ENERGY INTEGRATION OF CORN COB IN THE PROCESS OF DRYING THE CORN SEEDS

Mohamad Elbashir Rajab ELQADHI[1], Siniša ŠKRBIĆ[1*], Omer Ali MOHAMOUD[1], Aleksandar AŠONJA[1]

[1]Faculty of Economics and Engineering Management, University Business Academy, Novi Sad, Serbia

[*] Corresponding author; E-mail: sinisa.skrbic@in-tech.rs

A greater contribution to energy production in the future should be expected from agricultural biomass, because current research indicates low utilization of agricultural biomass specifically in the direct combustion process. The paper presents an example of energy integration of the corn cob in the process of drying seed corn. The paper presents the efficient method of drying corn seed with one's own corn cob. The technological process of drying is presented through the technological process of operation of the corn seed dryer on the corn cob, the energy industrial plant of the dryer and the technological process of two-pass drying of the cob. The main characteristic of a given dryer is the process of two-pass drying of the cob, because the air passes through the cob layer twice and in that way energy is saved. The drying time on the presented dryer has been shortened from the usual time from 90 h to 80 h, i.e. by 11%. This increase in performance results in a 15% reduction in dryer operating costs.

Key words*: Biomass, corn seed, energetic efficiency, dryer, thermal energy, two-pass drying*

Introduction

Fossil fuels that are in use today are characterized primarily by high emissions of CO_2 and other pollutants [1-3], uneven distribution of sources, expensive production and etc. On the other hand, we have renewable energy sources that are evenly available, environmentally friendly and can significantly compensate for the needs of fossil fuels in the production of electricity, heat and fuel for transport [4].

The use of renewable energy sources (biomass) can be an important factor in assessing the status of economic activities because locally available renewable resources from agriculture and forestry can be used [5]. Biomass can be transformed into a useful form of energy using thermochemical processes, all depending on the type and amount of available biomass, its humidity, the required amount of energy, the level of investment, etc. [6]. Agricultural biomass is an almost intact resource in terms of energy. Today, there is a large amount of unused biomass in agricultural production; AP Vojvodina alone has biomass on 1.78 million hectares [7]. Various residues in crop production such as: corn stalks, corn cob, straw, sunflower stalks, sunflower husks, fruit stones, residues from pruning fruit trees and vines, etc, they are a relatively easily usable form of energy [8]. The production and use of biomass for energy purposes reduces the emission of harmful gases and contributes to the protection of the environment. Biomass is a very acceptable fuel from the point of view of environmental impact because it contains very little or even no toxic substances, such as sulfur and heavy metals found in fossil fuels. The main advantage of biomass over fossil fuels is its renewable value [9]. It is calculated that the load of the atmosphere with CO_2 when using biomass as fuel is negligible, since the amount of CO_2 emitted during combustion is equal to the amount of CO_2 absorbed during plant growth [10].

About 2,000 billion tons of dry biomass are produced on our planet every year [11]. About 1.2% is used for food, 1% for paper and 1% for energy production, while the remaining 96% is rotten (one part is used as organic fertilizer) [11]. Unfortunately, research shows that only in AP Vojvodina (northern Republic of Serbia) only 3.15% of agricultural solid biomass is used for energy needs in the process of direct combustion, while for example 2.64% of biomass is burned in the field [12].

Due to the growing need for energy, new methods in energy production are emerging, on the other hand, existing ones are being improved, all with the aim of increasing the share of renewable energy sources in the energy balances of countries [13,14]. The current situation on the energy market related to the current global energy crisis, increasingly expensive fossil fuels and efforts to protect the environment, impose the need to change drying technologies and the transition to biomass as an energy source. For the above reasons, replacing the most commonly used fossil fuels (oil, gas, heating oil, coal, etc.) with locally available biomass in the grain drying process is very important.

Several research papers have analyzed the efficiency of two-stage drying of seed corn. In the process of two-stage drying of seed corn, when using fuel oil, energy savings of 20 to 26% were achieved [15], and when heating oil was used, savings of 13% were achieved [16]. In research [17] on corn drying on a convective dryer driven by the waste heat of exhaust gases (diesel generator), the average drying speed was between 0.83 and 1.4 g/min, and the drying time was between 305 and 515 min. Research [18] has shown that the amount of moisture in the corn cob has an effect on increasing energy consumption and prolonging the drying time, because moisture condensation from the fluid can occur.

The aim of this paper is to present a method for drying seed corn with your own corn cob. This method will be shown in one example where the corn cob was successfully used for drying seed corn. The capacity of the dryer is 90 t/day. The dryer is designed for a harvesting capacity of 4,400 t of raw cob per season. Within the presented research, by optimizing the operation of the presented seed corn dryer in the process of two-pass drying of the cob, the drying time was reduced by 11%, and the costs by 15% compared to the classic drying methods.

Corn Cob as a Source of Energy

Corn is the third most important crop in the world [19-21], mostly grown in the USA, China, India and Brazil [22,23]. In the Republic of Serbia, and especially in AP Vojvodina, corn is the most important plant species [24]. The cob is made up of seed and corn cob. The corn cob has long been used in all parts of the world as firewood, for mats and animal feed, for production furfural (plastics) [25], insulation [26], a medium for growing mushrooms, metal polishing agent [27], and etc.

The most efficient method of using corn cobs for energy purposes is direct combustion in the process of drying a corn seed cob. The main advantage of this method is that the amount of corn cob from the crowned seed corn is sufficient to completely dry the total mass [28,29]. The size of the shell is very important for the combustion process, the ideal length of the shell should be from 1 to 1.5

times the diameter of the shell [30]. This ash as a resource can further be used in agriculture for soil regeneration [31], or in construction for the production of cement (concrete) [32-34].

