Обґрунтовано економічну доцільність зниження енергоємності, прямих експлуатаційних витрат у процесі сушіння фруктів в сушарці за рахунок використання сонячної енергії. Застосування в геліосушарці теплового акумулятора та плоского дзеркального концентратора дозволяє підвищити економічну ефективність процесу сушіння на 20 %. Очікуваний економічний ефект від використання розробленої геліосушарки складатиме 6,075 тис. грн/рік

Ключові слова: сонячна енергія, геліосушарка фруктів, дзеркальний концентратор, тепловий акумулятор, економічна ефективність

Обоснована экономическая целесообразность снижения энергоемкости, прямых эксплуатационных расходов в процессе сушки фруктов в сушилке за счет использования солнечной энергии. Использование в гелиосушилке теплового аккумулятора и плоского зеркального концентратора позволяет повысить экономическую эффективность процесса сушки на 20 %. Ожидаемый экономический эффект от использования разработанной гелиосушилки составит 6,075 тыс. грн/год

Ключевые слова: солнечная энергия, гелиосушилка фруктов, зеркальный концентратор, тепловой аккумулятор, экономическая эффективность

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SUBSTANTIATION OF ECONOMIC EFFICIENCY OF USING A SOLAR DRYER UNDER CONDITIONS OF PERSONAL PEASANT FARMS

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1. Introduction

Today there are many high-temperature automated devices for drying fruits. However, their application is unprofitable while processing small volumes of freshly picked fruits under conditions of personal peasant farms (PPF). This is primarily due to the large capital investments and high energy consumption. An application of natural drying of fruits in the open air under conditions of natural lighting requires considerable labor resources and has low productivity. That is why during technical renovation and when designing new facilities, it is necessary to solve questions in relation to economic, technical and biologically justified selection of one or another variant of technical solution [1].

In the process of drying fruits in fruit drying machines, energy-resource saving is tried to be achieved by forming a situation when energy, economic and biological efficiency do not match while the priority is given to the former at the expense of the latter. That is why biological and economic factors should not be reduced in favor of energy factor because their combination determines the overall efficiency of the process, and their interconnection forms technological process of drying [2–5].

In the search for a compromise solution, we in parallel assess certain elements of energy system that have different production objectives but are aimed at achieving the same goal. For example, reducing energy consumption for drying under condition of maintaining quality indicators of the dried material and substantiation of optimum design and technological parameters of technical means of drying [2, 4, 5].

The given arguments made it possible to determine main directions of improving technological, energy efficiency of the drying process with the use of solar energy. Currently, fruit drying machines of this type are not widely used in Ukraine. This predetermines the relevance of selection of optimal design of a fruit drying machine with rational technological parameters. The effective use of such a dryer under conditions of PPF is possible only on the basis of substantiation of its economic efficiency.

2. Literature review and problem statement

High dynamics of growth in the consumption of energy resources, as well as depletion of technical fuels (natural gas, coal, peat, etc) allowed us to determine priority directions of replacing scarce types of energy (electrical or thermal) with alternative sources [2]. One of these sources is solar energy that can be used for the generation of electrical energy or low potential heat for, in particular, for drying wet materials of plant origin.

In papers [3, 5], the authors propose, for the process of drying raw materials, using technical tools based on alternative energy sources. In particular, [3] suggested a method for the calculation of technological and economic parameters of the technical means of drying and formulated an actual task of performance inmprovement and a selection of optimal fruit drying machine by the criterion of maximum economic effect. The described technique is very general. In addition, there is a lack of mechanism for the justification of criteria for determining minimum direct operational costs. Article [5] defined specific materials consumption of a dryer design relative to energy consumption and an increase in the productivity of the machine, as well as economic effect and payback period. However, there are no details regarding the indicators of operating costs for the maintenance of the dryer and full cost of the works it performs.

