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DETERMINATION ON ENERGY EFFICIENCY IN CORN GRAIN DRYING

The object of research is the technological processes of corn grain drying, energy plants. One of the most problematic areas for agricultural producers is providing energy for technological processes of bringing grain material to the indicators of product sales. And during the war and post-war period in Ukraine, this requires non-standard approaches and ways of implementation. Therefore, for operation in autonomous mode, the technology involves the use of biomass, electricity from solar panels and/or a diesel generator to supply the coolant to the grain drying zone. The availability of biomass is ensured by cleaning grain material after harvesting and crop residues.

The study examined the technology of corn grain drying in "Agrotechservice" LLC of the Poltava district of the Poltava region (Ukraine) using the Saphir 2134 modular grain dryer with an improved biomass boiler.

The results of studies of the operation of a grain dryer using different types of fuel (gas, diesel fuel, alternative fuel) showed that the energy consumption for reducing humidity by 1 ton-percent was: for gas – 1.5 m^3; for diesel fuel – 1.8 l; for biomass – 3.4 kg. The total cost of drying on a Saphir 2134 grain dryer was obtained, which is 0.205 USD, which is 3.7 times less than when using natural gas and 9.2 times less than when using diesel fuel. This is due to the fact that the proposed technology involves the use of an improved biomass boiler and alternative energy sources. This provides the possibility of obtaining average daily savings using a grain dryer of this model with an improved biomass boiler, which will be about 1.1 thousand USD. Compared to similar corn grain drying processes, these studies have shown the economic feasibility of using biomass as an energy material for the production of thermal energy in the corn grain drying process.

Keywords: *corn grain drying, biomass, grain dryer, energy efficiency, biofuel boiler, alternative energy sources.*

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1. Introduction

Agriculture, in particular the grain industry, is one of the key sectors of the economy of many countries around the world. However, military operations in Ukraine have significantly affected the ability of the agricultural sector to function effectively due to the destruction of energy infrastructure, instability of fuel and electricity supplies, as well as problems with logistics. As a result, many enterprises face difficulties in ensuring the technological processes of post-harvest processing, drying, storage and preparation of grain for sale.

Additional challenges facing agricultural producers today:

– shortage and high cost of energy resources – caused by the destruction of power plants and energy supply systems, interruptions in the supply of gas and diesel fuel;

– dependence on centralized energy sources – agricultural producers are forced to look for alternative solutions due to the unreliability of traditional energy supply systems;

– the need to modernize grain processing enterprises – many elevators and granaries operate using outdated technologies that require significant energy costs;

– problems with logistics and exports – due to the destruction of transport infrastructure and the blocking of ports, the conditions for exporting grain are complicated, which forces the products to be stored longer, requiring additional resources for drying and maintaining quality.

Thus, possible ways to solve issues related to energy efficiency and energy independence of agricultural enterprises are the introduction of alternative energy sources, optimization of energy consumption, state support, development of local logistics and storage.

For the introduction of alternative energy sources, the optimal use of biomass-based installations is; the use of solar panels and wind energy systems to ensure autonomy; the use of combined technologies (solar + diesel generation) and biomass for the uninterrupted operation of enterprises.

To optimize energy consumption, it is necessary to switch to energy-efficient drying installations running on alternative fuels (pellets, wood chips, biomass) [1]. It is also advisable to use heat recovery technologies to reduce energy costs [2] and establish automation and digitalization of processes to increase the efficiency of energy consumption management [3].

Therefore, in the conditions of war and post-war conditions, the problem of energy supply to the agricultural sector of Ukraine is critical for the country's food security and economic stability. The introduction of non-standard approaches, such as the transition to renewable energy sources, modernization of technologies and the development of autonomous energy supply systems, will allow not only to overcome current challenges, but also to form a more stable and independent agro-industrial system for the future.

An analysis of literary sources indicates that scientists pay significant attention to increasing the energy efficiency of the corn grain drying process. In particular, in work [2], the authors investigated the effect of preheating corn cobs on drying efficiency. It was found that heating at a temperature of 50 °C for 6 hours allows to reduce the drying time

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by 7 hours, increase the moisture release rate by 10.9 % and increase the dryer productivity by 22.5 %. At the same time, the seed quality remains at a high level.

