Springer Proceedings in Energy

Krzysztof Mudryk
Sebastian Werle *Editors*

Renewable Energy Sources: Engineering, Technology, Innovation

ICORES 2017

Springer

Prospects of Growing Miscanthus as Alternative Source of Biofuel

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Abstract The paper presents the results of research work aimed at determining process parameters for production of quality briquettes from Miscanthus raw material. Raw material was obtained from southern Ukraine from the autumn harvest. The obtained results clearly indicate that adequate grinding, humidity reduction of less than 15% and application of agglomeration pressures above 37 MPa, results in obtaining satisfactory quality briquettes. Compliance with the developed technological assumptions should not in practice lead to technical problems that will have a significant impact on the dissemination of this activity in rural Ukraine.

Keywords Miscanthus · Briquettes quality · Jakość brykietu · Density Mechanical durability

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K. Mudryk and S. Werle (eds.), *Renewable Energy Sources: Engineering, Technology, Innovation*, Springer Proceedings in Energy,
https://doi.org/10.1007/978-3-319-72371-6_78

1 Introduction

In modern conditions for agricultural development urgent problem is meet the ever growing needs of mankind, especially energy. Today 35% of the world's energy needs through use of available oil, coal, natural gas, which are non-renewable. Renewable energy sources for real opportunities to increase their share are very limited. Demand for energy from renewable sources in Ukraine is growing every year. Search for effective alternative sources of renewable energy is very urgent. One of them is the aboveground vegetative mass of plants that accumulate through photosynthesis, solar energy into vegetative organs and biomass can be converted into biofuel.

A key area of innovation identified at this stage of research the possibilities of using bioenergy crops as an alternative fuel. Today, the structure of the world of alternative energy biomass is about 13%. Subsequently, the share of renewable energy by 2040 will reach 47.7% projected researchers. The largest share of biomass in energy production typical for the EU: Latvia—26%, Finland—20%, Sweden—19%, Denmark—13%, Portugal and Austria—12% [1]. International experience shows that a promising feedstock for biofuel production is bioenergy plants. Interest in the growth and implementation of highly herbaceous plants such as species of the genus *Miscanthus Anderss*. is increasing [2].

The problem of biofuels can be solved in several areas: the use of the most efficient sources of biofuel from plant resources, improving technology transformation of raw materials for biofuels and biofuels feasibility study. Organizing of wide biofuel production in Ukraine has all the prerequisites, but their share in the energy balance is low. Ukraine has a great potential of biomass available for energy use, as G.G. Heletuha marks [3].

Today priority crops are already well defined that analyzed as a source of biofuels. However, the choice of effective raw materials depending on soil and climatic conditions of cultivation has its own feature. Among others herbaceous power plants including one of the highest ranks of introduced plants Miscanthus or "elephant grass". It belongs to the Department of angiosperms (Angispermal), class monocots (Monocatyledoneace), number (Glumifloreae), cereals family (Gramineae), kind (Anderssons), species (*Miscanthus giganteus*). This is hybrid of Miscanthus Chinese (*M. sinensis Anderss*., Diploid) and Miscanthus sugar flower (*M. sacchariflorus* (Maxim.) Benth., Tetraploid). In a temperate climate in the third year of growing Miscanthus productivity ranges from 10 to 30 t/ha dry weight, calorific value—from 14 to 17 MJ/kg [4]. It was first tried in Denmark. Biomass can be collected annually. From one hectare in temperate climates can be got 25–35 tons of dry mass per year and even more in irrigated field [5].

The largest plants impairment by frosts was observed in the first year of wintering after planting. Freezing may be subject to 90% of the plants. Large plants winter better (over 5 buds) than small (5). Small snow or complete absence makes the plant vulnerable to frost and promotes freezing. Mulching with straw crops Miscanthus crops can increase the level of wintering to 79–92%. Spring frosts lead to only minor yield losses due to the high regenerative ability of plants. Further plant adapts and tolerates winter. Starting from the second year of vegetation Miscanthus, plant resistance is higher in winter. Miscanthus belongs to thermophilic and moisture-loving plants.

Giant Miscanthus (*Miscanthus giganteus*) is a perennial grass plant, which is typical for C4-photosynthetic way. Unlike sugar cane, sorghum, corn and other C4-plants Miscanthus can grow in cool climates. This feature allows Miscanthus to realize its potential productivity in more northern climates, but it is different biomass feedstock for biofuels and cellulose [6]. You can see that in these plants during photosynthesis is complete utilization of carbon dioxide is not released into the atmosphere, and re-use process. Biomass while burning does not create the greenhouse effect.