Main direction of scientific paper [6] is the substantiation of economic efficiency of using various types of technical means of drying, in particular determining direct operating costs for the process of drying grain and the justification of economic effect of the use of drum grain solar dryer, compared with a standard drum dryer SZSB-8A. One of the main indicators of the grain dryer SZSB-8A is its efficiency – fuel consumption per 1 rouble/t, which on gaseous fuel is 267 rouble/t of dried grain with fuel saving of 8 m^3/t; on liquid fuel is 295 rouble/t of dried grain when fuel saving of 6 kg/t (prices on the energy resources in the Russian Federation as of 2012). That is, the authors pay significant attention to the analysis of the reduction in energy consumption, direct operating costs for the process of drying grain in a drying machine through the use of solar energy. However, they did not take into account the represented production costs per unit of manufacturing, annual economic effect due to the introduction of the machine, the payback period of the solar dryer. These papers relate exclusively to determining the economic effect of presowing air-thermal treatment of the seeds of grain crops and may not be used by us in full.

The authors of article [7] perform an analysis of the efficiency of project implementation of a solar dryer for drying wood GSO-2, focusing their attention on the payback period. Economic efficiency of the solar dryer is considered in relation to performance of the chamber, comparing it to the atmospheric technique of drying. However, they disregard the calculation of direct operating costs for the drying process matching with the technical means of drying. The proposed technique cannot be used because there are no details concerning the described renovation expenses, maintenance and repair of the solar dryer.

Papers [8, 9] suggested using convection and radiation solar dryers for drying lumpy and shredded fruit raw materials, which have electrical source of thermal energy. Economic effect of dryers is achieved by partial reduction in the consumption of power resources, leading to a decrease in the production costs. However, in [8], the substantiation of economic efficiency is not fully examined. The authors did not take into account the cost of production per unit of a dried product and the fluctuation in the electricity price. Article [9] presents a comparison of the cost-efficiency of the two variants of dryers (solar dryer and electric dryer). But much to our regret, the authors did not consider the input operational performance indicators of the examined dryers and market prices for fruit raw materials linked to a particular area of the PPF location.

In article [10], author suggested using solar dryer of mine type with additional air collectors, which contain an accumulator of heat with solid heat accumulating material based on sand. A solar dryer operates by the principle of an active system without using traditional energy sources and provides for a stable regime of drying and high quality of the dried product in the evening hours and cloudy weather. In the given drying unit they took into account the effect of energy, economic and biological efficiency of the drying process in the machine on the quality of the dried product. Since the worst aspect of solar energy is irregularity [11], then there is a question about achieving the goal of maintaining a stable mode of drying and obtaining high quality product when using only traditional methods of drying without heating the heat carrier. In addition, when assessing economic efficiency, the author did not take into account the cost per unit of production, annual operating costs for using the accumulator, materials-construction-installation work.

As is known from paper [12], a 100 % substitution of traditional energy sources with the alternative ones does not produce high economic effect. That is why it is necessary to look for a compromise solution that is based on the optimum partial replacement of traditional energy sources by the alternative ones. For example, the use of a flat mirror concentrator to enhance the slant flows of morning and evening sunlight. Accumulation in the night time of excess heat from the reserve source of energy, using a heat accumulator with solid heat accumulating material based on pebbles, which is characterized by high heat-absorbing capacity and heat emission. These systems are quite efficient and gained repuation in the program of passive energy supply "Smart Home" and do not require significant specific investment [13].

Thus, economic efficiency of the production of dried fruits in a solar dryer is determined not only by the direct cost of funds but should consist of energy, labour, structural, technological effects. That is why a crucial aspect for making a decision when using a solar dryer with thermal battery and flat mirror concentrator (SD with TB and FMC) for drying fruit under conditions of PPF is to substantiate its economic efficiency, which implies determining direct operating costs, economic effect and payback period.

3. The aim and tasks of the study

The aim of this research is to substantiate economic efficiency of using a solar dryer with thermal battery and flat mirror concentrator under conditions of PPF.

