Solar radiation energy density	q_r	$\frac{Wt}{m^2}$	800÷1000
6	Efficiency coefficient of the solar air collector	η_c	-	0,5÷0,6
7	Surface area of the collector	F_c	m^2	4,0
8	Volumetric flow rate of air in the solar air collector	G_v	$\frac{m^3}{h}$	0,1
9	Transmissivity coefficient of the collector glass cover	$\lambda_{t.c}$	$\frac{W}{(m \cdot ℃)}$	0,75÷0,90
10	Absorber coating absorption coefficient of the collector	α	-	0,85÷0,95

IV. DISCUSSION

The hottest days in the city of Karshi typically occur in the summer season, specifically in the month of July. During this time, the relationship between the air temperatures entering and exiting the solar air collector (FSAC) is formed as follows (Figure 4.1) [7].

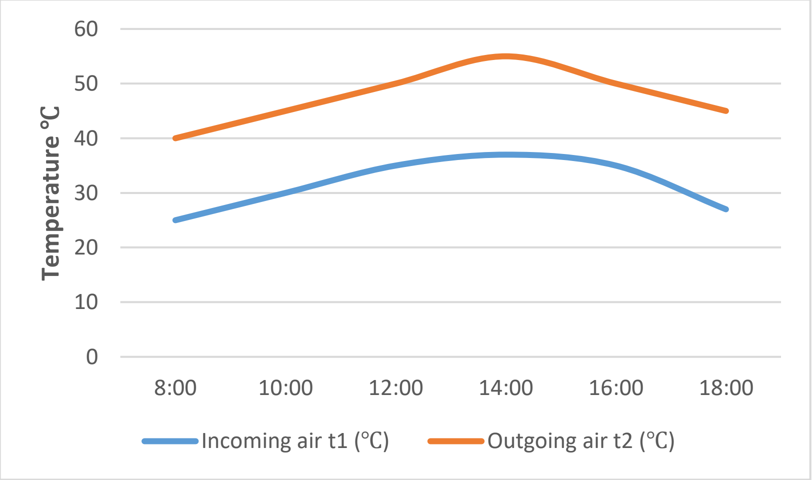

Fig 4.1. Relationship between t_1 and t_2 temperatures.

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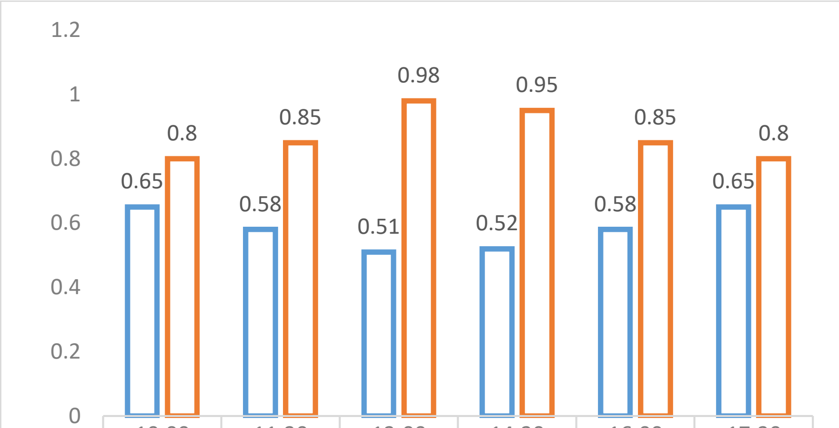
The amount of solar radiation changes throughout the year in different regions of the Republic of Uzbekistan. For example, in Tashkent region, the average solar radiation lasts for 2889 hours per year, while in Karshi, this figure reaches 3095 hours.



	10:00	11:30	13:00	14:30	16:00	17:30
ηc	0.65	0.58	0.51	0.52	0.58	0.65
qr	0.8	0.85	0.98	0.95	0.85	0.8

Fig 4.2. Changes in solar radiation density over time.

During the summer months (June-August), solar radiation is at its highest. During this period, the duration of solar radiation accounts for 84-95% of the total possible radiation period. In winter months (December-February), solar radiation decreases, and the duration of solar radiation accounts for 40-50% of the possible radiation period. The intensity of solar radiation varies at different times of the day. The highest intensity occurs between 12:00 PM and 2:00 PM, as the sun is directly overhead during this time [8].

The relationship between solar radiation (q_r) in the summer months and the efficiency coefficient (η) of the flat plate solar air collector (FPSAC) is shown in Figure 4.2.

The efficiency of a flat solar air collector certainly changes in direct proportion to the air flow velocity, as shown in figure 4.3.

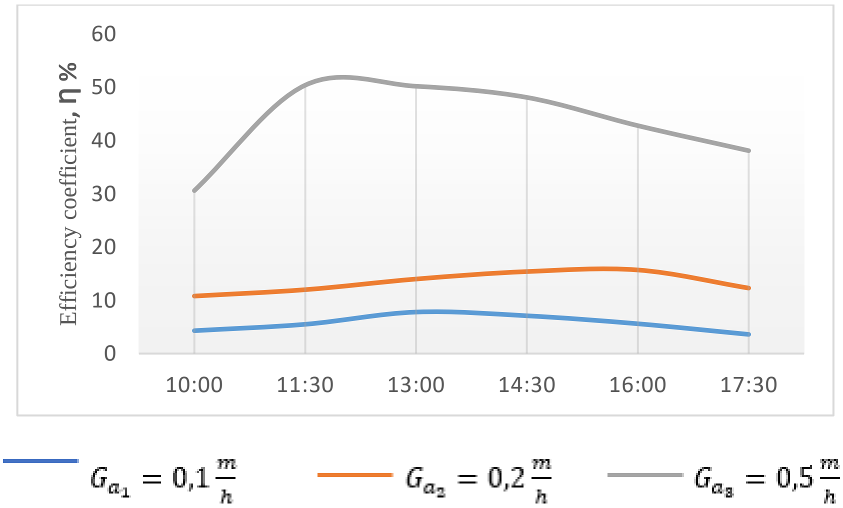


Figure 4.3. Graph showing the change of the flat solar air collector's efficiency coefficient with respect to the air flow value over time.

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V. CONCLUSION

A proposal has been made to use a flat solar air collector in the drying chamber of a small pyrolysis reactor to adequately dehydrate biomass. Scientific research has shown that, through the efficient use of collectors in the Kashkadarya region, it is possible to dry biomass effectively. By applying solar energy collectors (FSAC), it was possible to reduce excess electricity consumption and make efficient use of natural alternative energy sources.

The results of the conducted studies indicate that the use of solar collectors in the initial drying process of biomass increases the efficiency of the pyrolysis unit by 20-30%. As a result, the proposed pyrolysis unit with a solar collector helps to reduce the consumption of heat energy required for its specific needs.

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