In the Republic of Serbia, the energy potential of corn cobs is estimated at about 1.2 Mt or about 430 ktoe [35]. The calorific value of the absolutely dry corn cob is 18.35 kJ/kg [12]. The lower calorific value corn cob changes with a moisture content of 5% - 17.45 kJ/kg, by 10% - 16.4 kJ/kg, by 15% - 15.36 kJ/kg, by 20% - 14.3 kJ/kg and by 25% - 13.3 kJ/kg, fig. 1 [10].

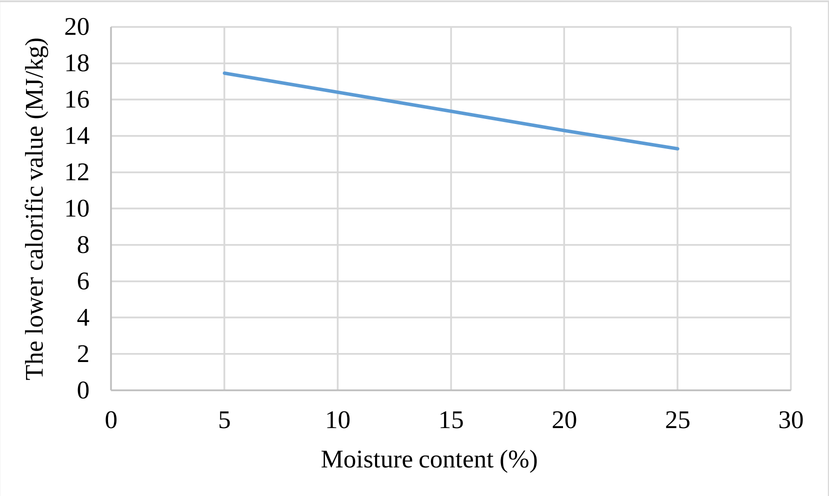

Figure 1. Dependence of the lower heat value corn cob on the moisture content

Materials and Methods

Technological Process of Dryer Plant Operation

The process of receiving seed cobs of corn was organized gradually according to the length of ripening time, first for early-growing hybrids, then for medium-growing and finally for late-growing hybrids. The same hybrid is inserted into one chamber (bin) of the dryer. Harvested cob should not wait longer than 12 hours to dry, because the quality of wet seed decreases. Also, temporary storage of wet cob in baskets (porches) for several days is not recommended, especially in conditions when air temperatures are lower than 0°C, because internal cracks in the seed can occur due to water freezing in microcapillaries. Corn seed production technology means that the ear of corn is often harvested with a high moisture content (up to 38% before it physiologically matures), in order to reduce the risk of damage from frost, insects and diseases. In order to store it safely, it is necessary to reduce the moisture content to ~ 13%. Depending on the moisture content and the characteristics of the hybrid, drying can take up to 100 hours per bin. Since most seed dryers for corn are realized on the principle of drying in a thick fixed layer, for these reasons it is necessary to consume large amounts of thermal energy.

Fig. 2 shows a schematic representation of a corn seed dryer on a corn cob that is the subject of research in this paper.

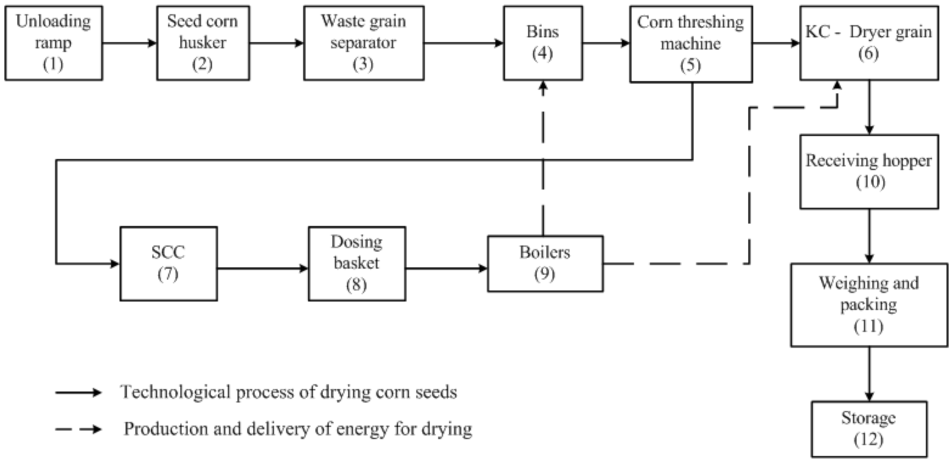

Figure 2. Schematic representation of a corn seed dryer on a corn cob

After measuring the mass, sampling and determining the moisture, the seed corn in the cob goes to the unloading ramp (1) where it is unloaded from tractor trailers, fig. 2. Further, the cobs are distributed by belt conveyors to the seed corn husker (2) where the cob is separated from the husk, while the cobs are further passed through the selective conveyor belt (selective table), ie. waste seed separator (3) and it is distributed in bins (4). The speed of filling the bins is 15 t/h. There are a total of 7 bins used for drying cobs, the capacity of one bin is 35 t/bin. The floor dimensions of one bin are 3.75x6.5 m. Inside the bin, perforated slopes are placed at an angle of 23°, the floor is made of stainless steel (AISI 304; 1.4301) 3 mm thick. The perforated floor is corrugated with a wave diameter of 65 mm. The openings on the floor are 20x3 mm transversely placed in relation to the direction of the wave, the light surface of the opening is 32.5%. The channels in the bins are placed at identical distances, their dimensions are: height 1.1 m, length 5.75 m, width of the channel at the top 0.2 m, width at the bottom 0.52 m. There are always 6 bins in operation, while one is off. Drying in bins takes up to 2.5 days/bin. In the bins, the initial humidity of the cobs is 38% and is removed up to 15%, after which the cobs are distributed to the corn threshing machine (5). The crowned seed is distributed to the KC by elevator and belt conveyors after purification (6). In the KC, the seed is dried as needed, where it dries up to 13%, ie. for safety up to 12.5%. A total of 4 KC with a capacity of 22 t/KC were installed, fig. 4-a. Each KC has its own centrifugal fan that takes the working fluid from the air duct of warm air at 42°C. Belt conveyors further distribute the dried seed from the KC to the receiving hopper (10), then it is weighed and filled into bags (11) and further transported to the warehouse.