To achieve the set aim, it was necessary to fulfill the following tasks:

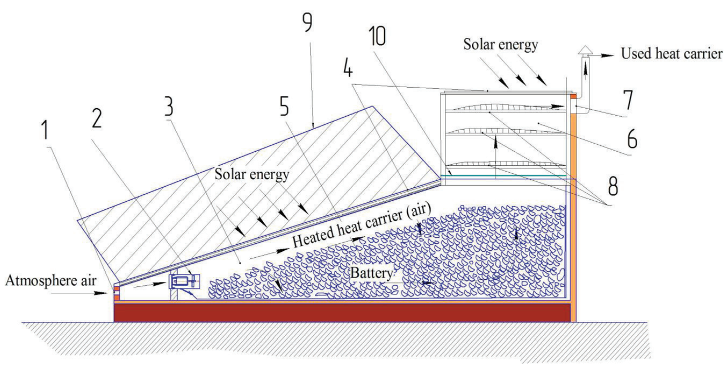
– to improve the method for determining economic efficiency of using a solar dryer with thermal battery and flat mirror concentrator;

– to assess economic efficiency of a solar dryer compared with traditional technical means of drying.

4. Materials and methods for the substantiation of economic efficiency of solar dryer with thermal battery and flat mirror concentrator

4. 1. Design and technological scheme of a solar fruit dryer and the calculation of its operating costs

In the agroindustrial production, active systems for using solar energy have been widely applied in such countries as England, Canada, Poland, Germany, France, Holland, Kazakhstan, and Russia [13]. For example, for drying plant raw materials, in particular, fruit, the solar energy is actively used for the drying needs under conditions of PPF. This type of dewatering the material [11] can be fully applied for the zone of Western Polissya. In particular, at the Lviv National Agricultural University Department of Energy, a solar dryer with thermal battery and flat mirror concentrator was designed, which is a passive system for using solar energy [14], which is displayed in Fig. 1 and whose technical specifications are in Table 1.



a

b

Fig. 1. Solar dryer with thermal battery and flat mirror concentrator: *a* — design and technological scheme; *b* — general view; 1 — input channel; 2 — fan with heater; 3 — air duct; 4 — air collector; 5 — heat accumulating material (pebble); 6 — drying chamber; 7 — return channel; 8 — sieves; 9 — flat mirror concentrator; 10 — valve

Table 1

Technical characteristics of a solar dryer with thermal battery and flat mirror concentrator [1]

Parameter	Indicator
Weight of dried material m_f, kg	5,5
Area of air collector S_a, m^2	1,5
Area of flat mirror concentrator L, m^2	1,5
Weight of thermal battery m_{tb}, kg	50
Inner volume of drying chamber V_{dc}, m^3	0,5

A solar dryer operates in the following way. Sieves 8 are filled with the cut fruits and are placed in the drying chamber. Air from the external environment enters the air pipe, under the absorber, through a layer of heat accumulating material, it is heated up and passes into the drying chamber. Part of the heat accumulates in the thermal battery. The used heat carrier is removed by natural convection into the environment through the exhaust channel.

An advantage of this type of dryers is partial dependence on solar activity. This predetermines its complete geographical orientation and design specifications, the capacity of using additional source of electricity to power the fan and the heater, as well as substantial saving of energy in the morning, evening and night time using a flat mirror concentrator and thermal battery.

Substantiation of economic efficiency of the application of technical means of drying under conditions of PPF is represented by the following basic indicators:

– the total cost of the work performed by a solar dryer and an electric dryer;

– operating costs for the maintenance of a solar dryer and an electric dryer;

– specific investment in a solar dryer and an electric dryer;

– specific materials consumption for the designs of a solar dryer and an electric dryer;

– an annual saving on operating costs when using a solar dryer.

