

Preparation of lignocellulosic waste for combustion process

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Introduction

The solid fossil fuels - hard and brown coal, have still remained the main pillar of the power industry in Poland. The assumptions from the "Development strategy on renewable energy sector" accepted by the Council of Ministers in 2000, and the resulting legislative provisions, including the "Polish Energy Policy up to 2030" adopted by the Council of Ministers (November 2009) are the reasons for the growing interest in the renewable energy sources. In accordance with the latter document, the contribution of renewable fuels in the energy balance in Poland should be gradually increasing up to the level of 15% in 2020, and 20% in 2030.

Regarding conditions existing in Poland, biomass is the main renewable energy source. It is defined as "[...] solid or liquid substances of plant or animal origin which undergo biodegradation, derived from products, waste and residues from agricultural and related industries and industries processing these products, as well as parts of other waste that is biodegradable and cereal grains which do not meet the qualitative requirements for cereals within the intervention purchase [...] and cereal grains, which are not included in the intervention purchase" [1]. Undisputable advantages of various types of biomass which primarily include the so called zero emission and renewability, often go together with unfavourable physical and chemical properties from the aspect of their use. Wide range and high content of moisture as well as low bulk density, and consequently – relatively low combustion heat value per mass and volume unit belong to these disadvantages. These properties cause a number of logistic and technical problems.

Due to the increasing interest in biomass as fuel, the new sources of biomass have been being searched. A significant amount of waste (usually from Ukraine and Belarus) present on the Polish market is a visible effect of this search. The waste is known as pulp or lignocellulosic waste which is post-hydrolysis lignocellulosic biomass waste - a by-product from the production of furfural or liquid bio-fuel. The effective use of lignocellulosic waste is conditioned on its processing to formed fuel likely to be used in grate heating devices, the professional energy sector and heating sector. The formation process is a method for eliminating such unfavourable properties of lignocellulosic waste as low energy density, high susceptibility to abrasion and dusting.

Research materials and methodology

Research material – post-hydrolysis lignocellulose

Biomass can be divided into biomass of consumption (food) plants and lignocellulosic biomass – LCB [2, 3], which includes only energetic plants, agricultural and forestry residues and waste materials. The traditional food crops such as cereal, rape, sugar beets and other root vegetables form the biomass in the form of consumption plants. Saccharides and starch are the fundamental components of those plants. The lignocellulosic biomass is formed by three elemental components: cellulose, hemicellulose and lignin. The lignocellulosic biomass originates from:

- timber residues (sawmill, forestry and from paper industry)
- various paper waste

- agricultural residues (e.g. maize straw, sugar beet residues)
- energetic crop cultivation (e.g. willow, Virginia Mallow and energetic grasses).

The post-hydrolysis lignocellulose was used as the research material (country of origin: Belarus). The tested initial lignocellulose, directly after its delivery in big bags, was a material mixture similar to fine timber sawdust. Darker or lighter colour indicated the heterogeneity of a sample obtained in the amount of ca. 1 Mg. Physical and chemical properties of the averaged post-hydrolysis lignocellulose sample are presented in Table 1.

Table 1

Physicochemical properties of post-hydrolysis lignocellulose

Determination	Measurement unit	Value
<i>Technical analysis:</i>		
- total water content W_t^r	% w/w	20.6
- analytical water content W^a		4.3
- ash content A^a		8.0
- volatile matter content V^a		60.30
<i>Elementary analysis:</i>		
- carbon content C_t^a		54.0
- hydrogen content H_t^a		5.09
- nitrogen content N^a	% w/w	0.18
- oxygen content (calculated)		28.27
- total sulphur S_t^a		0.46
- chloride content Cl^a		< 0.005
<i>Calorific value:</i>		
- as received Q_i^r	kJ/kg	16,329
- in analytical state Q_i^a		20,183
<i>Combustion heat Q_c^a</i>	kJ/kg	21,399

An analytical evaluation carried out for the tested lignocellulosic biomass draws attention to some crucial values of fuels. The combustion heat of tested sample Q_c^a equal to 21,399 kJ/kg is higher than the standard range of this parameter for biomass [4]. On the other hand, the calorific value Q_i^r equal to 16,329 kJ/kg is within the range characteristic for the biomass (woody and non-woody one) and brown coal [4, 5]. Total sulphur content S_t^a in the tested sample equal to 0.46 % w/w is considerably higher than in the typical woody biomass - it rather corresponds to the non-woody biomass - whereas low chloride content Cl^a below 0.005% is typical for the woody biomass [4, 6].

