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Mechanical durability of briquettes from digestate in different storage conditions

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Abstract. A present research was conducted to determine mechanical durability of digestate briquettes and potential influence of different storage condition. Experiments were performed on briquette samples produced from digestate feedstock with moisture content of 8.2%, ash content of 10.9% and gross calorific value of 17.15 MJ kg^{-1} by hydraulic piston press with working pressure of 18 MPa with external diameter 50 mm and length 40–60 mm. Briquette samples were divided into two groups and stored inside and outside building. Both groups were subjected to five experimental testing during specific time period from May until late November 2014. Mechanical durability of each briquette was measured after every testing, subsequently overall mechanical durability of specific groups was calculated. Results showed the lowest mechanical durability after first measurement: 98.85% for Group 1 and 98.95% for Group 2. The biggest change in mechanical durability was observed between first and second testing, values of following measurements were approximately equal. The highest mechanical durability was achieved after fifth testing: 99.65% for Group 1 and 99.63% for Group 2. It implied mechanical durability equal to 99.44% for Group 1 and 99.45% for Group 2 in average. Research proved very high mechanical durability which corresponds to the highest category of this quality indicator given by standard EN ISO 17225-1. Difference between mechanical durability of groups stored in different conditions was considered as minor. Thereby briquettes made from digestate are not only secondary product of proper waste management, effectively modified fertilizer but as was found by results of this research it is also suitable fuel with outstanding mechanical properties.

Key words: biomass, densification, biofuel, abrasion resistance, renewable energy, quality control.

INTRODUCTION

Attempt to deal with solid biofuel quality is nowadays an important issue due to their consideration as a sustainable and environmental friendly renewable source of energy and substitution of fossil fuels. Moreover briquettes became a market product and its production increases these days consequently, however it must be produced in very high quality to attract the general public (Ivanova, 2012). Digestate, waste material from biogas plant stations, is commonly used as a fertilizer (Roubík et al., 2016) but after proper processing this waste material can be used as a feedstock for the briquette production. Digestate has its specific chemical and mechanical-physical properties which directly affect final quality of briquettes as well as all materials used as a feedstock for briquette production (Kratzeisen et al., 2010). Those specific properties (ash content, moisture content, calorific value, combustibility) are the reason why all kinds of briquettes must be subjected to quality tests. Mechanical durability (abrasion resistance), next important property of feedstock, is considered as one of the main indicator of the briquette quality which describes the ability of briquette to remain intact during its handling, transportation and storage (Kaliyan & Morey, 2009a; Ivanova, 2012; Muazu & Stegemann, 2015; Tumuluru et al., 2015).

Previous studies done by Kaliyan & Morey (2009a), Ivanova et al. (2014) and Repsa et al. (2014) showed that mechanical durability is the prevalent form of expression of physical quality of briquettes. Mechanical durability express the degree of briquette damage, thereby it helps to select suitable parameters for production and optimizes the densification process to produce high-quality briquettes.

It was already published in previous studies of Temmerman et al. (2006), Kaliyan & Morey (2009a), Ivanova (2012) and Tumuluru et al. (2015) that degree of mechanical durability is influenced by several factors as a characteristics of used feedstock material (moisture content, particle size, content of lignin), technical specification of production (operating temperature and pressure, type of the press) and storage conditions (relative air humidity and air temperature).

Influence of different storage conditions has been described in another published research done by Brožek (2013) which concluded that manner of briquette storing has major influence on their mechanical durability. Higher mechanical durability was observed at briquettes samples stored in heated condition apart from unheated storage conditions with weather changes.

The aim of this paper was to determine mechanical durability of digestate briquettes stored in different storage conditions by experimental way thereby to define the physical-mechanical quality of this biofuel. Furthermore the purpose was to analyze possible differences in mechanical durability between variously stored briquettes and to specify preferable storage condition.

MATERIALS AND METHODS

The production of briquette samples and subsequent quality testing was conducted in accordance with mandatory technical norms, European and International standards for solid biofuels. Namely as a basis, an International Standard EN ISO 17225–1:2015 which describes basic properties of feedstock and final products as an acceptable shape, diameter, length, moisture content, ash content, content of chemical elements and inter alia allowed values of mechanical durability was used.