Substantiation of the economic efficiency of SD with TB and FMC was determined by comparing its operational and economic indicators with the traditional means of drying, on the example of the electric dryer of chamber type "Dachnik-4" (made in Ukraine), which is typical for the conditions of PPF.

A criterion for the substantiation of rational design and technological parameters of SD with TB and FMC under conditions of PPF is the minimal direct operating costs [15]:

$$D_{OC}=C_R+C_{TM}+C_{SP}+C_{CE} \rightarrow \min, \text{ UAH/kg}, \quad (1)$$

where C_R are the costs of renovation of a solar dryer, UAH/kg; C_{TM} are the costs for technical maintenance and repair of a solar dryer, UAH/kg; C_{SP} are the expenditures on salaries of personnel, UAH/kg; C_{CE} are the cost of used electricity, drive of fan and instrumentation operation, UAH/kg.

The cost of renovation of a solar dryer is determined by formula

$$C_R=\frac{k_m \cdot k_D \cdot C_{SD}}{k_{TM} \cdot S_D \cdot P_{SD}}, \text{ UAH/kg}, \quad (2)$$

where k_m is the coefficient that takes into account the cost of materials and construction-and-assembling work of a solar dryer; k_{TM} is the coefficient of depreciation on the technical maintenance and repair of a solar dryer; k_D is the coefficient of depreciation on the renovation of a solar dryer; C_{SD} is the solar dryer price, UAH; S_D is the seasonal use of a solar dryer, hours; P_{SD} is the productivity of a solar dryer, kg/s.

The cost of manufacturing a solar dryer is determined by formula:

$$C_{SD}=C_a+C_f+C_{tb}+C_{dc}, \text{ UAH},$$

where C_a is the price of air collector, UAH; C_f is the price of fan, UAH; C_{tb} is the price of heat accumulator, UAH; C_{dc} is the price of a drying chamber, UAH.

The cost of making an air collector is determined by formula

$$C_a=C_{Sa}\cdot S_a, \text{ UAH},$$

where C_{Sa} is the cost of making one square meter of air collector of a solar dryer, UAH/m^2; S_a is the area of receiving surface of air collector, m^2.

The cost of manufacturing a flat mirror concentrator is defined by formula

$$C_{mc}=C_{Smc}\cdot L, \text{ UAH},$$

where C_{Smc} is the cost of making one square meter of a mirror concentrator, UAH/m^2; L is the square of a mirror concentrator, m^2.

The cost of making a heat battery is determined by formula

$$C_{tb}=m_{tb}\cdot Cm_{tb}+S_{tb}\cdot C_e+C_v, \text{ UAH},$$

where m_{ra} is the weight of heat accumulating material of a heat accumulator, kg; Cm_{tb} is the price of heat accumulating material on the battery per 1 kg, UAH/kg; S_{tb} is the area of heat transfer of the surface of the battery of a solar dryer, m^2; C_e is the price of a square meter of the battery enclosure, UAH/m^2; C_v is the cost of the battery valve per one meter of the width of a solar dryer, UAH.

The cost of manufacturing a drying chamber is calculated by formula

$$C_{dc}=S_{dc}\cdot C_e, \text{ UAH},$$

where S_{dc} is the area of a drying chamber, m^2; C_e is the price of a square meter of the drying chamber enclosure, UAH/m^2.

Productivity of a solar dryer is determined by formula

$$P_{SD}=\frac{m_f\cdot 10^{-3}}{\tau}, \text{ kg/s},$$

where m_f is the mass of fruit raw materials, kg; τ is the duration of the period of drying, s.

The cost of technical maintenance and repair of a solar dryer is determined by formula

$$C_{TM}=\frac{C_{SD}\cdot k_{TM}\cdot k_m}{S_D\cdot P_{SD}}, \text{ UAH/kg}. \quad (3)$$

The expenditures for the salaries of personnel is calculated by formula

$$C_{SP}=\frac{k_{SP}\cdot k_{cw}\cdot k_{ASP}\cdot n}{S_D\cdot P_{SD}}, \text{ UAH/kg}, \quad (4)$$

where k_{SP} are the wages of staff, UAH/hour; k_{cw} is the coefficient of complexity of the work; k_{ASP} is the coefficient of additional wages; n is the number of staff, people.