Considering sulphur, its high content can be a derivative of habitat conditions or the lignocellulose biomass processing before placing it on the pile. To destroy the structure of lignocellulose in order to produce bio-fuel, thermo-chemical and biochemical methods are applied, while acid hydrolysis (with concentrated or diluted sulphuric acid) is one of the phases of biochemical methods for the production of liquid bio-fuel [7]. In regard to the lack of information on the origin and processing history of the tested lignocellulosic waste, it cannot be unambiguously stated whether such high sulphur content is a result of acid hydrolysis.

Moisture content and particle-size distribution are significant properties of raw materials regarding the agglomeration process. Total moisture content W_t in the research material was 20.6 % w/w. The observed, previously mentioned, heterogeneity of the sample confirmed the previous experiments at the Institute for Chemical Processing of Coal (IChPW) on the post-hydrolysis lignocellulose with moisture content exceeding even 60 % w/w.

The particle-size distribution of the raw material belongs to factors deciding on the effectiveness of compacting process. A principle, according to which the smallest the briquette is, the lower the upper limit for coal raw material grinding should be, applies to the coal briquetting processes. The principle of selecting a particle composition comparable to the Fuller curve for the densest packing should be applied for all briquetting materials [8]. According to the Fuller curve, the content of particle class with the size from 0 to $i = D/10$ (where D is the size of the largest particles) should be about 1/3 of the total quantity of bulk material. It was assumed that the same principles on the particle-size distribution of raw material should be applied for the compacting process of the lignocellulosic waste biomass.

The analysis of determination results for the particle-size distribution of the tested batch of lignocellulose (Fig. 1) shows that the grinding process of this raw material does not meet the above requirement related to the content of ca. 33 % by weight of particles with a diameter below 1.0 mm. The content of particle-size class from 0 to 1.0 mm ($D/10 = 1.0$) is 81.4 %. Despite the absence of larger fractions, so fine grinding of the material may ensure the high packing degree of particles. High losses due to dusting or conveying of the bulk material can be regarded as disadvantages.

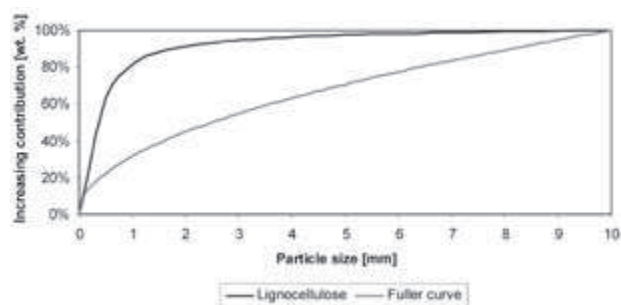


Fig. 1. Grain size distribution of post-hydrolysis lignocellulose

Applied agglomeration techniques and methods of product evaluation

The studies on the production of formed fuel from post-hydrolysis lignocellulose involved the application of the non-binder pressure agglomeration process performed in a laboratory hydraulic press and a granulator with a ring die.

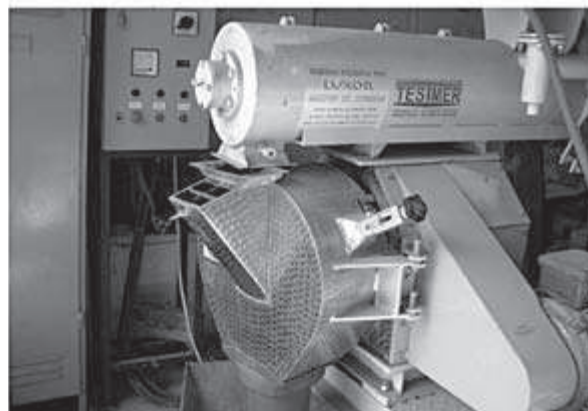
The briquetting tests on the laboratory scale were conducted in the PW-1 hydraulic press with the die volume of 60 cm³. The press enables to produce single cylindrical-shaped briquettes with 35 mm diameter and height depending on the quality ("compressibility") of the pressed material and the exerted pressing pressure. The post-hydrolysis lignocellulose with the initial moisture content (20.6 % w/w) was pressed applying the pressing pressure of 4, 6, 8 and 10 MPa.