Material

The briquette samples used for the experimental research were produced from the digestate material which originates from the biogas plant located in the Central Bohemian Region, Czech Republic. Feedstock used for the biogas production contains 40% of cattle manure, 30% of grass silage and 30% of maize forage. Raw unprocessed digestate material was obtained in the liquid form with 6% of dry matter. Based on such a composition, extracting of dry matter from raw digestate is highly time and energy consuming (using laboratory dryer with limited volume), therefore not feasible. According this fact, raw feedstock was firstly dehydrated mechanically and then naturally by the solar energy, without using other energy sources, on open area where the largest portion of moisture was evaporated and makes it less energy demanding process. Subsequently it was dried in the laboratory dryer LAC type S100/03 to the solid state with moisture content 8.2%.

Sampling and distribution

Prepared material was densified by the hydraulic piston press BrikStar type 30–12 (Malšice city, Czech Republic) which operates with feedstock moisture content 8–15%, density of final products is about 900–1,100 kg m^{-3}, operating pressure 18 MPa and operating temperature 60 °C. Briquettes were produced into cylindrical shape with the identical diameter of 50 mm, length varying from 40–60 mm and consequently different weight from 72.00–142.45 g (see Fig. 1).

Figure 1. Briquette samples from digestate before experimental testing.

Before experimental testing, the briquettes were randomly divided into two groups (Group 1 and Group 2) and stored in two different storage conditions from April 2014 until November 2014 (226 days in total). Mentioned storage time period was divided to five intervals ended by performing of mechanical durability tests; first test was performed at 29^{th} day, second test at 53^{rd} day, third test at 88^{th} day, fourth test at 148^{th} day and fifth test was performed after 226^{th} day of storage. Briquettes from Group 1 were stored in the laboratory with constant relative air humidity around 40% and air temperature equal approximately to 21.5 °C. Briquettes from Group 2 were stored outside the building, covered by the plastic bag and exposed to the weather changes.

According to meteorology station of the Czech University of Life Sciences Prague the following climate data were measured during an observed time period: average air temperature equal to 14.7 °C (min. 3.5 °C and max. 27 °C) and relative air humidity in average equal to 71.4% (min. 38.5% and max. 96.1%). Process of the weather changes is noted in following graphs showed in Fig. 2.

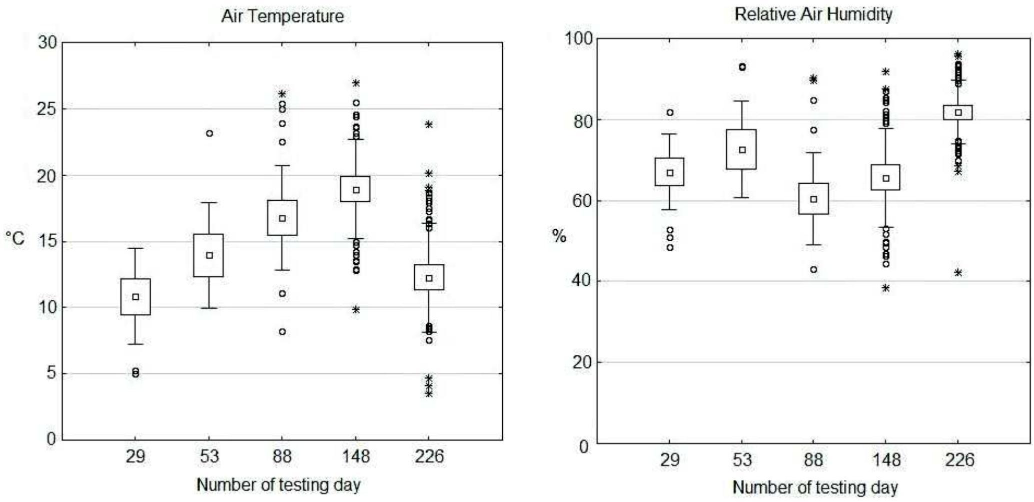

Figure 2. Weather changes in specific time intervals during observed time period.

Experimental procedure

During experimental testing in the framework of this research the moisture content, ash content and calorific value of feedstock material were determined and briquette samples were repeatedly (n = 5) subjected to mechanical durability tests. All above mentioned measurements were conducted following European Standards: EN 15234–1:2011, EN 14918:2009, EN 14775:2009, EN 14774–2:2009 and EN 15210–2:2011 which is describe below.