Homeland of Miscanthus is vastly Japan, Manchuria, Korea, Thailand, the US east coast. Under natural conditions, this plant grows to a height of 6 m in diameter stems can be up to 6 cm. After planting a single culture can be harvested annually for 15 years or more, and vegetation can take up to 30 years. At the beginning of the V century Miscanthus was grown only in China as erosion culture. In Europe it was in the XVI century, but was considered only as an ornamental plant.

Miscanthus plants during the growing season require a small amount of water, characterized by rapid growth and development of stems and leaves. For the production of the dry weight of Miscanthus requires annual precipitation at 600–700 mm. To start the growth of leaves required minimum temperature + 5 + 10 °C. Daily temperatures in terms of European countries and Ukraine are sufficient to obtain high yields of biomass [7].

Miscanthus has a well-developed root system (2.5 m deep), characterized by rapid growth and relative stability to low temperatures. This root system promotes the use of batteries and water from the soil. It is suitable for growing in medium-fertile soils with low groundwater [8, 9].

The stem is very strong and has great endurance to mechanical damage, because it contains large amounts of lignin and cellulose.

Yield of energy crops depends on the climate, soil and other conditions. Depending on the type of energy crops cultivation process has its own characteristics. Conditions of Ukraine are suitable for growing Miscanthus. As for Ukraine Miscanthus is a new crop cultivation which requires the introduction and study in different soil-climatic zones—forest-steppe of Western. In the western steppes of Ukraine significant portion of soil is degraded and low-subject to reclamation. As for growing crops they are unsuitable, but appropriate in growing bioenergy crops.

Considering the urgency, the purpose of the analysis was a new culture—Miscanthus and outline the prospects for its use as a source of high-quality raw materials for Fitoenergetik in Western Forest.

Field research was conducted by conventional agronomic research and special techniques. The studied areas are directly in the middle of the southern slope of 2–3° slope. The depth of the water table 4–6 m topsoil generating breed—carbonate loess-like heavy loam. Profile soil humus formed by accumulative type of soil formation. The morphological features are typical black earth soil deep on loess loam. The humus content in the upper horizon is 3.39%, which corresponds to the level of family—little humus. With the depth the humus content decreases to 2.68% in the upper horizon and the transition to 1.25% in the lower transition horizon. Reaction environment is neutral with a tendency to increase water pH from 6.8 to 7.0 with depth, hydrolytic acidity decreases from 0.70 to 0.35 mg-eq./100 g of soil parent material. For agrochemical providing nutrients available to plants, soil belongs to the following gradation: alkaline hydrolyzed nitrogen is very low maintenance, mobile forms of phosphorus is standard, exchangeable potassium is increased.

Growing Miscanthus for improving processes for providing biomass will help to successfully implement the production of biofuels from raw materials of vegetable origin. It is given the simplicity of the plants to soil conditions, it is advisable to grow on unproductive soils. It grows on fields that are unsuitable for agriculture—too acidic, waterlogged or contaminated, but give environmentally friendly materials.

Miscanthus is sensitive to the quality of the soil, so the fertile soils yield can reach up to 30 t/ha per year, and the poor—barely reach 10 t/ha. For growing Miscanthus most suitable loamy, sandy and degraded lowland peat with stable for years during the growing season with supply of moisture. Do not lay Miscanthus plantations on sandy soils with low and unstable supply of moisture and high weediness perennial rhizomes and weeds. By moving the contents of elements phosphorus and potassium can be used soils with low to medium security.

Bookmark Miscanthus plantations should be placed on favorable crop rotation and degenerate in the fields of natural and cultivated grasslands and pastures and degraded soils not suitable for agricultural use.

The cultivation of the soil should be directed at creating conditions that would ensure the full shooting, good growth and development of plants throughout the growing season. Tillage system for heavy accumulation of moisture and nutrients involves peeling disc followed by deep plowing and cultivation. When laying areas after Miscanthus grasses and meadow lands launched to reduce the use of old vegetation herbicides of continuous action (4–6 l/ha) and conduct multiple processing turf disc harrows, cultivators or cutters.