Studies [4] on parallel blowing of drying chambers showed that the use of this technology improves the filtration of the drying agent through the ear pile, increases the drying rate and increases the chamber productivity by 14.8 % compared to sequential blowing. This approach also has a positive effect on the quality of seeds, in particular on their germination and growth strength.

The introduction of differentiated temperature regimes, which include a gradual increase in the temperature of the drying agent depending on the grain moisture, allows to increase the average drying temperature by 2–3 °C without deteriorating the quality of the seeds. This ensures an increase in the productivity of the dryer.

It should be noted that the use of recycling of the spent drying agent [5] allows to improve the potential rate of improvement of the drying process without losing the quality of the seeds. This method involves increasing the energy efficiency of the process. In work [6], a sensitivity analysis of the input parameters of the drying process model, including different fractions of recycling, was performed, and their impact on the quality of the dried product was analyzed. The authors in work [7] investigated that using condensation in the drying of corn grain increases the drying efficiency by 32–56 % due to energy savings compared to conventional hot air drying.

The authors [8, 9] in their works focus on the use of renewable energy sources, such as solar collectors, wind power plants and heat pumps, to reduce dependence on traditional fuel resources in the grain drying process. This contributes to increasing energy efficiency and reducing energy costs.

A study published by the Bioenergy Association of Ukraine [10] considers the possibility of using corn residues as fuel for heat generators that provide heating and drying of grain. This approach allows for the effective utilization of agricultural waste and reduces costs for traditional energy carriers.

To obtain comparative results of different types of grain dryers in terms of their energy efficiency, the authors [11] conducted relevant studies. Thus, it was found that the drying efficiency for a mixed-flow dryer was lower (12 %), compared to a convection dryer (57 %). In this case, the use of pre-treatment provides for a reduction in energy consumption, an increase in drying efficiency and high quality of the resulting grain.

An important element is compliance with the appropriate drying temperature regime, which affects the quality of the resulting grain [12]. Exceeding permissible temperatures can lead to the formation of microcracks, reduced seed germination and loss of nutrients. On the contrary, insufficient heating prolongs the drying process, increases the risk of mold and mycotoxin development, which negatively affects the safety of the grain. To intensify low-temperature drying, it is possible to use short-term heating to 800 °C and use a heat pump [13]. This allows preserving the properties of grain seeds at the level of 99–100 %.

However, the considered works did not investigate the complex impact of using alternative energy sources in dryers and their impact on the energy efficiency of the drying process of grain of agricultural crops.

Thus, increasing the energy efficiency of the drying process of corn grain is possible through the implementation of complex measures, such as optimizing technological modes, upgrading equipment and using alternative energy sources. The application of these approaches will contribute to reducing energy consumption and ensuring high quality of the final product.

The aim of the research is to increase the energy efficiency and economic feasibility of the technological process of corn grain drying in autonomous operation, using alternative energy sources, in particular biomass, compared to traditional energy carriers, using the example of the Saphir 2134 modular grain dryer.

2. Materials and Methods

The object of research is the technological processes of corn grain drying, energy plants.

The subject of research is the interaction of the coolant with corn seeds, the influence of the parameters and operating modes of the dryer on the process indicators.

The scientific hypothesis is the existence of technical and technological solutions, the implementation of which will allow corn grain drying with a high level of energy efficiency.

The research of the drying process indicators was carried out based on the results of experimental studies on the Saphir 2134 grain dryer in the conditions of "Agrotechservice" LLC, Poltava region, Ukraine. The grain dryer was located in a special hangar. The process of supplying the coolant by fans to the perforated walls of the grain columns was stable and uniform. The coolant with the appropriate temperature was formed in a biofuel boiler unit [14].

To control the drying parameters in the Saphir 2134 grain dryer, humidity and temperature sensors are installed, which provide continuous monitoring of the process. The SMART LOOP humidity control system allows to accurately determine the level of grain moisture at the outlet, which allows to avoid both overdrying and underdrying of products. RTD temperature sensors located in different zones of the drying chamber provide high-precision temperature control with an accuracy of one degree Celsius. This level of automation helps optimize the drying process, increase energy efficiency and the quality of finished products. The electronic components in the grain dryer are manufactured by Schneider Electric (France).