Basic parameters of the technological drying process

The basic parameters of the technological drying process are: cob inlet humidity in the "bin of corn-on-the-cob"(bin) 38%, cob output humidity from the bin 15%, seed moisture output from the "kongskilde cell" (KC) 13%, drying time of the total amount of seed corn up to 70 days and the drying time of the 35 t cob mass in one bin is 80 hours (season average).

The paper presents the solution of a corn seed dryer on a corn cob, through: the technological process of operation of the corn seed dryer, dryer power plant and technological process of two-pass drying of cob.

The analysis of the results of the research on the process of drying corn seeds was presented through the dependencies: dependence of hot air flow through the centrifugal fan on the frequency of the current in the bins (with and without cob), the dependence of the electric motor current on the frequency of the current in the bins (with and without cob) and dependence of hot air flow on the charge of KC.

To investigate the dependence of hot air flow on the charge of the KC, the boiler K1 for hot air supply KCI, III and IV is included in the paper, fig. 3. The temperature at the beginning of the hot air duct was 50.3°C. There were two centrifugal fans in front of the KCI and III. The electric motors of the centrifugal fan operated at a frequency of 45 Hz. The KC I was filled 45% with corn seed, KC III with 50% and KC IV with 25%. The ambient air temperature was 20.4°C, and the air flow was 6,000-13,000 m^3/h.

The instruments used for the measurement are:

- measurement of air velocities was performed with a portable instrument "Testo 425",
- temperature measurements in hot air ducts at 42°C and in the bins were controlled by a glass mercury and alcohol thermometer.
- measurement of the moisture was performed with a Portable moisture meter for granular products mini GAC.
- measurement of warm air temperatures in the duct directly at the fan outlet, and at the entrance to the KCwas performed with a portable instrument "Testo 325".

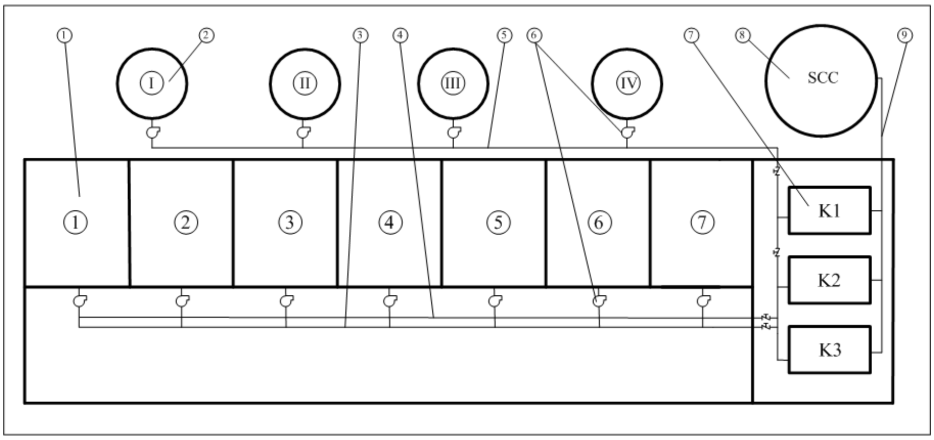

Figure 3. Schematic representation of the technological process of drying seed corn (1 - bins from 1 to 7; 2 – KC from I to IV; 3 - upper channel of warm air temperature 32°C; 4 - lower channel of warm air temperature 42°C; 5 - hot air duct for KC, 6 - centrifugal fans, 7 - boilers from K1 to K3, 8 - storage for corn cobs (SCC), 9 - system for extraction and transport of corn cob to boilers)

The corn cob and chaff are the only sources of thermal energy for drying cobs and seeds on the observed technical system, which is pneumatically transported by a centrifugal fan via pipeline DN300 to the storage (7), which has a capacity of 64 m^3. The corn cob is transported using an agitator and transferred to the dosing basket (8) using screw and belt conveyors, fig. 4-b. The dispenser inserts the corn cob into the fireclay of the boiler (9), fig. 4-c. The temperature in the firebox is from 400 to 800°C depending on the drying conditions. The regulation of the dosing of cob in the furnace is performed on the basis of measuring the temperature of the furnace and the temperature of the drying air in the middle channel of the dryer. The primary air is injected by a centrifugal fan into the boiler furnace. The produced combustion products are pushed by the same fan through the heat exchanger tubes. Further through the sedimentation chamber, they go purified into the chimney. The outside air is sucked in by centrifugal fans placed next to the bins, flows through the eye of the exchanger tube, heated and injected into the energy channel of warm air at 42°C [36]. The hourly consumption of corn cob per boiler is ~ 273 kg/h depending on the drying conditions.

a) *b)* *c)*

Figure 4. Corn seed dryer: a) KC for drying corn seeds; b) Transport corn cob to the boiler; c) Boiler

Energy Part of the Dryer

The boilers presented in the paper use corn cob as an energy source for the drying process. The plant consists of three boilers UT-850 each 850 kW, tab. 1. For the needs of drying, 650÷700 kg of corn cob/h are consumed, which are automatically delivered to the boiler. The specific design of the heat exchanger ensures efficiency and energy utilization ~ 80%, tab. 1. The calculated values required for drying energy in the presented seed cob dryer are shown in tab. 2.