The hydraulic press with the densification piston system BrikStar type 200-16 having the capacity of 200 kg/h and the maximum pressing pressure 18 MPa is the core element of the industrial line for producing the wood briquettes from sawdust. Two batches of raw materials with different moisture content were subjected to pressing under the pressure of 12 MPa:

- lignocellulose with moisture content of ca. 13 % w/w (according to the information provided by an operator of this production line, the total moisture content in the raw material at the level of 13 % w/w is the optimum value)
- lignocellulose with moisture content of 20.6 % w/w.

Pellets from the research material were produced in the granulator using a ring die type PD-1 with the nominal efficiency from 0.4 to 1.2 Mg/h by Przedsiębiorstwo Produkcyjno – Usługowe Maszyn i Urządzeń Rolniczych TESTMER Warszawa S.A. (Manufacturing and Service Company of Agricultural Machinery and Equipment TESTMER Warszawa S.A.) (Fig. 2). The applied device is an example of the granulator with the closed granulating chamber and the compacting system consisting of the cylindrical, perforated die and densification rolls. Like in the industrial hydraulic press, the pellets were obtained from the raw material dried up to the level of moisture content of ca. 13 % w/w and from the initial raw material.

a.



b.

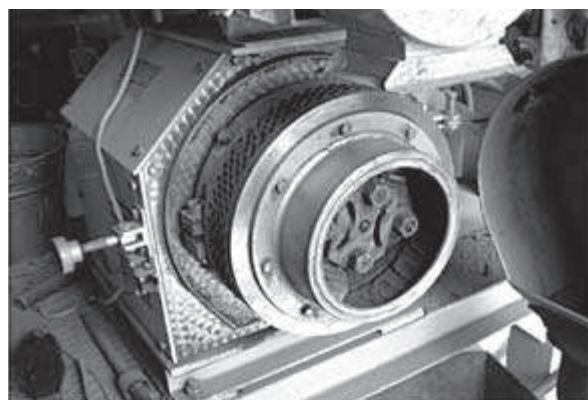


Fig. 2. Granulator with ring die, type PD-1

a – general view of operating part
b – compacting system: ring mould with densification rolls

The produced briquettes were tested on the drop strength and water absorption. The drop strength of briquettes was determined by their free fall on the steel plate from a height of 1 m and counting a number of free falls which did not cause their degradation. The water absorption was determined in accordance with the standard PN-G-04652: 1997 "Formed fuels. Determination of absorption and water resistance".

Two following mechanical parameters were assumed as the quality measures of pellets obtained from the post-hydrolysis lignocellulose: the compressive strength of pellet layers and abrasion resistance determined by the drum method, as well as water absorption. The compressive strength was determined in accordance with the own procedure based on the measurement of a force which – exerted axially on the top surface of the granulate layer with a height of $H = 270$ mm – would reduce that height by 20 mm and the influence of that force on the cross section of the granulate layer.

The abrasion resistance was determined using the adapted standard PN-G-04650 "Formed fuels. Determination of mechanical strength by the drum method." This method is based on mechanical processing of a granulate sample in a steel rotary drum with an internal

diameter $d = 225$ mm (equipped with two symmetrically arranged ribs), weighing the number of processed pellets remaining on a sieve of 3 mm mesh size and comparing this quantity to the total sample weight subjected to mechanical processing. The determination is made after 100 (R_{100}) and 500 (R_{500}) drum rotations.

The water absorption of pellets was determined using the adapted method applied in the above-cited standard PN-G-04652: 1997. The determination was made for 1 dm³ of pellets placed under the water table in a perforated container.

Test results

The applied pressing pressure was a changeable parameter in the tests conducted in the laboratory hydraulic press. The obtained briquettes were analysed regarding their drop strength immediately after their production (initial value of strength), and then after 24, 72 and 168 hours after the production. The test results are shown in Figure 3.