To substantiate the economic efficiency of the corn grain drying process, the cost of a ton-percentage was used for drying one ton of grain by 1 %. A ton-percentage is a specific value in the grain elevator industry and is used to determine the cost of services or fuel consumption (gas, diesel fuel, biomass) for drying or cleaning grain. Accordingly, the value UAH/ton-percentage was used to determine the cost, and the value m^3/ton-percentage was used for the consumption of natural gas for drying one ton of grain by 1 %.

3. Results and Discussion

To ensure the autonomy and continuity of the technological process of grain drying for "Agrotechservice" LLC a technological process was proposed and implemented, which involves the use of alternative energy sources, the scheme of which is presented in Fig. 1.

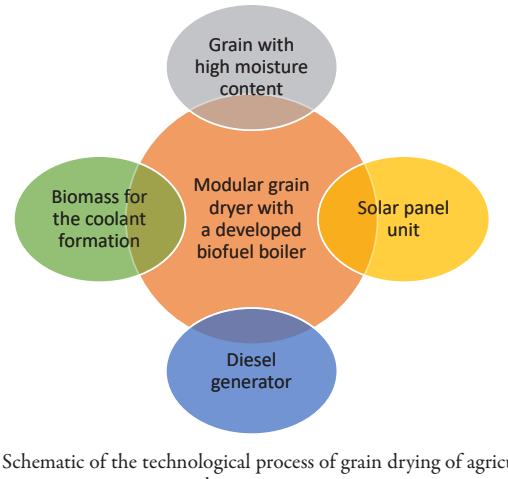

Fig. 1. Schematic of the technological process of grain drying of agricultural crops using alternative energy sources

Biomass (residues of corn stalks, sunflower, straw, chopped wood) for forming the coolant is stored in a special room (Fig. 2) and fed by

a conveyor to a special bunker, from which it is fed by screws into the combustion chamber of the biofuel boiler. The screw pitch and its rotation frequency provide the necessary supply of biomass.

Fig. 2. Biomass storage room

The combustion chamber of the boiler (Fig. 3, *a*) is made of AISI 310S steel with a thickness of 10 mm, ensuring reliable operation of the grain dryer and extended service life. The boiler operation process is configured in such a way that when biomass is fed into the combustion chamber, air is supplied from the environment by appropriate fans. In parallel, another fan is turned on to remove smoky air to ensure traction and stable combustion of biomass. To improve the efficiency of the grain drying process, air is supplied to the grain cooling zone through special channels to the fan for heating and then to the grain drying zone.

The Saphir 2134 grain drying unit (Fig. 3, *b*) implements the "cross flow" grain drying technology, which involves blowing heated air perpendicular to the grain movement.

a *b*

Fig. 3. General view of the elements of the grain dryer: *a* – Saphir 2134 grain drier; *b* – biofuel boiler for forming the coolant [14]

The technological process of grain drying is as follows. Grain is fed into the upper part of the grain dryer by means of a loading device, where the screw loads the columns in turn with a uniform distribution along the entire length. At the same time, the fans pump heated air into the drying chamber, removing heat from the pipe elements. Then, the heated air under the pressure of the fans is blown through the perforated walls of the grain columns, heating the grain and causing the evaporation of moisture from its surface.

Effective air mixing with effective biomass combustion ensures uniform temperature of the heated air at all points of the grain dryer.

In the absence of gas and electricity supply to the farm, the grain dryer will perform the technological process of grain drying in an autonomous mode, using a diesel generator (Fig. 4, *a*) and a solar battery unit (Fig. 4, *b*).

Given the experience of operating grain dryers, in further calculations it is necessary to take into account that the actual fuel consumption, as a rule, is from 1/2 to 2/3 of the maximum consumption declared by the manufacturers. This is explained by the fact that in the technical characteristics, manufacturers indicate fuel consumption for the mode when the burners operate at maximum power continuously for one hour. However, in real conditions of grain drying, the burners automatically switch between the "large" and "small" fire modes under the control of the control system, which maintains the required drying temperature.

a *b*

Fig. 4. General view of the elements that ensure the autonomy of the grain dryer, which are used in the process of corn grain drying at "Agrotechservice" LLC of the Poltava region: *a* – diesel generator; *b* – solar battery block

The results show that when the moisture content is reduced from the initial 21 % to the conditioned 13.5 % at a temperature of 65 °C for 23 hours, 295 tons were dried. The productivity of the Saphir 2134 grain dryer in the conditions of "Agrotechservice" LLC for corn, with a decrease in humidity by 7.5 % in the grain heating mode, was 12.83 t/h. The number of dried ton-percentages per hour was: 12.83 t/h×7.5 % = 96.2 t/%, and the total number of ton-percentages as a result of the experiment was 2212 t/%, while 7520 kg of biomass was consumed. To assess economic efficiency, it is possible to calculate the biomass consumption per 1 t/%, for this let's divide the amount of biomass consumed by the number of ton/percentages: 7520 kg/2212 t/% = = 3.4 kg/1 t/%.