Phosphorus, potassium and nitrogen fertilizers are applied to soil fertility of middle of spring pre-sowing cultivation at the rate of nitrogen, phosphorus, 40–60 kg/ha of potassium and 100–120 kg/ha of a.s. In soils of high fertility fertilizers do not make any major power in the soil, no fertilizing after planting Miscanthus. In low fertile soil in the second year after planting nitrogen, phosphate and potash fertilizers are applied in doses of 45–50 kg/ha of a.s., and potassium—90–100 kg/ha a.s. On the third and following years fertilizers are not contributed under Miscanthus. Until now fallen leaves of Miscanthus accumulate as litter which decomposes the source of supply and a strong root system increases the salinity of the soil and uses remote forms of nutrients from the soil.

For planting should be used high yield Miscanthus varieties with high potential for adaptability to soil and climatic conditions of the region growing and hybrids that have been tested in research institutions.

Miscanthus is propagated vegetatively as triploids, pollen is sterile and does not form seeds. More often propagated Miscanthus rhizome division (rhizomes), parts (segments) roots 10–12 cm, weighing 20–50 grams, which have at least 5–6 buds. For this planting material Miscanthus rhizomes should hummock second or third year of vegetation, even when they are at rest divided into fragments, i.e. rhizomes.

Planting is carried out in early spring in moist soil. Not allowed planting in later periods in dry soil. In this regard, planting should be carried out in early April, when the upper most soil saturated with moisture. Planting Miscanthus rhizomes segments held or stored freshly prepared on the day of planting. The density of planting is 1 ha within 10–16 thousand units landing (rhizomes). The width of the rows is 70 cm. The distance between plants in a row is 70 cm. The depth of planting rhizomes is 8–10 cm.

In the first year after planting and germination Miscanthus clear expression of its line, and the emergence of weeds, loosening held rows and weed protection zone with a width of 1–12 cm from each side of the line. Two to three weeks after first loosening the appearance of weeds between the rows held reprocessing rows using a cultivator.

In the second year after planting in soils of low fertility it is carried feeding of complete mineral fertilizer at the rate N60P40K120 kg/ha of a.s. Mineral fertilizer is introduced in early spring before the row cultivation. After fertilization and germination of weeds one must spend loosening rows cultivators width buffer zone on each side of the line to 18 cm.

In the third year after planting rows loosening does not hold, as Miscanthus plants to cover the soil then aisle space and overgrown its rhizomes, because weeds are not competitive.

The results of our research on energy crops of Miscanthus deserve considerable attention as a source of fuel energy. This high-performance culture provides a large output of dry matter and energy of aboveground mass. Giant Miscanthus Test results give reason to believe that it is highly flexible and high-performance culture.

It has been studied the biological, ecological, morphological features of plant, defined yield of vegetative mass. It has been found Western forest-steppe conditions are favorable for growth and development of giant Miscanthus. It analyzes the engraftment rate of plants, which amounted to 91%, while planting using irrigation in conditions of sufficient soil moisture (60–70%), it increased to 97%. Under western steppes giant Miscanthus shoots appear at 28 days after planting, which is held in early April. Sprout shoot one, sometimes two, depending on the number of sprouted buds simultaneously rhizome. The period from germination to full unit lasted 15 days. Plants growing in the second year of vegetation are characterized by intense regrowth that occurs in the second week of April. The next phase of growth and development has three leaflets that last long. The plants quickly form new meromes body that analyzes the tillering stage, or buds formation in the second week of June. This phase occurs in plants have long growing season to late autumn. For plants, this phase is characterized by the development of roots that will serve as a full planting material and significant accumulation of reserve substances and use them during wintering. The appearance of nodes on the stem, and a significant increase in leaf analyzes the phase out of the tube, which can be seen in the second week of August. Later on the plant ejection panicles is observed in the third week of September, and then comes the flowering. During the growth and development of plants Miscanthus growing in terms of the transition average daily temperatures fall below 10 °C, during which observations came in the second week of October, causing shrinkage puff-stems mass. In plants under such conditions suspend growth processes of development. Nutrients of puff stem mass transport to the roots, where it accumulates.

The main morphological parameters of giant Miscanthus are plant height, number of stems and leaves depended on the phases. During intense growing season, when it is the beginning of technical maturity, the plants reach maximum size. The height of plants in panicle emergence stage reached in the first year growing to 180 cm. Number of shoots observed 8.2 units, respectively, the number of sheets counted 72.6 pieces per plant. For the analysis of plant in a phase of exit in the tube plant height was 144.1 cm, while the number of shoots 6.8 pc and leaves—46.6 pieces per plant. The slightest manifestation of morphological parameters is observed on the plants during tillering, which analyzes the height, which is 50.4 cm, the number of shoots—5.2 units, and the number of leaves only 25.8 units per plant. In contrast, plants in the second year after regrowth of vegetation marked the height of a much larger, indicating that the resulting rate is 61.2 cm. Under such features growing season of plants growing in the second year charged to 22 stems. This analysis indicators show a rapid increase vegetative mass as feedstock for biofuel production.

