IMPACT OF STRAW FRACTIONAL COMPOSITION ON BRIQUETTE QUALITY

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Abstract. Growing prices for traditional energy resources make alternative energy sources and extraction methods attractive in this situation. Straw unused in agricultural production technology as grain production residue can be successfully used for biofuels, heat and electricity production. The obtained grain and straw ratio per hectare is from 0.8 up to 1.2. Assuming that the average grain yield in Lithuania is approx. 2.9 $t \cdot ha^{-1}$, with one million hectares under cereals, 3200 thousand tons of cereal straw are yielded in Lithuania. Considering the fact that, without damage to the soil, other agriculture industries can utilize in average up to 12-15 % of straw yield; therefore annual straw fuel potential in Lithuania is about ~400 thousand tons and the energy equivalent is approximately ~100 toe. Straw is a "messy" fuel, so before usage for biomass burning in a heat plant it must be processed technologically. For this purpose biomass is crushed, dried, pressed into briquettes or pellets. Using the briquetting technology, the energy value of straw volume is increased by 13 times. This option facilitates the transportation of straw, improves their technological properties. The Institute of Energy Engineering and Biotechnology, Aleksandras Stulginskis University has studied the influence of fractional composition of triticale straw chaff on the briquette quality. The briquetting machine "Biomasser BSO6" was used to form straw briquettes from homogenous 50, 40, 30, 20 mm length, mixed 50 mm and 20 mm long chopped straw and the changes in the size and density of the produced briquettes were investigated. The research has shown that briquettes with the best physical - mechanical properties were formed from chopped straw of different lengths, the density of the briquettes was 747.59 m^{-3}, and they showed the highest stability after pressing.

Keywords: briquettes, straw, triticale, physical characteristics, density.

Introduction

The modern world consumes large amounts of energy, while fossil fuel resources are not renewable, consequently, there is a need to utilise renewable natural fuel resources, which are widely spread on the whole Earth [1]. One of the ways to make this type of fuel more user-friendly is briquetting. The compacted biomass is stored more easily, the problems concerning self-heating in a fuel layer can be avoided, spores of some kind of mould can be destroyed, transportation goes much easier, the technological characteristics are improved, the biomass is more convenient to utilize in households and in industry [2].

Consumption of biofuel increases year after year, whilst modern technologies of compacting and burning allow better utilisation of agricultural residues as straw [3; 4]. As stated in the paper [3] straw is one of the most suitable agricultural residues for the briquette production due to their favourable chemical composition. Utilisation of straw in heat and electricity production is steadily gaining popularity, in Lithuania as well. This is caused by increasing areas under cereal crops that leads to large amounts of straw [3; 4]. Taking into account the grain and straw ratio which can reach to 0.9-1.2 [4-6] indicates that utilization of approx. 0.5 million tons of straw can save 0.14 million tons of imported fuel each year in this country [7].

The most common types of briquetting presses used in technological lines for briquette production for fuel are extruders and piston presses. The briquettes produced in an extruder have higher density [8]. The density, mechanical strength and stability are the key mechanical characteristics of biofuel briquettes [9,10]. The parameters depend on the used material, structure, water content, compacting pressure, arrangement of particles in the briquetting die, on cooling and storage conditions [9].

Regarding wide diversity of raw materials and a variety of factors influencing their characteristics many scientists are working on issues of optimisation of the briquette production. The influence of the compaction parameters on the briquette quality is studied by: Olt, Laur, Repsa, Smits, Kakitis; composition of raw materials by: Kronbergs, Rozinskis, Kakitis; changes in briquette characteristics after compacting: Pupinis, Jasinskas; energetic efficiency of production by: Raila et. al.

The objective – to investigate the influence of fractional composition of chopped straw used for biofuel production on the shape stability and density of briquettes.

Materials and methods

It was chosen to carry out studies on triticale straw, cultivar "Fidelio". In late summer the left triticale was cut with a scythe and tied into bundles. The tied bundles were stored in a barn and later on in October they were chopped into pieces of the required length with a specially made chopping machine. The chopped straw fractions of different length, i.e., 20, 30, 40 and 50 mm were made with this technique.