Table 1. Basic technical and technological characteristics of the boiler UT-850

Technical and technological characteristics of work	The amount of size
Nominal thermal power (kW)	850
Type of regulation	Manual
Max. fan flow (m^3/h)	90,000
Fuel tank capacity (m^3)	1.55
Boiler dimensions (mm)	2,300 x1,800 x 3,810
Chimney diameter (mm)	500
Degree of utilization for corn cobs (%)	80
Consumption corn cobs per hour (kg)	266
Consumption of corn cobs per day (kg)	6,384

Table 2. Calculated values of parameters required for drying energy [36]

Calculated sizes	Value
The surface of the opening in the floor of the new dryer bin (m^2)	10.72
Air flow velocity through bins (m/s)	0.2-0.4
The amount of air in one bin (m^3/h)	19,426-38,825
Warm air flow temperature 42 ° C through the bin (fan capacity per bin) (m^3/h)	35,000
Fan capacity for 6 bins (m^3/h)	210,000
Required power of the heating plant at t_1=42°C and t_o=10°C for 6 bins in operation (MW)	2.06
Required amount of air, temperature 42°C for one KC (m^3/h)	15,000
The required amount of air for 3 KC (m^3/h)	45,000
Required power of the heating plant at t_1=42°C and t_o=10°C for 3 KCs in operation (MW)	0.44
Total required thermal power of the power plant (MW)	2.5

Technological process of two-pass drying

The main characteristic of the corn seed dryer is the process of two-pass drying of the cob, because the air passes through the cob layer twice and in that way energy is saved [10]. Centrifugal fans placed in front of the cob bins can suck air from the hot air duct at 42 or 32°C, depending on which blind above the chamber is open [27, 28]. During the drying process, care should be taken that three bins are they blow from the lower channel of warm air with an air temperature of 42°C, and three bins from recirculation, ie. from the upper hot air duct with a temperature of 32°C. Three fans draw ambient air through the boilers (at least two boilers), the air is heated, and passes through the hot air duct 42°C, blinds, chamber, fan, air distribution duct under the bin, perforated floor, air distribution channels in the piston layer (II phase of piston drying), air further passes through windows on 32°C hot air ducts, recirculation ducts above the other three fans, blinds, other three fans, through the air distribution ducts in the other three bins, through the perforated floor, through the air distribution channels in the cob layer, through the cob layer and air exits into the atmosphere through the windows on the outer wall of the dryer (I phase of cob drying). In the first three bins there is corn that is partially dried with a moisture content of 24%. This cob is dried at an air temperature of 42°C till 13 to 15% humidity. In the other three bins, there is a cob with a moisture content of about 38%, and it is dried with recirculated air at a temperature of 32°C. This cob is dried to about 24% moisture content. The air temperature must not exceed the value of 42°C, due to the sensitivity of the germ, since it is seed corn.

The speed of air through the layer cob should be in the range of 0.2-0.4 m/s. The drying process of the cob lasts from 70 to 90 hours (average 80 hours), depending on the moisture content in the cob, air flow and air temperature.

Results and Discussion

Dependences of hot air flow through the fan on the frequency of the current in the bins (with and without cob)

Measurement of air flow was performed in the distribution channel under the sloping floor in bin 1 with and without cob at a current frequency of 43 Hz, ie. air velocities of 12.4 m/s. The cross-sectional area of the channel was 0.72 m^2. Based on this cross-section, an air flow of 8.93 m^3/s or 32,141 m^3/h was obtained. The air temperature in the bins at the measurement point was 36.3 to 37°C. After this measurement, the current frequency was raised to 48 Hz and an air flow of 38,880 m^3/h was obtained. At a frequency of 50 Hz, an air flow of 43,891 m^3/h was obtained. Since there was a very strong air flow in bin 1, the frequency was reduced to 47.5 Hz. This frequency corresponds to an air flow of 38,000 m^3/h, which corresponds to the design value. For further calculations, the air flow through one bin of 38,000 m^3/h was adopted.

The measured air temperatures at the opening for inserting the cob into bin 1 in the attic were 21 and 22°C at a frequency of 43 Hz. The measured air flow velocity above the cob (at 43 Hz) was 0.74 m/s. It varied from 0.4 to 1.6 m/s. The first third of the bins had a lower value of the speed than the average, the middle of the bin was higher, and at the end of the bin the values of the speed of air flow through the cob layer were lower. Air temperatures ranged from 21 to 26.8°C. At the end of the bin, the air temperatures were higher. By raising the frequency to 48 Hz, then to 50 Hz, air velocities ranged from 0.5 to 1.9 m/s. The mean value was 1.12 m/s. The first and third thirds of the bin had higher values of speeds, and the middle third had lower values. This means that at 50 Hz the opposite result of 43 Hz was obtained. Therefore, lower frequency values for fan operation of 47.5 Hz were chosen.

Fig. 5 show the processed diagrams of the dependence of the flow of hot air through the fan on the frequency of the current, in bin 3 without the cob and with the cob. An increasing curvilinear dependence of the air flow through the fan in front of bin 3 on the current frequency was established. This dependence is very important in order to know with what frequency the current will work on a certain fan, ie. from the diagrams fig. 5 can be read the dependence of the air flow through the fan, ie bin.

By starting boiler K2, and then boiler K3, temperature measurements were performed in the lower channel with warm air at 42°C and in bins 3, 5 and 7, with air flow through the boiler, fan and bin of 36,432 m^3/h (43 Hz and 27 A). The temperature in the hot air channel at 42°C was stable at 54°C, while the temperature values in the bins were: in bin 3 (43°C), in bin 5 (45°C) and in bin 7 (50°C). From these data, it can be stated that the closer the bin was to the boilers, the higher the air temperature, because the fans worked more efficiently closer to the boilers (they had lower resistance to air flow). If we take into account that the surface of the perforated floor is 26.63 m^2 (7.1x3.75 m) and the average value of the porosity of the cob of 43% (41 to 45%), then the air flow at 43 Hz 30,454 m^3/h at 50 Hz 46,252 m^3/h.