Vintage biomass first year is going, as it is in most 1–3 t/ha. With 2-year yield collected annually because it can reach up to 10 t/ha or more, and the 3rd and the next is 15–20 t/ha.

Harvesting is carried out after the plants after the growing season and frosts are almost dry (20–25% moisture) and soil-frozen and is suitable for the passage of heavy machinery. The snow is little (2 cm) or missing. Harvesting is carried out in a dry and clear weather.

When wet biomass and the presence of snow harvesting is carried out in spring after drying, good pass technique on the field to dry clear weather.

Harvesting is conducted by direct combine harvesting, crushing biomass in special vehicles and delivering them to their storage and processing. Use self-propelled forage harvesters, or other available units. Mowing height should not exceed 10–12 cm from the ground. The resulting mass can be used directly for heat processing into briquettes, pellets or granules.

Subject to the requirements and productivity of manufacturing operations for growing Miscanthus provided energy plantations use areas—15–20 years or more.

Growing crops benefit only large scale (to reduce cost) when receiving the harvest of at least 15 tons/ha. Revenue can also be raised if the use of planting crops for the next breeding and sale of planting material.

The analysis of the prospect of growing Miscanthus, it should be noted that this hardy plant that grows 20 years and over. Culture requires virtually no costs for tillage and after planting does not require treatment. Low operating costs growing open up the possibility of using this crop in Ukraine and it is appropriate for the conditions of forest-steppe of Western. Vintage going through the normal harvesting and the resulting mass can be used directly for heat or processing into briquettes or pellets. One ton of dry weight Miscanthus is equivalent to 400 kg of crude oil. Yield can be increased if the use of crops for further breeding culture and implementation of new parties of rhizomes as planting material.

Experience shows that a high yield of Miscanthus is only possible by careful adherence to all elements of growing technology and first it is time planting. It was established on the basis of morphological parameters of formation of vegetative mass acts as feedstock for biofuel production. Plants are characterized by large growth rates during the active growing season. Miscanthus giganteus most marked in terms of height and length of plant leaves, which indicates accumulation of biopotentials as plant material for use in bioenergy.

The situation in Ukraine, unfortunately, is not as developed as in neighboring Poland, although our capacity no less, and perhaps more. We just have not fully realized that all around us there are many resources that can be used as local biofuels.

2 Material and Methodology of Research

The material for the study was biomass of giant Miscanthus (*Miscanthus* × *giganteus* Greef et Deu) collected from an experimental plantation co-hosted by the State Agrarian and Engineering University in Podillia (Fig. 1). The harvested biomass in November 2015 was crushed on a axle cutter with a cutting length of 20 mm reflecting the conditions of a single-stage harvest using self-propelled choppers. The raw material prepared has been seasoned to obtain a moisture content of 12–14%. Moisture at this level is recommended for solid biofuels produced from agro feeds. A further stage of research was conducted at the Laboratory of Technology for Production and Quality Assessment of Biofuels in Cracow.

The material of 14% moisture content was milled on a POR ECOMEC hammer mill using 10 and 15 mm sieves.

The raw material through the proper agglomeration (Fig. 2) was analyzed to determine the key parameters relevant for energy utilization. The moisture content of the raw material was determined in accordance with PN-EN ISO 18134-1: 2015-11. The test sample weighing more than 300 g was placed in a calcined and weighed to 0.1 g weighed cell and dried at 105 °C ± 2 until weight was determined.

The bulk density BD [kg m^{-3}] was measured in accordance to the procedure described in PN-EN ISO 17828: 2016-02 by determining the mass of the material in a known volume.

The granulometric composition of the crushed biomass according to PN-EN 15149-2: 2011 standard was also determined using the ø 8 hole sieves; 3.2 mm and weave sieves # 2.8; 2; 1.6, 1.4; 1; 0.5; 0.25 mm.