Mechanical durability test (DU test)

Process of durability testing were performed according to mentioned European Standards EN 15210–2:2011 which describes requirements and conditions of this test in detail. Testing was performed in special dustproof rotating drum with placement of rectangular steel partition powered by electricity. Drawing of this drum with description and dimensions is showed at Fig. 3. Minimal weight of tested group of samples is stated to 2 ± 0.1 kg[2], testing time is defined as 5 minutes which corresponds to 105 ± 0.5 rotations of drum and special sieve with holes size smaller than 45 mm was used for removing of abrasion from briquettes after testing. Briquette samples were tested five times during nine month of research duration and dates of performing the tests were following: 7th May 2014, 29th May 2014, 3th July 2014, 1st September 2014 and19th November 2014.

[2] In the case of this particular research less material than is specified in the standard has been used; other requirements of standard have been fulfilled.

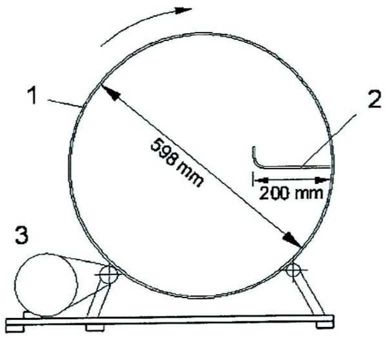

Figure 3. Drawing of rotating drum: 1–Drum, 2–Partition, 3–Engine (c).

Each briquette sample was weighed before and after testing and final mechanical durability of every briquette was calculated by using following formula:

$$DU = \frac{m_a}{m_e} \cdot 100 \tag{1}$$

where: D – mechanical durability (%); m_a – weight of briquette sample after mechanical durability testing (g); m_e – weight of briquette sample before mechanical durability testing (g).

RESULTS AND DISCUSSION

Final result values showed very high level mechanical durability of briquettes made from digestate, overall average value was equal to 99.44% (minimum 96.25%, maximum 99.99%). It corresponds to the highest grade of this quality indicator ($DU \geq 95\%$) given by International standard for solid biofuels EN ISO 17225–1:2015. Previous research has proved suitability of digestate as a feedstock for production of densified fuel for combustion and recommended digestate as an excellent substitute for wood material (Kratzeisen et al., 2010). As it is visible from Fig. 4 the lowest mechanical durability was observed during first testing (98.90%) which corresponds to 105 rotations (29th day) and the highest mechanical durability during last fifth testing (99.64%) which corresponds to 630 rotations in total (226th day).

Fig. 4 also illustrates that the biggest difference between specific testing was observed between first (105 rotations) and second test (210 rotations). This phenomena was caused by abrasion of sharp edges of briquettes which comprised the main part of first abrasion. Previous research done by Temmerman et al. (2006) has showed reverse trend of mechanical durability changes. Result values of mentioned research has presented decreasing level of mechanical durability with increasing number of testing ($n = 5$) but time interval between testing~~s~~ or condition of storage of samples was not specified.

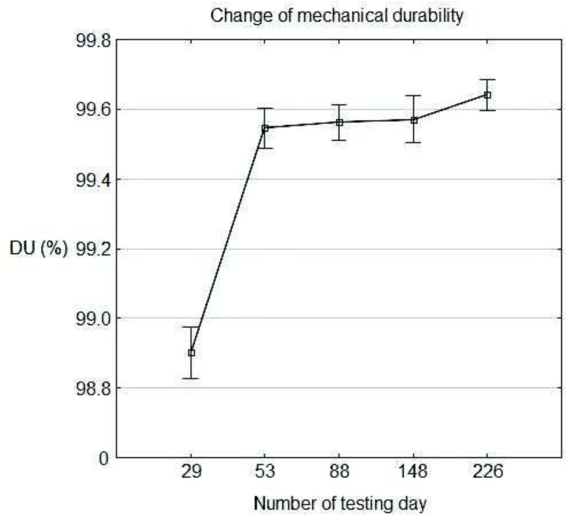

Figure 4. Average mechanical durability of all briquette samples (%) during specific testing.

For clearer evaluation of result~~s~~ values achieved in this research a comparison with mechanical durability of different feedstock material published by other authors was used, see in Table 1.