Estimation of straw moisture content. The moisture content of straw was estimated according to the changes in the weight of the samples, dried in the "Memmert 600" oven at temperature 105 ± 2 ºC.

Briquetting of different straw fractional compositions. The screw type briquetting press "Biomasser BSO6" with the capacity 40 to 50 $kg \cdot h^{-1}$, 4.2 kW electric motor and the diameter of briquettes of 76 mm were chosen for our studies. The equipment is designed for briquette production from straw, hay, oilseed rape and other herbal plants. At the beginning of the study the press was filled with control straw chaff for setting the optimal operation parameters of the unit. The equipment then was consistently supplied with raw material of different fractional composition. First of all, the hopper for briquetting was filled up with chopped straw, length of chaff – 20 mm. After chaff compacting, the process was continued with straw fraction 30 mm, 40 mm and 50 mm long and with mixed straw 20 mm and 50 mm long. The mixture of chaff was made using the scales "Sartorius" with equal proportions of 20 mm and 50 mm straw fractions in mixture. Briquetting was carried out at operating temperature of the press cylinder 270 ºC and with a cooler–stabilizer – 5500 mm long.

Briquette length, diameter and density measurements. While examining the briquette enlargement during storage, pressed briquette samples were measured with a caliper "Proma Digital" immediately after briquetting and later on – after 12 hours and after 24 hours until the briquettes size was stabilized. The briquettes were measured immediately after briquetting and placed in airtight clutched plastic bags to protect them from atmospheric influence ant then they were stored.

The briquettes with steady-state dimensions were weighed and their volume was determined on a special test bench. The straw briquette density was calculated then. The density of a mound layer of chaff was estimated from the know volume of the tank.

From the known densities of the briquettes and chopped straw, the value of the compaction ratio was calculated:

$$k_{susp} = \frac{\varsigma_{br}}{\varsigma_0} \tag{1}$$

where k_{susp} – straw compaction ratio;
ς_0 – density of straw chaff m^{-3};
ς_{br} – density of a compacted briquette m^{-3}.

The measurement results were evaluated using MS Excel software, average values and errors were calculated, and package Anova was used for least reliable margin estimation.

Results and discussion

Straw of triticale cultivar "Fidelio" was compacted with the briquetting equipment "Biomasser BSO6". It produced briquettes of a cylindrical shape, random length with a hole of 20 mm diameter in the center of a briquette. Different fractions of straw chaff were used, their moisture content was 10.54 ± 0.22 %. 10-15 % moisture content of raw material is recommended both by manufacturers of the press and by the scientists who have studied the straw compaction process [10]. In order to evaluate the stability of the briquette shape, diameter and length 50 briquettes were measured in two or three different positions and in four directions. The average diameter of briquettes, measured immediately after compaction, was 76 ± 0.036 mm, whilst their length was different and random (23.1 mm to 83.5 mm) – in the places of natural cracks. The diameter and length measurements were repeated after 12 hours and after 24 hours.

Essential changes in the briquettes size took place in the transverse direction within the first 12 hours: the briquette diameter decreased on average by 2.4 percent. During the next 12 hours the average value of the measurement results varied slightly, but their dispersion was higher. This also confirms the research results [10] showing that major changes in the briquettes stabilization occur within the first 12 hours. The confidence interval expanded on the average by 8.1 percent – 0.54 mm to 0.58 mm. At the same time the briquette size in longitudinal direction had changed insignificantly, lower than 0.5 percent of the briquette length variation was determined.

Within 24 hours after compaction the changes in the diameter of briquettes made from 20 mm straw chaff were the most significant (Fig.1). The diameter decreased from 76 ± 0.022 mm to 73.9 ± 0.115 mm. Somewhat lower changes were determined in the briquettes from 50 and 30 mm long pressed straw chaff: from 76 ± 0.039 mm to 73.9 ± 0.1 mm and from 76 ± 0.035 mm to 74 ± 0.086 mm respectively. The diameter of the briquettes from pressed 40 mm chaff decreased as well from 76 ± 0.046 mm to 74 ± 0.08 mm. The lowest changes in the diameter were determined in the briquettes made from mixed chaff 20 and 50 mm long – from 76 ± 0.041 to 75 ± 0.145 mm.