Based on the fact that to reduce humidity by 1 t/%, it is necessary to spend 3.4 kg of fuel, it is possible to calculate the cost of biomass per 1 t/%, for this it is possible to multiply the cost of one kilogram of biomass by the amount of biomass required to reduce humidity by 1 t/%:2.5 USD·3.4 kg = 8.5 USD.

Organoleptic assessment of grain after drying using the proposed technology showed the preservation of the main quality characteristics that are essential for further storage and processing. Corn grain did not lose its natural color, remained uniform in shape and structure, without signs of overdrying, blackening or damage. Also, no foreign odors were observed that could indicate overheating or burning of biomass during drying, which confirms the stability of the heat supply mode. Taste characteristics (when determined within the framework of laboratory analysis) remained unchanged, without bitterness or other deviations that could arise from the destruction of organic substances. Thus, it can be stated that the use of an improved biomass boiler in conditions of autonomous energy supply provides not only economic efficiency, but also allows maintaining a high level of grain quality.

To compare the efficiency of the technological process of corn grain drying, "Agrotechservice" LLC conducted studies on the operation of the grain dryer on different types of fuel, the results of which are given in Table 1.

The results of the economic efficiency of corn drying using different types of fuel are presented in Table 2.

Analysis of the research results showed that to reduce the moisture content during grain drying in the conditions of "Agrotechservice" LLC by 1 ton-percent at a cost of 3.4 kg of biomass, the total cost of drying on the Saphir 2134 grain dryer is 0.205 USD, which is 3.7 times less than when using natural gas and 9.2 times less than when using diesel fuel.

The graph of the dependence of specific costs and cost of corn grain drying is shown in Fig. 5, and the cost of corn grain drying on different types of fuel is shown in Fig. 6.

The results indicate that natural gas has the lowest specific costs, which indicates its effective use, and biomass requires the rawest materials for drying 1 ton of grain. However, biomass provides the lowest drying cost per 1 ton/% – it is almost 4 times cheaper than natural gas and 9 times cheaper than diesel fuel.

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Table 1

Results of research on corn grain drying using different types of fuel

Indicators	Indicator value		
	Natural gas	Diesel fuel	Biomass
Fuel used, m^3/l/kg	3864	1872	7520
Moisture content of corn before drying, %	22	22	21
Moisture content of corn after drying, %	14	14	13,5
Grain temperature, °C	80	80	65
Drying time, h	23	10	23
Dried ton-percentage, t/%	2576	1040	2212
Dried, t	322	130	295

Table 2

Results of comparative studies of corn grain drying using different types of fuel at "Agrotechservice" LLC

Indicators	Indicator value		
	Natural gas	Diesel fuel	Biomass
Fuel consumption per 1 ton-percent, m^3/l/kg	1.5	1.8	3.4
Fuel cost, USD	0.5067	1.052	0.060
Drying cost per 1 ton-percent, USD	0.759	1.894	0.205
Drying cost per 1 t, USD	7.597	18.937	2.052

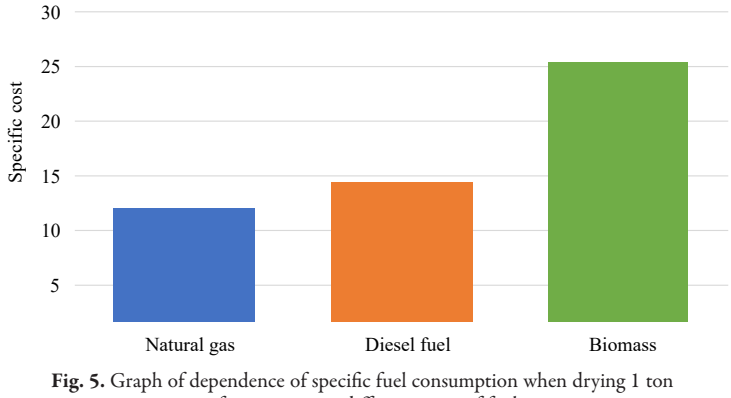

Fig. 5. Graph of dependence of specific fuel consumption when drying 1 ton of corn grain on different types of fuel