Table 1. Mechanical durability of briquettes from different feedstock material in %

DU (%)	Material	Author
< 90.0	giant reed	(Ivanova, 2012)
	wheat	(Tumuluru et al., 2015)
	canola	(Tumuluru et al., 2015)
	sea buckthorn	(Novotný, 2015)
	big bluestem	(Theerarattananoon et al., 2012)
≥ 90.0	wood	(Brožek et al., 2012)
	corn	(Kaliyan & Morey, 2009b)
	miscanthus x gigantheus	(Ivanova, 2012)
	rice	(Muazu & Stegemann, 2015)
	canary grass	(Repsa et al., 2014)
≥ 95.0	**digestate***	Authors data
	cotton	(Eissa et al., 2013)
	hemp	(Ivanova, 2012)
	soybean (stalk)	(Rajkumar & Venkatachalam, 2013)
	paper + board	(Brožek, 2015)

*In the case of this research less material than according to standard was used for the mechanical durability testing. Other result values were achieved by different mechanical durability testing methods (standards), thus it has informative and comparable character.

It is essential to mention that referential values of other crops (Table 1) were produced under different manufacturing conditions, however they are still comparable. Final mechanical durability can be significantly affected by the factors like compressing pressure, feedstock moisture content, temperature or particle size (Temmerman et al., 2006; Kaliyan & Morey, 2009a). According to research of Saptoadi (2008) it has been determined that mechanical durability of wood briquettes increases with decreasing size of feedstock particle size. Results values from previous researches of Temmerman et al. (2006) and Al-Widyan & Al-Jalil (2002) related to compacting presure exhibits that mechanical durability increases with increasing of compacting pressure. Those researches were done by high pressure briquetting machines which used compacting pressure 12–35 MPa however result values of Yank et al. (2016) proved high mechanical durability 91.9% of briquettes from rice husk and bran produced by manual press generating ~~a~~ compacting pressure of 4.2 MPa. This result opens chances to produce briquettes in non-electrified regions or in small production sectors and extends the scope of briquettes production on global scale.

Influence of different storage conditions

Average result values of specific testings and storage conditions, see in the Table 2 and Fig. 5 differs at minimal level. Result values exhibited higher mechanical durability for outdoor stored samples from Group 2 than for Group 1 which was stored in indoor constant conditions. Average difference between Group 1 and Group 2 was equal to 0.015 %. It can be stated that result values in average were approximately equal despite the different relative air humidity and air temperature of storage condition.

Table 2. Average mechanical durability (DU) of different stored briquette groups after specific testing (%)

Testing day	29^{th}	53^{rd}	88^{th}	148^{th}	226^{th}	average DU
Group 1 (DU)	98.853	99.545	99.529	99.604	99.654	99.437
Group 2 (DU)	98.953	99.548	99.597	99.535	99.627	99.452

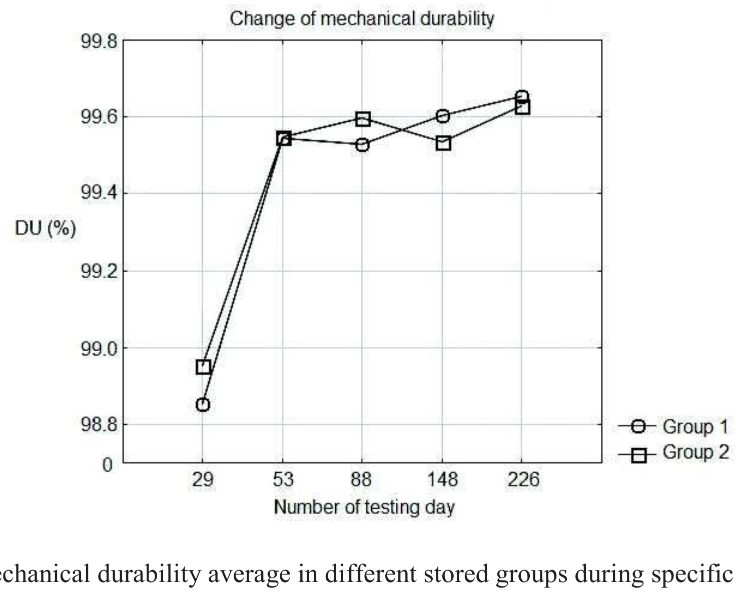

Figure 5. Mechanical durability average in different stored groups during specific testing.

According to previous research done by Kaliyan & Morey (2009a) the proper relative air humidity for storage of densified products is stated to 60–70% and air temperature should be equal to 25 °C and below Result values of this research also proved that increasing of moisture content of densified products to more than 13% can influence final product quality negatively (Kaliyan & Morey, 2009a).