The ash content according to the methodology proposed in PN-EN ISO 18122: 2016-01 was also measured. The ash content was determined by calcining the

Fig. 1 Collection of giant Miscanthus shoots using Solo saw *Source* Own elaboration

Fig. 2 Shredded Mushroom Shoots: from the right grinded on the ax cutter, then ground on a mill with ⌀15 mm and ⌀10 mm sieve *Source* Own elaboration

sample to constant weight at 550 ± 10 [°C]. It was also marked one of the most important energy parameters which is calorific value. This parameter allows to determine the amount of energy that can be generated by burning a fuel unit. High quality isoformibolithic C6000 calorimeter from IKA was used in this study. The device is fully automatic and only the placement of a properly prepared sample in the crucible is required. Calculations are performed in the device based on EN-14918: 2010.

Then the prepared raw material was subjected to a pressure agglomeration process on a hydraulic briquette machine with an open hydraulic working chamber made by POR ECOMEC model Junior. This briquetting machine produces briquettes with a diameter about 50 mm and a few centimeters in length. The agglomerations of the material were carried out at three working pressure values of 27, 37 and 47 MPa.

Next, the briquette was tested for durability after 24 h to determine durability index DU (%). The measurement was performed according to PN-EN ISO 17831-2: 2016-02 standard which was based on weight loss information during the test. For each fraction of material two tests were performed for the individual agglomerations pressure.

The specific density of analyzed briquettes was also determined on the basis of geometric measurements (volume determination) and masses. The sample consisted of 10 randomly chosen pieces of granulate.

3 Result and Discussion

The research presented in accordance with the previously methodology allowed to collect information characterizing the raw material in terms of energy use. Table 1 shows the basic data characterizing the material.

Table 1 Results of qualitative research of raw material

	Moisture content M_{ar} (%)	Ash content A_{ar} (%)	Calorific value $qp_{net,ar}$ (MJ kg^{-1})	Bulk density BD_{ar} (kg m^{-3})
1	13.31 ± 0.12	3.67 ± 0.23	17.52 ± 0.23	169.5 ± 3.9

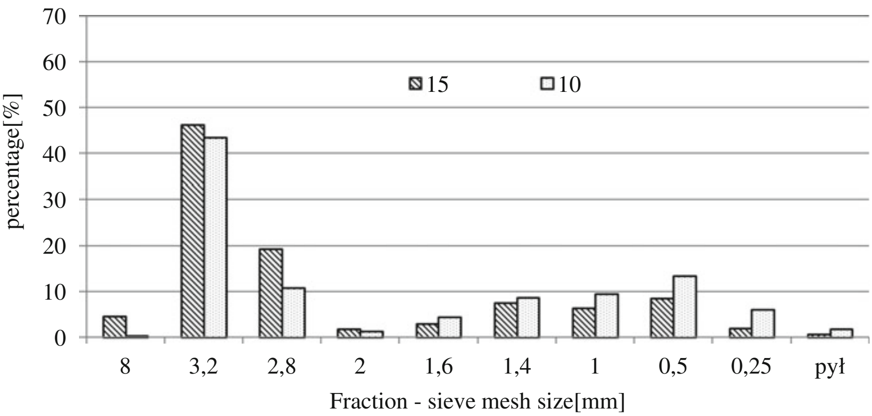

Fig. 3 Granulometric composition of raw material after milling on sieves ⌀15, ⌀10