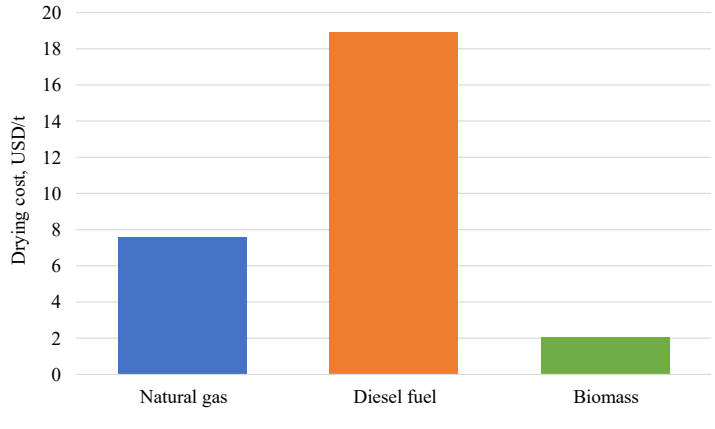

Fig. 6. Graph of dependence of cost of corn grain drying on different types of fuel in conditions of "Agrotechservice" LLC

It can be argued that natural gas is the most efficient, as it requires the least fuel to reduce moisture by 1 %. Diesel fuel has slightly higher costs, which makes it less attractive for drying. Biomass has the highest specific costs, which confirms its lower energy efficiency, but has the lowest cost.

As stated in [15], depending on the needs of the farm and the characteristics of the crop, the use of mobile dryers is the best solution for grain drying. However, the weather conditions of a particular year should be taken into account. For example, in 2022, in the conditions of "Agrotechservice" LLC, in order to lay grain for long-term storage, it was necessary to dry 50 % of early cereals, 70 % of sunflower, and 100 % of corn, which is impossible to do with mobile grain dryers. Therefore, the option of using the Saphir 2134 grain dryer with a biomass boiler is a more optimal and economically profitable option.

Thus, if there is a stable supply and storage of biomass, then it is the optimal option for use as an energy carrier for grain dryers, and the proposed option of a biomass boiler ensures the reliability and resource efficiency of the technological process.

The results obtained during the research were applied in practice at "Agrotechservice" LLC in the city of Reshetylivka, Poltava region during 2022–2024. The Saphir 2134 grain dryer with a biomass boiler provided drying of wheat, sunflower and corn harvested in the fields of the farm. The scope of application of this technology is not limited to a specific farm, the materials for the boiler design are patented and can be implemented in other farms.

Partial restrictions on the use of research results are associated with a certain level of smoke during biomass combustion in the boiler. However, these processes do not affect the quality of the resulting products. Therefore, additional research is being conducted to develop a gas emission cleaning system to improve the environmental performance of the boiler.

The introduction of martial law in Ukraine became the main factor in the development of a biomass boiler for grain drying and improving the technological process by ensuring its autonomy. And the biomass used as a heat source during drying solved the problem of energy supply interruptions.

4. Conclusions

An autonomous technological process of grain dryer operation using alternative energy sources is presented, which is relevant during periods of interruption of energy supply.

It was established that the decrease in humidity during grain drying in the conditions of "Agrotechservice" LLC by 1 ton-percent at a consumption of 3.4 kg of biomass, the total cost of drying on the Saphir 2134 grain dryer is 0.205 USD.

It is noted that natural gas has the lowest specific costs, and biomass requires the rawest materials for drying 1 ton of grain. However, biomass provides the lowest cost of drying per 1 t/% – it is almost 4 times cheaper than natural gas and 9 times cheaper than diesel fuel.

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Conflict of interest

The authors declare that they have no conflict of interest regarding this study, including financial, personal, authorship or other, that could influence the study and its results presented in this article.

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Data availability

Data will be provided upon reasonable request.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the presented work.

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