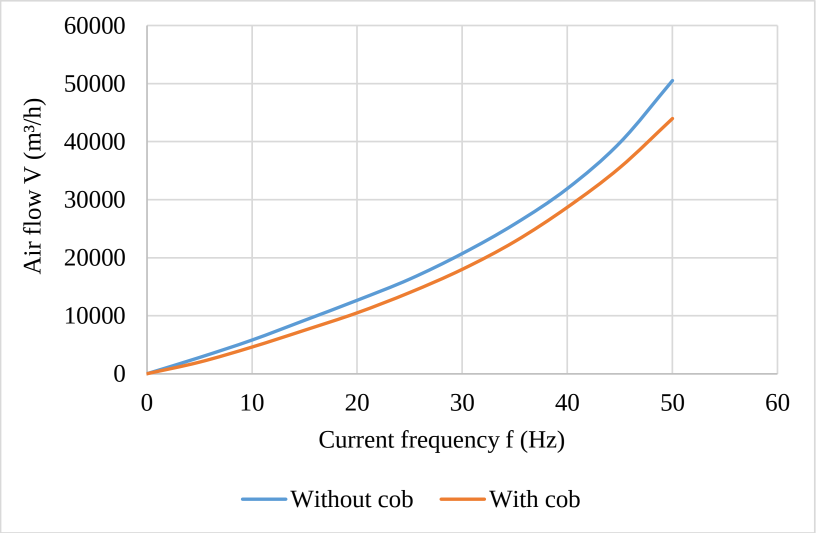

Figure 5. Diagram of the dependence of the flow of warm air through the fan on the current frequency: a) without cob and b) with cob

In front of bin 1, the fan effort increased due to the blowing of air through the cob, and therefore the air flow at the same operating frequency decreased. For example, at a frequency of 43 Hz, the air flow through the empty bin was 36,432 m^3/h, and with a filled bin with a cob, the flow was reduced to 32,131 m^3/h or by 9.23%. This should be kept in mind when using the diagram of the dependence of air flow on the frequency of the current when the fan is idling (without cob), fig. 5.

Dependences of electric motor current on frequency in BBCs (with and without cob)

Fig. 6 show the dependences of the current of the centrifugal fan electric motor on the current frequency in bin 1 without the cob and with the cob. This information is also important in order to know how much the electric motors of the fans are loaded during operation (empty and with a full bin). Based on the obtained results, it can be stated that the operation of centrifugal fans and boilers K2 and K3 is quite satisfactory. The fans were not maximally loaded (35 A at 50 Hz), where there were still reserves for operation (up to 43 A).

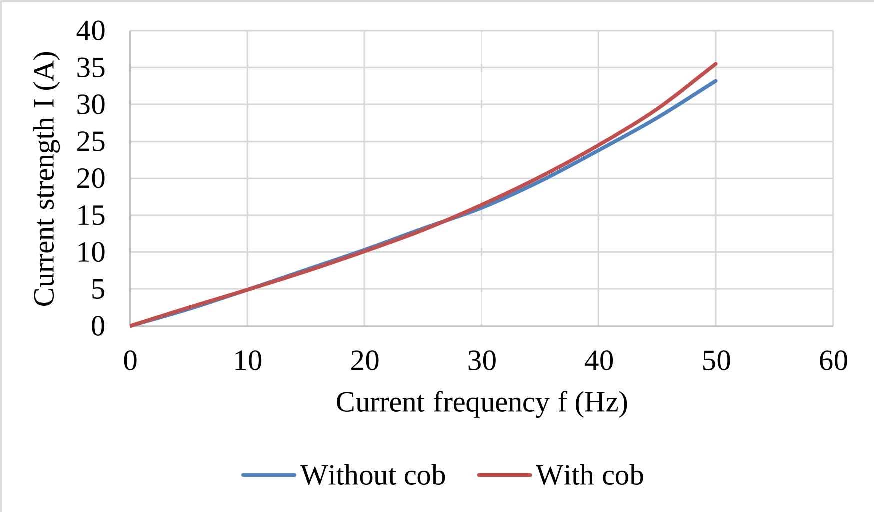

Figure 6. Diagram of dependence of electric motor current on frequency: a) without cob and b) with cob

Dependences of hot air flow on the charge of KC

During the first test of KC III, KC I and III were still involved in the work. The average measured air temperature was 43.7°C. The average air flow rate was 10.64 m/s. The cross-section of the channel at the measurement site was 0.368 m^2. Multiplying the average air velocity in the duct and the cross-sectional area of the duct, the value of air flow of 3.92 m^3/s or 14,115 m^3/h was obtained. The KC load with corn seed was 50%. The mean measured air temperature was 40.5°C. The mean air flow velocity was 6.63 m/s. The air flow was 8,795 m^3/h. The filling of KCs with corn seed was 45%.

During the examination of KCs IV, KCs I, III and IV were also included in the work. The mean measured air temperature was 42.3°C. The mean air flow rate was 5.47 m/s. The air flow was 7,252 m^3/h. The KC load with corn seed was 25%.

During the second study, KCs III were involved in the work of KCs I, III and IV. The mean measured air temperature was 42.4°C. The mean air flow velocity was 7.0 m/s. The air flow was 9,286 m^3/h. The KC load with corn seed was 50%.