The smallest changes took place in the briquettes which were formed from 20 and 50 mm chaff. In this case the briquette diameter decreased on the average by 1.37 %, i.e., by 1.046 mm. At the same time the changes in the diameter of briquettes made from pressed 20 mm straw chaff were the highest and decreased on the average by 1.14 mm.

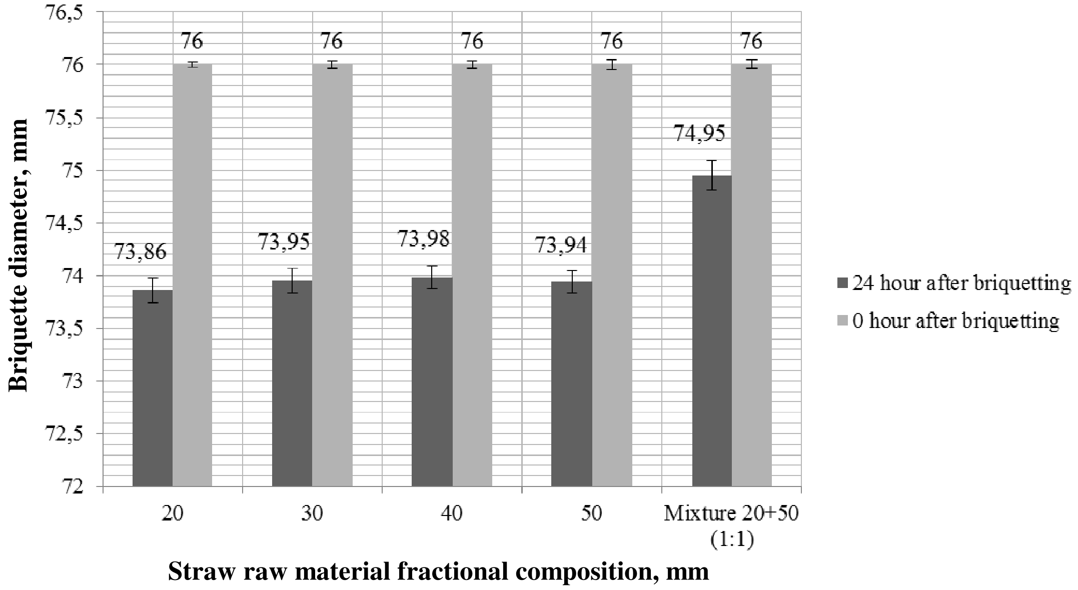

Fig. 1. **Changes of briquette diameter values**

Triticale straw was compacted to 711...747 m^{-3} during the briquetting process. Its density was similar to that of straw briquettes from different cereals, compacted with the screw-type briquetting press "Biomasser BSO6": from rye – 758.5 m^{-3}, wheat – 710.1 m^{-3}, wheat/rye ratio 4:1 – 770.7 m^{-3}, [3]. Dependency of the briquette density on the fractional composition of used straw is shown below (Fig. 2).

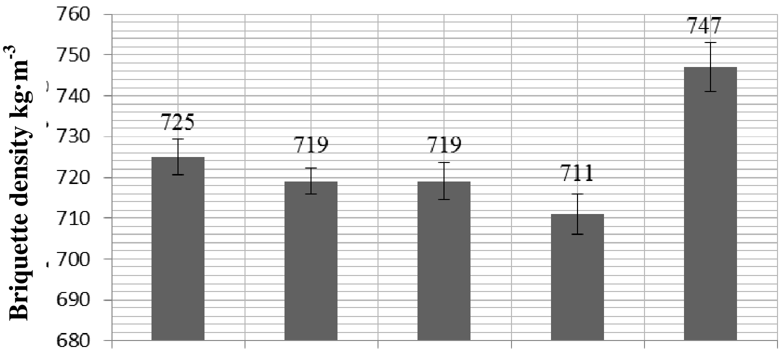

Fig. 2. **Density of briquettes from straw chaff with different fractional composition**