The tariff rate for agricultural workers, coefficients of complexity and additional charges, coefficients that take into account the cost of installation, technical maintenance, repairs, depreciation charges, seasonal load of a solar dryer were taken from the regulation documents [9–11].

The cost of the used electricity to drive the fan and of the instrumentation operation is determined by formula

$$C_{CE}=\frac{W_e\cdot(N_f+N_I)}{S_D\cdot P_{SD}}, \text{ UAH/kg}, \quad (5)$$

where N_f is the power of fan, W; N_I is the power of instrumentation, W; W_e is the price of 1 kW hour of electricity, UAH.

4. 2. Calculation of operational costs of electric drier of chamber type

At present, for drying fruits under conditions of PPF they use high temperature home drying machines of periodic action, in particular the electric dryer of chamber type “Dachnik-4” whose technological scheme and design ensures high percentage of moisture removal while maintaining quality indicators of dried fruits.

Based on the technical characteristics of the drier “Dachnik-4” represented in Table 2, let us define direct operating costs for drying fruits.

Table 2

Technical characteristics of the electric drier of chamber type “Dachnik-4”

Parameters	Indicators
Productivity, kg/hour	0,848
Specific installed capacity (electric), kW/(kg·%)	0,8
Dimensions, mm	340×450×590
Unit weight, kg	14
Load weight, kg	4–7

Direct operating costs for the drying of fruits in the chamber dryer “Dachnik-4” [9–12]:

$$D_{OC}=C_R+C_{TM}+C_{SP}+C_{CE}\rightarrow\min, \text{ UAH/kg}, \quad (6)$$

where C_R is the cost of renovation of the dryer, UAH/kg; C_{TM} are the costs of technical maintenance and repair of the dryer, UAH/kg; C_{SP} are the expenditures on salaries of personnel, UAH/kg; C_{CE} is the cost of used electricity, UAH/kg.

The costs of renovation of the dryer is calculated by formula:

$$C_R=\frac{k_m\cdot k_{TM}\cdot k_{cw}\cdot k_D\cdot C_D}{S_D\cdot P_D}, \text{ UAH/ kg}, \quad (7)$$

where k_m is the coefficient that takes into account the cost of installation of the dryer; k_{TM} is the coefficient of depreciation on technical maintenance and repair of the dryer; k_{cw} is the coefficient of complexity of work; k_D is the coefficient of depreciation on the renovation of the dryer; C_D is the price of the dryer, UAH; S_D is the seasonal use of the dryer, hours; P_D is the productivity of the dryer, kg/s.

The book value of the dryer depends on the type of energy it uses. The price of the dryer “Dachnik-4” is UAH 3600 (according to the TOV "Company Technoprom-Product", the main manufacturer and supplier of household dryers in Ukraine).

The costs of technical maintenance and repair of the dryer are determined by formula

$$C_{TM} = \frac{C_D \cdot k_{TM} \cdot k_{em}}{k_m \cdot (S_D \cdot P_D)}, \text{ UAH/kg}, \quad (8)$$

where C_D is the price of the chamber dryer, UAH; k_{em} is the coefficient, which takes into account replacement of elements of equipment of the machine.

The expenditures for salaries of the personnel are calculated by formula

$$C_{SP} = \frac{k_{SP} \cdot k_{cw} \cdot (k_m + k_{ASP}) \cdot n}{100 \cdot (S_D \cdot P_D)}, \text{ UAH/kg}, \quad (9)$$

where k_{SP} are the wages of staff, UAH/hour; k_{ASP} is the coefficient of extra wages; n is the number of staff, people.