During the third examination of KC III, only one KC was included in the work, ie. KC III. The mean measured air temperature was 41.9°C. The mean air flow rate was 13.2 m/s. The air flow was 17,511 m^3/h. The KC load with corn seed was 50%. During this measurement, the flaps were not closed on the intake ducts of other fans, so false air was drawn in KC III and the air temperature in the duct at the entrance to the KC was lowered. During the re-examination of KC III, only one KC was included in the work, ie. KC III. The mean measured air temperature was 38.8°C. The mean measured air velocity was 11.43 m/s. The air flow was 15,168 m^3/h. The KC load with corn seed was 50%. These test results are shown in the diagram of the dependence of the flow of warm air on the charge of the KC with corn seed in bin III, fig. 7.

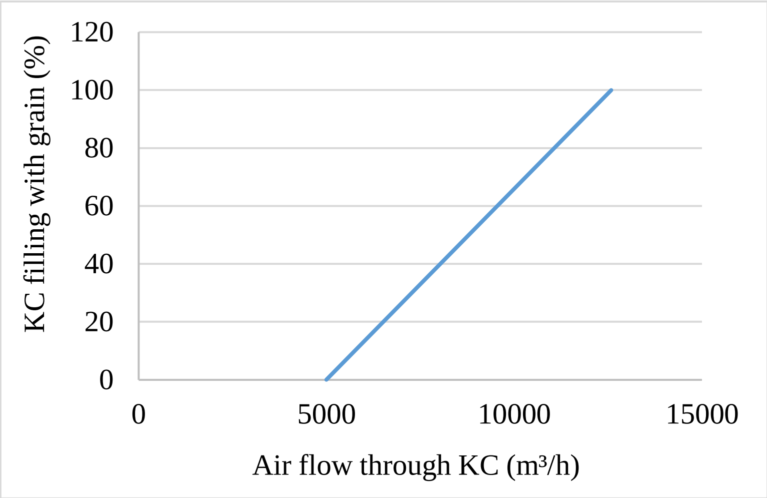

Figure 7. Diagram of the dependence of the flow of warm air on the charge of KC

The following facts can be stated in fig. 7: if only one KC is included in the work (for example III) then the flow of hot air increases and amounts to about 15,000 m^3/h, at a KC charge of 50%. With the inclusion of more KCs in the work (for example I, III and IV), the flow of hot air decreases and it amounts to 5,150 to 9,290 m^3/h, with a KC load of up to 50%. If the charge of the KCs increases to 100%, the flow of warm air increases to 13,000 m^3/h, if three KC are included in the work. If all four KC were included in the work, then the flow of warm air would probably be reduced even more. When switching on the fan at KC, care should be taken to ensure that the other valves are closed, if one of the KC is not working, because then there is a suction of false air from that KC and lowering the temperature in the KCs in operation. Very good test results were shown by the fans that serve the KC. The fans and the boiler that serves the KC were not maximally loaded, there were still reserves for work. The boiler is designed for only 55% of the capacity intended for KC, and the remaining 45% of the thermal energy is directed to the cob dryer.

The technical system of the described dryer corn seed is a sustainable, energy-efficient technical solution from the aspect of independence from the use of fossil fuels. During the technological process itself, the amount of energy produced (corn cob) required for the drying process (cobs and corn seeds) is higher than necessary, so that all excess corn cob can be freely sold on the market. Furthermore, significant savings are achieved related to transport and handling costs because the energy is produced in the technological process and fully automated transport by pneumatic transport, stored in a silo, and still dosed in boilers if necessary. Much higher transport and handling costs are realized by using fossil fuels, for example, research [37] showed that for drying corn seeds with an initial moisture content of 30.36%, to a final moisture content of 14.72% - the consumption of kerosene was 0.55 kg /h, that is, for drying corn cobs with an initial content of 27.53%, to a final moisture content of 11.55% - the consumption of kerosene was 0.91 kg/h. In the research [38] indicated approximately the same drying time for seed corn for 35% moisture, where the drying time was from 84 to 120 hours and depended on the type of hybrid.

Analyzing the obtained results of the hot air temperature test, it was found that the temperatures in the bins were equalized when cob were inserted, which increased the resistance to air flow, so in that case the amount of air in the bins was more evenly distributed.

The operation of the dryer is much more balanced when almost all fans were involved in the operation, than in the case of individual operation of the fan and one boiler. Temperatures and air flows were more uniform during the operation of the entire dryer. The main feature of the presented seed dryer is the energy efficiency of the dryer due to air recirculation. The air from the lower hot air duct at 42°C, passing through the cob layer is further taken to the upper warm air duct at 32°C which is recirculated again to the second bin with a wet cob. This solution of air recirculation (or two-pass drying) achieves: energy savings (energy consumption), reduction of energy capacities to be installed, and thus reduction of costs for the power plant and distribution network, reduction of operating costs and reduction of environmental pollution.

The advantages of corn cob as a fuel in corn seed driers are: it is suitable for substituting expensive fossil fuels; environ-mentally friendly - neutral in terms of CO_2 emissions; there is no possibility of pollution of natural resources (water, air and land) [39]; renewable annually; locally available fuel; suitable for heat energy production; easy for handling, transport, storage and delivery to boilers; fully automated energy supply plant; leaves much less ash compared to other types of biomass, e.g. straw; ash is suitable for the production of cement (concrete and mortar) [40-42], i.e. further for soil fertilization; very simple technical solution for transporting corn cob from storage to firebox; economically viable dryer solution, there aren't transport and handling costs for energy sources; little storage space is required due to the low weight of the corn cob; satisfactory drying capacities up to 90 t/day.

Conclusions

The presented dryer corn seed on corn cobs is an ideal example of the use of a renewable energy source "corn cob" in the drying of products. In the presented example of drying, corn cob is the only necessary energy source for the production of thermal energy, which makes this dryer very efficient and economical.