Despite the fact that result values of mechanical durability observed in this paper are approximately equal higher mechanical durability was exhibited for outdoor stored Group 2. There is contradiction with previous research results of Brožek (2013). Mentioned research was also focused on influence of different storage conditions and long-term storage (9 months) of briquettes but it proved that mechanical durability of briquette samples stored in closed heated room was equal to 91.77% in average which was higher than mechanical durability of briquette samples stored in closed unheated room which was equal to 86.80% in average. Difference between results of mentioned previous research of Brožek (2013) and results of this paper can be explained by weight influence of briquette samples below.

Briquette weight influence

At the beginning of the experimental research the briquette samples were chosen and distributed randomly which caused weight inequality between groups. According to data the part of research focused on briquette weight has stated that Group 1 contained briquette samples with higher weight. This fact is visible from Fig. 6 below which displays weight distribution of briquette samples within different groups.

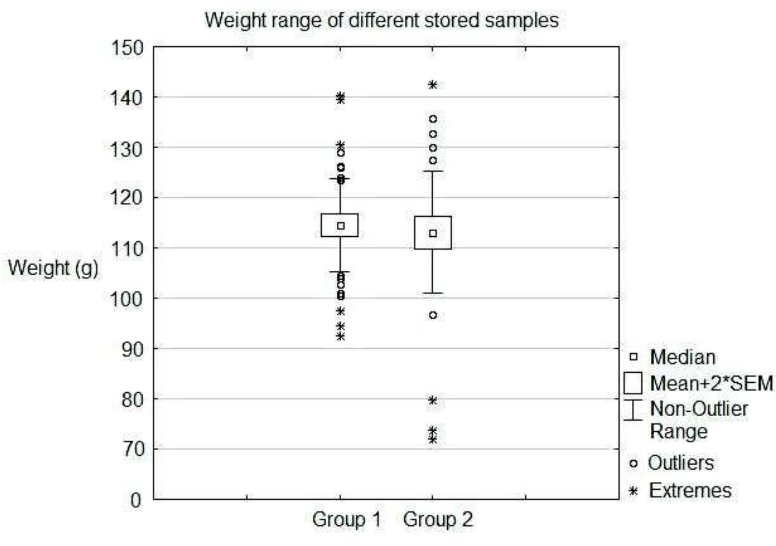

Figure 6. Weight distribution of briquette samples in observed groups (g).

For the purposes of this paper evaluation initial values of briquettes samples were distributed according to the briquette weight and mechanical durability of each different weight group was subsequently calculated. Those processed values as it is visible from Fig. 7 reflected that best degree of mechanical durability was stated for briquettes from groups with weight range 90.01–130.01 g. The lighter and also heavier briquettes showed lower degree of mechanical durability.

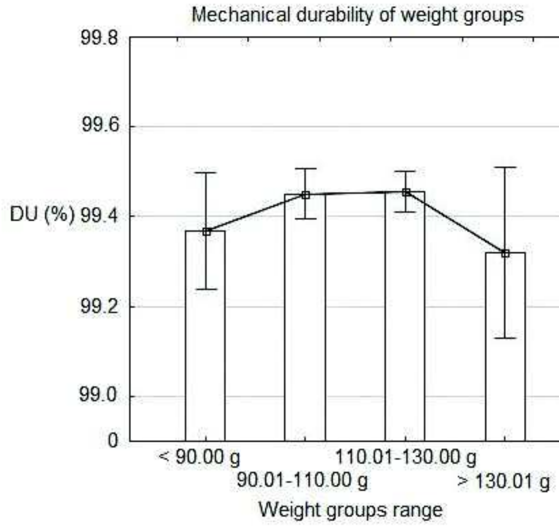

Figure 7. Comparison of mechanical durability of briquette sample groups with different weight.

CONCLUSIONS

The results of this paper implies that briquettes made from digestate exhibited very high mechanical durability (99.44% in average) in accordance to the evaluation of standard EN ISO 17225–1:2015 as well as in comparison with other tested feedstock material from previous researches. The degree of mechanical durability of digestate briquettes was not influenced by the different storage conditions in a considerable extent. Therefore briquettes from digestate are not demanding on storage condition. Higher mechanical durability was observed at briquette samples with weight range from 90–130 g (middle weight groups). Briquette samples with lower of higher weight exhibited lower mechanical durability. The research results contribute to the conclusion that briquettes made from digestate are not only secondary product of proper waste management, effectively modified fertilizer but it is also suitable fuel with outstanding mechanical properties.

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