The cost of used electricity is determined by formula

$$C_{ce} = \frac{N_D \cdot W_e}{S_D \cdot P_D}, \text{ UAH/kg}, \quad (10)$$

where N_D is the power of the dryer, W; W_e is the price of 1 kW·h of electricity (as of 1.05.2016, according to the press service of the company PAT "Lvivoblenergo", the price of 1 kW·h was UAH 0.714), UAH.

4. 3. Substantiation of economic efficiency of a solar dryer

The substantiation of economic indicators of a solar dryer was carried out in accordance with DSTU 4397 (Agricultural machinery. Techniques for economic evaluation of equipment at the testing stage). The calculation of economic efficiency of a solar dryer is performed by formula

$$E_e = \left[Z_1 \cdot \frac{B_2}{B_1} \cdot \frac{P_1 + S_T}{P_2 + S_T} + \frac{U_1 - U_2 - S_T (C_2 - C_1)}{P_2 + S_T} - Z_2 \right], \text{ UAH}, \quad (11)$$

where Z_1, Z_2 are the given manufacturing costs per unit of production in the proposed solar dryer, UAH; B_2/B_1 is the factor that takes into account an increase in productivity of the designed machine compared to the existing one; P_1, P_2 are the shares of deductions off the book value for a full restoration of the existing and designed means of work: $P_1=P_2=0{,}125$; U_1, U_2 are the annual operating costs of using a battery and a concentrator in a solar dryer based on the volume of products manufactured using the developed means of work, UAH; S_T is the standard coefficient of payback period; C_2, C_1 are the related capital investments of consumption using the existing and designed means of work in terms of the calculation of the amount of work with the help of the designed means of work.

The annual operating costs U_1 and U_2 and related capital investments in the existing and designed work environments are included in the estimate for materials-construction-installation works, which are included in the costs of Z_1 and Z_2, which is why $C_2=C_1=0$.

The payback period of a solar dryer is determined by formula

$$T = \frac{E_e}{C_{SD}}, \quad (12)$$

where C_{SD} are the capital expenditures of a solar dryer, UAH.

5. Results of the substantiation of indicators of economic efficiency of a solar dryer

Based on the calculations, we constructed a dependence of direct operating costs for drying and the required area of air collector on the mass of the dried material (Fig. 2).

A reduction in direct operating costs in a solar dryer takes place when filling the sieves with drying material of weight 1.1 kg for air collector of area 1.5 m² and amounts to UAH 63,34 (Fig. 2). With an increase in the filling of the sieves, the costs are reduced while the air collector's area increases proportionally.

The data we received are represented in Tables 3, 4 to conduct economic analysis of project efficiency of the application of a solar dryer under conditions of PPF.

Data from Tables 3, 4 demonstrate that 83 % of all operating costs are due to salaries, electricity, maintenance and repair.

When using a solar dryer, the technical and economic efficiency owing to the reduction in direct operating costs for drying fruits, compared with the electric fruit dryer "Dachnik-4", which runs on electricity, is UAH 4,82 per 1 kg of dried fruits at the energy saving of 3,4 kW·h.

Thus, an annual economic effect of the implementation during summer-autumn season of a solar dryer is UAH thousands 6.075. The cost of the dried products (apple and pear) in a solar dryer is UAH 24.06 per 1 kg. The payback period of a solar dryer is 0.22 year.