Corn cob is an economically cheap, energy-significant and environmentally friendly biofuel, and is recommended for the production of thermal energy in agriculture in order to save fossil fuels.

The main characteristic of the dryer corn seed is the process of two-pass drying of the cob, because the air passes through the cob layer twice and in that way energy is saved. The key results of the research are as follows:

- The drying process of the cob lasts from 70 to 90 hours (average 80 hours), depending on the moisture content in the cob, air flow and air temperature
- The drying time on the presented dryer has been shortened from the usual time from 90 h to 80 h, i.e. by 11%.
- By increasing the performance of the dryer, drying costs are proportionally reduced 15%.
- The optimal air flow for drying corn cobs in bins was 38,000 m^3/h and was achieved at a frequency of 47.5 Hz.
- In the operation of 3 KC, with grain filling of 50%, the flow of hot air was from 5,150 to 9,290 m^3/h, and when the cells were filled to 100%, the flow of hot air reached up to 13,000 m^3/h.

The biggest benefit from the research is energy saving, i.e. two-process drying of corn cob significantly improved the energy efficiency of the presented dryer. As the only source of energy, biomass was used as a renewable energy source. Therefore, along with the shown savings, the design parameters of the dryer were also achieved.

Further research on such technical systems should be directed in the direction of researching the possibility of cogeneration, ie simultaneous production of electricity and heat by burning corn cob.

References

[1] Hirz, M., *et al*., Greenhouse Gas Emissions of Electric Cars - A Comprehensive Evaluation, *Technical Journal, 16* (2022), pp. 280-287. https://doi.org/10.31803/tg-20220407135956

[2] Negi, H., *et al*., Indian Scenario of Biomass Availability and Its Bioenergy-Conversion Potential, *Energies, 16* (2023), 5805. https://doi.org/10.3390/en16155805

[3] Blagojević, N., *et al*., Analysis of a Solar Plant for the Production of Hot Consumption Water for the Hospital, *Advanced Engineering Letters, 1* (2022), pp. 23-27. https://doi.org/10.46793/adeletters.2022.1.1.4

[4] Prvulovic, S., *et al*., Resource Potential and Scope of the Use of Renewable Energy Sources in Serbia, *Energy Sources, Part B: Economics, Planning, and Policy, 11* (2016), pp. 901-910. https://doi.org/10.1080/15567249.2013.791898

[5] Maj, G., *et al*., Energy and Emission Characteristics of Biowaste from the Corn Grain Drying Process, *Energies, 12* (2019), 4383. https://doi.org/10.3390/en12224383

[6] Ibitoye, S.E,, *et al*., Improving the Combustion Properties of Corncob Biomass via Torrefaction for Solid Fuel Applications, *Journal of Composites Science, 5* (2021), 260. https://doi.org/10.3390/jcs5100260

[7] Ašonja, A., *et al*., The Validity for the Application of Solar Energy in Irrigation of Perennial Plants in Fruit Growing in the Republic of Serbia, *Applied Engineering Letters, 1* (2016), pp. 68-74.

[8] Ašonja, A., *et al*., Analysis of the Biomass Potentials of Hazelnuts and Nuts in the Republic of Serbia, *Tractors and Power Machines 24* (2019), pp. 101-106.

[9] Kažimírová, V., Opáth, R., Biomass Combustion Emissions, *Research in Agricultural Engineering 62* (2016), pp. S61-S65. https://doi.org/10.17221/69/2015-RAE

[10] Ašonja, A., Brkić, M., The Energy Efficiency of the Cobbed Seed Corn Dryer. In Proceedings - I Scientific-Professional Meeting "Energy Efficiency," Novi Beograd, Serbia, 25 October 2013, pp.34-52.

[11] Ašonja, A., *et al*., Energy Efficiency Analysis of Corn Cob Used as a Fuel, *Energy Sources, Part B: Economics, Planning, and Policy, 12* (2017), pp.1-7. https://doi.org/10.1080/15567249.2014.881931

[12] Škrbić, S., *et al*., Analysis of Plant-Production-Obtained Biomass in Function of Sustainable Energy, *Sustainability, 12* (2020), 5486. https://doi.org/10.3390/su12135486

[13] Konieczna, A., *et al*., Energy Efficiency of Maize Production Technology: Evidence from Polish Farms, *Energies, 14* (2021), 170. https://doi.org/10.3390/en14010170

[14] Kupreenko, A., *et al*., Heat Balance of Combined Heat Exchanger Aerodynamic Heating Dryers, *Advanced Engineering Letters, 1* (2022), pp. 80-87. https://doi.org/10.46793/adeletters.2022.1.3.2

[15] Kyrpa, Ya., *et al*., New Energy-Saving Method for Drying Maize Seeds, *Ukrainian Journal of Ecology, 11* (2021), pp. 56-62. https://doi.org/10.15421/2021_77

[16] Elbl, B., Podlesek. F., Optimizing Dryng Rate of Shelled Corn in the Feed Factory Črnci, *Krmiva, 45* (2003), pp. 209-217.

[17] Ononogbo, C., *et al.*, Energy Parameters of Corn Drying in a Hot Air Dryer Powered by Exhaust Gas Waste Heat: An Optimization Case Study of the Food-Energy Nexus, *Energy Nexus, 4* (2021), 100029. https://doi.org/10.1016/j.nexus.2021.100029

[18] Zlatanović, I., *et. al.,* Energy Efficiency Analysis of Corn Seed Drying Process in Maize Research Institute „Zemun Polje" – Zemun, *Agricultural Engineering, 2* (2011), pp. 87-96.