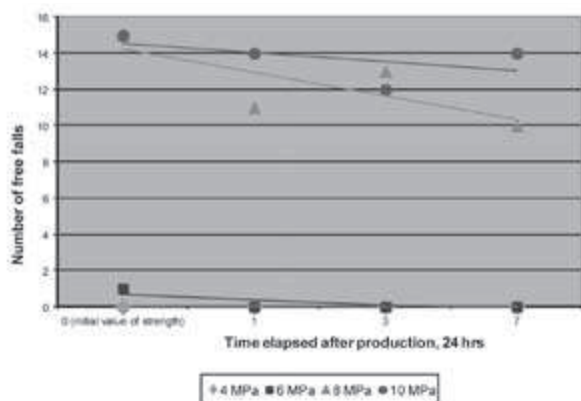


Fig. 3. Free-fall durability of briquettes made on hydraulic press with respect to applied forming pressure

For the material with moisture content of 20.6 % w/w subjected to briquetting in the hydraulic press, the pressing pressures of 4 and 6 MPa turned out as insufficient for the production of briquettes of structural stability. The durable products could be manufactured at the pressing pressure of 8 and 10 MPa. The briquette strength was observed to decline during the seasoning process in reference to their initial values of strength, and the stabilisation was achieved after about 72 hours of seasoning. That was caused by the evaporation of some part of moisture which - by the formation of water bridges - joined the particles of the briquetting material. At the same time, the lack of any other binder, which could form the stable interactions between the material particles, did not balance the strength drop caused by water loss.

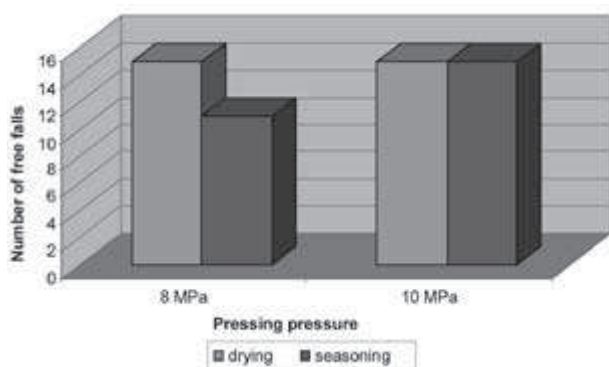


Fig. 4. Comparison of final treatment (seasoning and drying) on briquette free-fall durability

A test on drying the briquettes immediately after their production was carried out to determine a method of their final treatment. The produced briquettes were dried at 60 °C for one hour. Assuming

that the dried briquettes, like the briquettes after seasoning for 168 hours under a roof under the normal conditions, were the end product – the results of determined drop strength were compared with the values for briquettes after seasoning for 168 hours and are illustrated in Figure 4.

The changes in drop strength of dried and seasoned briquettes did not demonstrate any clear tendency. Regarding the above, the drying process seems to be more favourable for briquettes produced at the pressing pressure of 8 MPa (strength is greater by ca. 28 % compared with seasoned briquettes), whereas the briquettes obtained at the pressing pressure of 10 MPa have the same strength as the seasoned ones. In all cases, the intensive drying resulted in the enlargement of all cracks and fractures on their surface due to quick migration of moisture.

The tests conducted at the briquetting industrial line with a piston-type briquetting machine gave two batches of cylindrical-shaped briquettes with a diameter of ca. 50 mm and a length of ca. 100 mm (Fig. 5). The raw material dried up to the moisture content of ca. 13 % w/w was used to manufacture briquettes with less cracked surface, and whose initial value of strength was equal to 15 free falls. The initial strength of briquettes from the raw material with the moisture content of 20.6 % w/w was equal to 13 free falls, and many transverse and longitudinal cracks appeared on their surface. After 168 hours of seasoning, the mean drop strength of briquettes slightly decreased to 13 free falls for briquettes from the dried raw material, and 12 free falls for briquettes from the primary raw material.

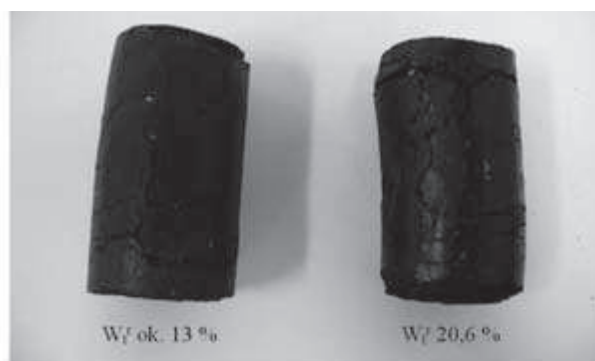


Fig. 5. Briquettes from industrial biomass briquetting line

Pelletising process of the post-hydrolysis lignocellulose in the granulator with the ring die provided the products of specific mechanical properties (after seven days of seasoning) presented in Table 2.