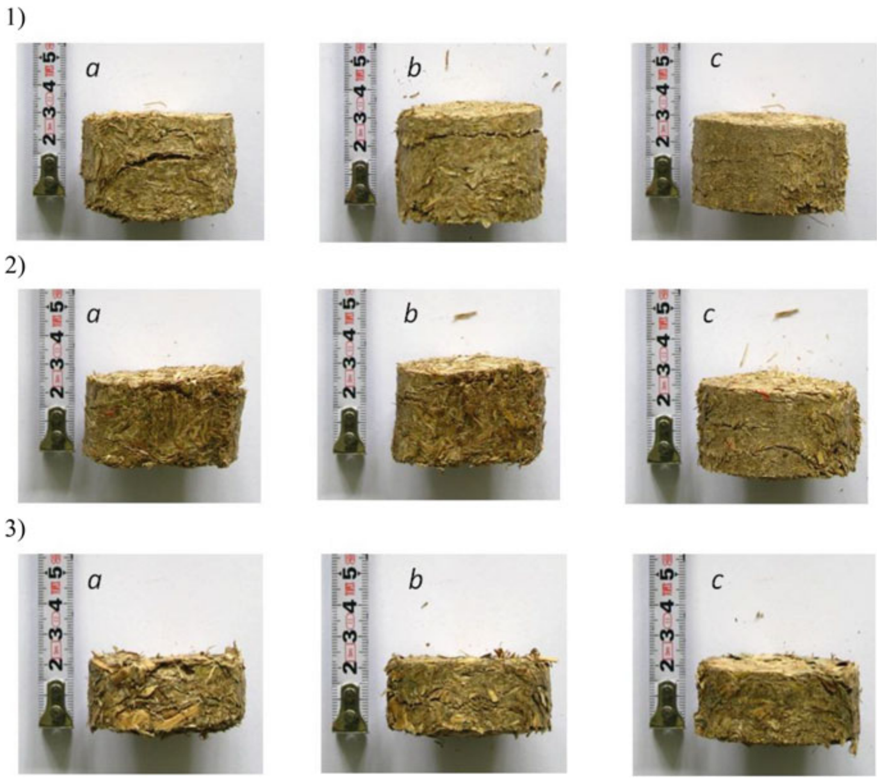

Fig. 4 View of example briquettes made of crushed material: **1** on a save with hole ⌀10 mm, **2** on a save with hole ⌀15 mm, **3** chopped raw material; compressed at working pressure: a—27 MPa, b—37 MPa, c—47 MPa

The parameter values of individual parameters are classic for energy crops and comparable to those of other researchers [10, 11].

The graph 3 shows the granulometric composition of the analyzed agglomerated raw materials. It can be seen that the distribution of individual fractions is similar. The largest group of over 40% are particles retained on a 3.2 mm sieve. Fine fractions dominated on 1.4; 1 and 0.5 mm. It can also be observed that the reduction of the sieve openings from ⌀15 to ⌀10 mm resulted in a decrease in the main fraction (8–3.2 mm) for small fractions. In the case of a sieve with 10 mm holes, the fine particle fraction was 0.5 mm (13.4%).

Figure 4 shows samples of briquettes obtained from the agglomeration of the tested raw materials using three agglomerated pressures. It can be observed that as the amount of raw material increases, the height of the briquette increases. This is due to the fact that in the case of materials with larger particles, the bulk density was lower, which resulted in less agglomeration in one agglomeration cycle. It can also

Table 2 Parameters of obtained briquettes

Sample	Working pressure (MPa)	Durability DU (%)	Specific density (kg m^{-3})
Crushed on a sieve ⌀10 (mm)	47	95.4 ± 1.3	942 ± 3
	37	92.6 ± 1.4	891 ± 8
	27	91.2 ± 1.1	822 ± 6
Crushed on a sieve ⌀15 (mm)	47	92.7 ± 1.2	928 ± 4
	37	91.3 ± 1.4	869 ± 5
	27	90.1 ± 1.3	814 ± 8
Chipped on the forage	47	89.6 ± 1.5	865 ± 6
	37	87.4 ± 1.4	789 ± 11
	27	85.3 ± 1.9	721 ± 7

be observed that the increase in pressure caused that the briquette got more regular shapes and there were no visible cracks and cavities.

Performed quality assessment tests of briquettes are presented in Table 2. It can be seen that the increase in agglomeration pressure caused an increase in the durability of obtained briquettes for all analyzed raw materials. Similar occurrence were observed at specific density. The highest density (942 kg m^{-3}) was characterized by briquettes obtained from the most crushed raw material. Density at this level compared to products used in the trade is satisfactory. Based on literature [11–13] it can be assumed that the density of over 850 kg m^{-3} is satisfactory. Considering the above mentioned criterion it should be noted that the agglomeration pressure of 27 MPa is not sufficient for each material. In the case of agglomeration of unmilled raw materials, the highest pressure is required, however, the stability of these granulates is low (below 90%) which may cause problems during longer logistic processes.

4 Summary

The research has shown that biomass from the Miscanthus plantation grown in the southern part of Ukraine is the raw material for obtaining high quality briquettes. Research has also shown that it is essential to use grinding in the technological process to obtain a high degree of milling. It seems to be sufficient for mill grinding mills with a perforation of ⌀15 mm. Reducing the size of sieve holes, e.g. up to 10 mm, can improve the quality of pellets, but it should be borne in mind that this significantly increases the energy consumption of the process.

The presented agglomeration method based on an open cell hydraulic briquette is a very accessible solution. The application of this agglomeration technique should enable the dynamic development of the solid biomass sector from biomass of the Miscanthus. The quality of the obtained briquettes, in terms of energy (calorific value > 17.5 MJ kg^{-1}) and physical properties make this product a local commodity and export commodity. Taking action to produce solid biofuels from raw materials obtained from energy plantations creates opportunities for the development of Ukraine's agricultural sector.

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