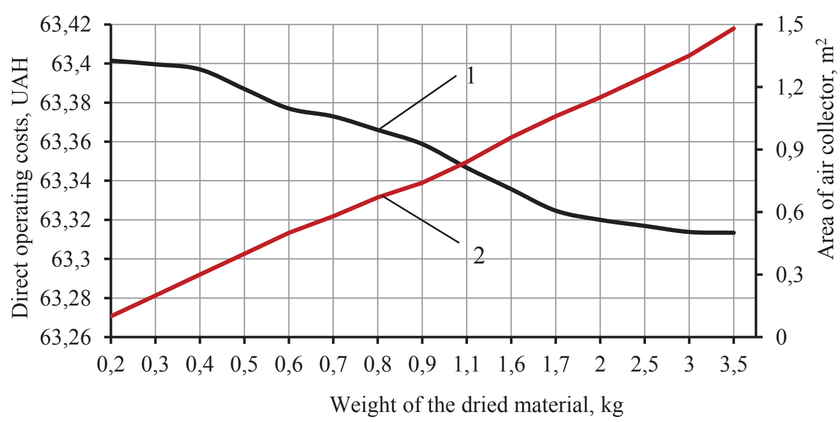


Fig. 2. Dependence of direct operating costs and the area of air collector on the mass of the dried material: 1 — direct operating cost, UAH/kg; 2 — area of air collector, m²

Table 3

Technical and economic efficiency of solar dryer

No. of entry	Indicator	SD with TB and FMC	Note
1	Machine productivity, kg/24 h	1,1	
2	Machine work duration, hours/year	1500	
3	Hour productivity, kg	0,11	
4	Deductions for factory treatment, UAH thousands	–	
5	Expenditures for salary		
5.1	Number of people employed	1	
5.2	Basic salary, UAH thousands	1,9	
5.3	Extra wage, UAH thousands	0,6	20 % off the basic salary
5.4	Taxes, UAH thousands	0,5	10,1 % off the amount
5.5	Total salary and taxes, UAH thousands	4,0	
6	Cost of electricity		
6.1	Installed power of electric engine, kW	0,146	
6.2	Consuming power, kW	0,146	
6.3	Price of 1 kW hour of electricity, UAH	0,3050	
6.4	Taxes for electricity, UAH thousands	0,20	
6.5	Installed power of heaters, kW	–	
7	Capital investments, incl. installation cost (6 %), UAH thousands		
7.1	Price of thermal battery, UAH thousands	0,15	
7.2	Price of drying chamber, UAH thousands	0,29	
7.3	Price of heaters, UAH thousands	–	
7.4	Price of air collector, UAH thousands	0,4	
7.5	Price of measuring instruments, UAH thousands	4,3	
7.6	Price of flat mirror concentrator, UAH thousands	0,3	
7.7	Price of fan, UAH thousands	0,2	
7.8	Total capital investments, UAH thousands	5,64	
8	Depreciation		
8.1	Amount of depreciation for thermal battery, UAH thousands	0,02	Norm of deduction 12,8 %
8.2	Cost of technical maintenance and regular repair, UAH thousands	0,023	25 % off the amount of depr. deduct.
9	Total costs, UAH thousands	9,84	
10	Specific expensitures for renovating a solar dryer, UAH thousands	0,16	
11	Annual economic effect of the implementation of machine, UAH thousands	6,075	

Table 4

Economic analysis of effectiveness of the project of implementation of a solar dryer

No. of entry	Indicator	Specific expenses	
		Solar dryer	Electric dryer
Indicators of efficiency of technical means of drying			
1	Annual economic effect, UAH/year	6075	3876,4
2	Payback period, years	0,22	0,6
Operating costs of technical means of drying			
3	Direct operating cots, UAH/kg	63,34	68,16
4	Electricity costs, UAH/kg	0,57	1,04
5	Expenditures for maintenance and repair, UAH/kg	2,84	1,52
6	Expenditures for salary, UAH/kg	59,2	65,2
7	Cost of renovation, UAH/kg	0,73	0,4

6. Discussion of results of the study of efficiency of using a solar fruit dryer under conditions of personal peasant farms

An analysis of existing technical means of drying fruits demonstrated that their application is unprofitable for the small volumes of processing freshly picked fruits under conditions of PPF. This is primarily due to a large capital investment and high energy consumption. That is why drying small amounts of fruits is advisable to carry out in a solar dryer that provides for the energy-efficient mode of drying.