[19] Murthi, P., *et al.*, Effects of Corn Cob Ash as Mineral Admixture on Mechanical and Durability Properties of Concrete – A Review, *IOP Conf. Series: Materials Science and Engineering, 1006*, (2020), 012027. https://doi.org/10.1088/1757-899X/1006/1/012027

[20] Zou, Y., *et al*., Field Decomposition of Corn Cob in Seasonally Frozen Soil and Its Intrinsic Influencing Factors: The Case of Northeast China, *Agriculture, 11* (2021), pp. 556. https://doi.org/10.3390/agriculture11060556

[21] Romaneckas, K., *et al*., The Energy and Environmental Evaluation of Maize, Hemp and Faba Bean Multi-Crops, *Agronomy, 13* 2023, 2316. https://doi.org/10.3390/agronomy13092316

[22] Skoufogianni, E., *et al*., Maize as Energy Crop. In Maize-Production and Use, *Intech Open: London*, (2019), pp.1-16. https://doi.org/10.5772/intechopen.88969

[23] Gandia, R.M., *et al*., Experimental Pressures Exerted by Maize in Slender Cylindrical Silo: Comparison with ISO 11697, *Engenharia Agrícola*, *41* (2021), pp. 576-590. http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v41n6p576-590/2021

[24] Sabljak, V., *et al*., Effectiveness in the Production of Seed Maize per Different Way of Detasseling, *Annals of Agronomy, 43* (2019), pp.101-108.

[25] Castillo-González, E., *et al*., Vermicomposting: A Valorization Alternative for Corn Cob Waste, *Applied Sciences, 11* (2021), 5692. https://doi.org/10.3390/app11125692

[26] Wojcieszak, D., *et al*., Effects of Harvest Maturity on the Chemical and Energetic Properties of Corn Stover Biomass Combustion, *Materials, 15* (2022), 2831. https://doi.org/10.3390/ma15082831

[27] Ašonja, A., Brkić, M., Justification of Use of Shingles as Biofuels. In Proceedings - II Scientific-Expert Meeting "Energy Efficiency", Novi Beograd, Serbia, 12 December, 2014, pp.45-53.

[28] Komazec, S., Dedić, P., Analysis of Seed Corn Drying by Own Cultivation at AD Sava Kovaćević in Vrbas, *Savremena poljoprivredna tehnika, 34* (2008), pp.151-157.

[29] Babić, M., Babić, Lj., Corncobs as Fuel in Seed Corn Crying, *Plant Breeding and Seed Production, VI* (1999), pp.85-90.

[30] Martinov, M., *et al*., Maize Cobs Processor: Preparations for Its Use as a Fuel, *Savremena poljoprivredna tehnika, 34* (2008) pp.26-31.

[31] Barišić, I., *et al*., Multidisciplinary Approach to Agricultural Biomass Ash Usage for Earthworks in Road Construction, *Materials, 15* (2022), 4529. https://doi.org/10.3390/ma15134529

[32] Suhail, M.A., *et al*., Research on the Usage of Corn Cob in Producing Lightweight Concrete, *Natural Resources 12* (2021), pp. 339-347. https://doi.org/10.4236/nr.2021.1210023

[33] Kamau, J., *et al*., Suitability of Corn Cob Ash as a Supplementary Cementitious Material, *International Journal of Materials Science and Engineering*, *4* (2016), 215-228. https://doi.org.10.17706/ijmse.2016.4.4.215-228

[34] Athira, V.S., *et al*., Agro-Waste Ash Based Alkali-Activated Binder: Cleaner Production of Zero Cement Concrete for Construction, *Journal of Cleaner Production*, *286* (2021), 125429. https://doi.org/10.1016/j.jclepro.2020.125429

[35] Djatkov, Dj., *et al.*, Profitability of Corn Cob Utilization as a Fuel in Small Residential Heating Appliances, *Thermal Science, 25* (2021), pp.2471-2482. https://doi.org/10.2298/TSCI200508221D
[36] Technical Documentation of NS-Termomontaža d.o.o. (2017) Corn Seed Dryer in the Company Sava Kovacevic, Serbia.
[37] Rodríguez-Fuentes, H., *et al.*, Design and Manufacture of a Dryer for Corn Grains, Ears and Cobs, *Turkish Journal of Agriculture - Food Science and Technology*, *10* (2022), pp. 142-146. https://doi.org/10.24925/turjaf.v10i2.142-146.4448
[38] Mabasso, G.A., *et al.*, Energy efficiency and physical integrity of maize grains subjected to continuous and intermittent drying, *Revista Brasileira de Engenharia Agrícola e Ambiental*, *40* (2022), 193-198. https://doi.org/10.1590/2317-1545v40n2187373
[39] Vujic, B., *et al.*, Public Perception and Awareness on Climate Changes and the Importance of Renewable Energy Sources, *Applied Engineering Letters, 5* (2020), pp. 68-74. https://doi.org/10.18485/aeletters.2020.5.2.5
[40] Šupić, S., *et al.*, Environmentally Friendly Masonry Mortar Blended with Fly Ash, Corn Cob Ash or Ceramic Waste Powder, *Materials, 16* (2023), 6725. https://doi.org/10.3390/ma16206725
[41] Agrawal, V.M., Savoikar, P.P., Sustainable use of normal and ultra-fine fly ash in mortar as partial replacement to ordinary Portland cement in ternary combinations, *Materials Today: Proceedings*, *51* (2022), pp. 1593-1597. https://doi.org/10.1016/j.matpr.2021.10.409
[42] Olatoyan, O.J., *et al.*, Potential use of biomass ash as a sustainable alternative for fly ash in concrete production: A review, *Hybrid Advances*, *4* (2023), 100076. https://doi.org/10.1016/j.hybadv.2023.100076

Submitted: 23.12.2023.
Revised: 30.01.2024.
Accepted: 18.02.2024.