The briquettes made from mixture of 20 and 50 mm straw chaff showed the highest density – 747 ± 5.9 m^{-3}. On the average their density was by 3.8 percent higher than that of the briquettes made from chaff of the same length: from straw chaff 50 mm long – 711 ± 4.8 m^{-3}, from 40 mm straw chaff – 719 ± 4.5 m^{-3}, from 30 mm straw chaff – 719 ± 3.14 $m^{-3}$and from straw chaff 20 mm long – 725 ± 4.33 m^{-3}.

The briquetting process reduces porosity of the compacted material, i.e., the volume of free space in a mound of straw. At the same time the volume of chopped straw is reduced and its density increases. The changes in the density of the same amount of raw material during pressing can be evaluated by the compaction ratio $k_{susp.}$ calculation. Its lowest value (10.92) was determined for straw chaff 20 mm long. Longer fractional composition of straw chaff showed (Table 1) linear growth of the compaction ratio (coefficient of determination 0.97):

$$k_{susp} = 54.8 \cdot l' + 9.79\,, \qquad (2)$$

where l' – length of chapped straw, m.

Table 1

Measurements and calculation results

Straw chaff		**Briquette parameters (after 24 hours)**		**Compaction ratio**
length of a fraction, mm	Mound density, m^{-3}	Diameter, mm	Density, m^{-3}	
20	66.4	73.86a	725a	10.92
30	63.7	73.95b	719ab	11.29
40	59.2	73.98b	719ab	12.15
50	57.1	73.94b	711b	12.46
Mixture (20+50)	62.1	74.95c	746c	12.03

Note: means with the same letter in the same column are not significantly different.

To assess the influence of the fractional composition of straw raw material and the difference between the values of the tests additional statistical calculations were carried out. Minimal significant difference $R_{.05}$ was set using packages MS Excel and Anova with 95 percent probability level. The difference between the mean values is significant, if it is equal or higher than the calculated threshold for significant difference $R_{.05}$:

$$R_{.05} = t_{lent.} \sqrt{MS_e \left(\frac{1}{n_A} + \frac{1}{n_B} \right)}, \qquad (3)$$

where MS_e – factor used to evaluate the difference between means of the compared data (determined from tables in MS Excel Anova software package);
n_A, n_B – number of repetitions for the first (A) and the second (B) samplings;
t_{lent} – Student's coefficient.

The calculation results are shown in Table 1. Status of difference – essential or not essential is marked with letters "a, b, c". Means with the same letter in the same column are not significantly different.

Comparable tests of briquette shape stability after compacting and density have shown that longer straw chaff decreased the density of briquettes, whilst increased the shape stability of the briquettes. The reliable difference between the estimated mean values was fixed at the marginal positions, when straw chaff 20 mm and 50 mm long was used for briquette production. The results indicate also the advantage of mixed fractional composition over homogeneous fractional composition of the raw material. The briquettes made from chaff mixture 20 and 50 mm long were more stable in shape and their density was higher. Their diameter decreased by 1.3 percent only. At the same time the diameter of the briquettes made from straw chaff of the equal length have changed on the average by 2.1 times more, i.e., by 2.7 percent. The density of the last-mentioned briquettes was also lower, 719 m^{-3} on the average. This means 28.5 m^{-3} less than that of the briquettes made from mixed chopped straw.

Conclusions

1. It was estimated that better properties – the highest density (747 ± 4.8 m^{-3}) and stability of the dimensions were typical for the briquettes formed from mixture of straw chaff 20 mm and 50 mm long, i.e., for the briquettes from mixed fractional composition of the raw material.
2. The density of the briquettes made from straw chaff of equal length is inversely proportional to the length of chaff used and to variation of their volume – the compaction ratio.
3. When the length of straw chaff was reduced from 50 mm to 20 mm, the density of the formed briquettes increased from 711 ± 4.8 m^{-3} to 725 ± 4 m^{-3}.

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