The proposed new design of a solar dryer for drying fruits includes the use of a flat mirror concentrator – to enhance the flow of slant morning and evening sunlight and a thermal accumulator based on pebble, accumulating over night time the excess heat from the reserve source of energy. This allows us, during the season of work of a solar dryer, to receive 30.2 kW·h or 108.5 MJ of thermal energy for the evaporation of moisture of the dried material. The process energy efficiency is 10.7 kW·h/kg or 38.8 MJ/kg that enables annual saving of about 0.35 Gcal of thermal energy and corresponds to the 5 m^3/year saving of natural gas or 3,4 kW·h of electricity.

The studies conducted in the work are a final stage of the comprehensive research into improving the efficiency of technological process of drying fruits based on the development of design and the substantiation of operating modes of a solar dryer, which will reduce the cost of energy.

In this work we have improved the technique of substantiation of economic efficiency of a solar dryer. The basis of this methodology is the simplified mechanism of calculation: energy, economic and biological efficiency of the drying process in a drying machine, direct operating costs of the drying process, comparing with the technical means of drying on the example of "Dachnik-4", expenses for renovation, technical maintenance and repair of the dryer, manufacturing costs per unit of production, annual operating costs of using a battery and a concentrator, materials-construction-installation work. Such an improvement will rationally define indicators for energy, economic and technological effects from the implementation of a solar dryer with thermal battery and flat mirror concentrator.

According to the obtained results of this study, it was found that solar dryers of this type should be used in the process of drying fruits under conditions of PPF; in this case, annual economic effect from its operation is UAH 6405.8 per year. Technical-economic efficiency of reducing direct operating costs for drying fruits in a solar dryer compared with an electric fruit dryer is UAH 4,82 per 1 kg. Thus, the main technical and operational parameters of the proposed solar dryer correspond to the estimated and are not inferior in any way to the technical characteristics in relation to the existing solar dryers and traditional technical means of drying.

It should be noted that the work paid insufficient attention to the analysis of using autonomous systems of power supply, for the formulation of generalizing results of the substantiation of solar dryer economic efficiency compared to the traditional technical means of drying. That is why appropriate research would be relevant for the formulation of a unified methodology for the substantiation of economic efficiency of a solar dryer compared with the traditional technical means of drying.

Summing up, we shall note that the use of solar dryers with thermal battery and flat mirror concentrator for drying fruits is appropriate and effective under conditions of PPF, which will increase the volume of high-quality dried products at the minimum of specific investments due to solar energy. The obtained results may be applied when designing and improving technical means of drying fruits, to improve technological, energy, biological and economic efficiency of the process.

7. Conclusions

1. We improved a technique of the substantiation of economic efficiency of a solar dryer with thermal battery and flat mirror concentrator, based on the simplified mechanism for calculating direct operating costs, economic effect and payback period of the machine depending on the fluctuation of prices for electricity and dried products.

2. As a result of the conductrd studies, we determined the economic effect from the use of a solar dryer, which is UAH thousands 6.075 per year and the payback period is 0.22 year. The resulted production costs per unit of product are UAH 63,34 per 1 kg. The cost of the dried product (fruits) in a solar dryer is UAH 24.06 per 1 kg. It was established that the use of a solar dryer in comparison with an electric dryer makes it possible to reduce direct operating costs by UAH 4,82 per 1 kg of dried fruits.

3. The obtained economic indicators are feasible owing to the developed new design of a solar dryer for drying fruits, which includes the use of a flat mirror concentrator and a thermal accumulator based on pebble. As a result of the use of the proposed design solutions, the strengthening of the flow of sunlight on the receiving surface of air collector is achieved, as well as the accumulation of excess heat for the partial replacement of a reserve energy source during clouds and over night time. This allows maintaining a stable regime of drying fruits within 24 hours and increasing efficiency of the drying process by 20 % compared with a household electric dryer.

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