Table 2

Mechanical properties of pellets from post-hydrolysis lignocellulose

Moisture content in raw material, % w/w	Mechanical properties of pellets		
	Compressive strength, MPa	Abrasion resistance R_{100} , % w/w	Abrasion resistance R_{500} , % w/w
ca. 13	0.716	83.3	51.0
20.6	1.324	99.2	97.1

Pellets from the lignocellulose with ca. 13 % of moisture content were characterised by low mechanical durability to compression and abrasion. Processing in the rotary drum resulted in the abrasion of 16.7 % by weight of pellets to the level of particle-size distribution lower than 3 mm only after 100 rotations, and just 49 % by weight of the tested batch after 500 rotations. Pellets produced from lignocellulose with 20.6 % moisture content had considerably better mechanical properties (Fig. 6). Beside more favourable mechanical properties, the course of pelletising process was much more efficient while the raw material with higher moisture content was used. The dried material was subjected to intensive abrasion in working elements of the granulator, which reduced the process efficiency.



Fig. 6. Pellets from post-hydrolysis lignocellulose with 20.6% moisture content

The absorption tests of produced briquettes and pellets demonstrated no water resistance. According to the standard PN-G-04652:1997, the absorption and water-resistance are determined after 24 hours of the sample total immersion in water. Only pellets and briquettes from the raw material with 20.6 % w/w moisture content retained their shape, but they were disintegrating when taken out of water.

Summary

Spatial scattering of the exploitation areas, changeable physical and chemical properties as well as low energy density (an amount of energy cumulated in one volume unit) are characteristic features of the renewable energy sources in the form of biomass. Apart from the first feature, the two others also refer to post-hydrolysis lignocellulose, whose changeable moisture content and low bulk mass create a number of technological and logistic problems. The economic efficiency in using this type of material can be improved by its processing into formed fuel suitable for the use in individual heating devices, the professional energy sector and heating sector.

The briquetting or pelletising technologies can be used for the non-binder formation of lignocellulosic waste. The selection of a device and a compacting technique should depend on the target application and the power engineering device, in which the formed fuel will be used. The energy sector, based on coal-dust boilers, pulverises the delivered fuel. That is why this sector shows the interest in the biomass fuel with increased energy density which can be pulverised in the adequate pulverising devices. Fuel in the form of pellets with satisfactory mechanical durability is useful for household consumers using modern designs of fuel boilers with automatic feeding. On the other hand, household consumers using great furnaces and boilers may express their interest in formed fuel in the form of briquettes.

Taking into account the agglomeration process with various techniques, the moisture content and particle-size distribution are the most important properties of the post-hydrolysis lignocellulose. The own experiences show that moisture content in the discussed material varies within a range from over ten to over twenty % w/w. As it is waste material, its particle-size distribution and mechanical purity pose a technological problem: beside various sizes of lignocellulose particles, the material stored at improperly secured landfill may exhibit the presence of foreign mechanical impurities.

To sum it up, the post-hydrolysis lignocellulose is characterised by the extreme heterogeneity (various moisture content within a very broad range, possible mechanical impurities), it is an elastic material with no binding properties. High pressing pressure at an adequate level of moisture content in the raw material should be applied in the material agglomeration. The obtained products are characterised by satisfactory mechanical properties, however the lack of resistance to water corresponding to the lack of resistance to environmental factors is the main disadvantage.

The application of post-hydrolysis lignocellulose for power engineering purposes can be among solutions for supplementing the

national sources of renewable energy resources and for implementing Polish obligations related to their increased contribution into the national energy balance. Like any other economic solutions, it also has to be effective considering the economic aspects. We should be aware of the fact that the production process of formed fuel does not only consist in the costs related to the compaction of raw material, but also the costs of transport, drying, sieving and seasoning of the end product. Considering the wide range of moisture content mentioned above, which is characteristic for the post-hydrolysis lignocellulose, drying of the raw material should be recognised as the operation which predominantly influences the production cost of the end product.

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