MECHANICAL DURABILITY OF DIGESTATE BRIQUETTES MIXED WITH MINERAL ADDITIVES

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Abstract. Briquettes produced from digestate have its specific properties which directly affect briquettes' quality and must be determined. Mechanical durability (DU) is considered as a main indicator of physical quality of briquettes and its determination is essential in overall quality evaluation. The study was designed to determine mechanical durability of briquettes from pure digestate, digestate mixed with zeolite and dolomitic limestone both added in ratio 6:1 (digestate:additive). Use of additives is common practice which improves quality of briquettes. All briquettes were produced under the same production conditions by hydraulic briquetting piston press (working pressure of 18 MPa) into the cylindrical shapes (diameter 65 mm, length from 30-80 mm) and subsequently divided according to feedstock into three groups: Group A-briquettes from pure digestate, Group B–briquettes from digestate + zeolite and Group C–briquettes from digestate + dolomitic limestone. All groups were stored for four months (constant air temperature 23 ºC and relative air humidity 45-60 % in average). Standard laboratory analysis of pure digestate properties determined gross calorific value (wet basis) equal to 17.02 $MJ \cdot kg^{-1}$, moisture content 9.21 % and ash content 15.71 %. During storage period were samples repeatedly ($n = 4$) submitted to test for mechanical durability determination by using of special rotating drum. Overall mechanical durability of groups was calculated and afterwards the result values were divided according to briquette weights into four groups for each feedstock and statistically tested. Final results of experimental testing showed that highest average mechanical durability was determined equal to 98.9 % for Group A, 98.2 % for Group B and the worst results 97.3 % were achieved by Group C. Upward trend of mechanical durability was observed during testing process for all groups. The findings of this study suggests that all tested groups fulfilled requirements for commercial briquette production at highest grade (DU≥95 %) according to standard EN 15210-2:2010, however it was proved that mixing digestate with additives did not improve its properties.

Keywords: biomass, densification, briquetting, biofuel quality, abrasion resistance, zeolite, limestone.

Introduction

Briquetting technology uses process of densification and operates with production factors as a compacting pressure, compacting heat and feedstock material properties without using of any binders. All those factors can influence quality of final products (briquettes) thus whole efficiency of briquette production [1]. Absence of binders can influences final briquette quality negatively [2]. Binding effect can be substituted and achieved by using mixed feedstock; containing various number of materials and/or additives which substitutes missing binder. Production of mixed briquettes is common practice because using of additives improves feedstock properties thus increases mechanical durability of briquettes. According to authors dealing with briquette quality issue mechanical durability is main indicator of briquette mechanical quality [3-6]. It is great attempt to produce high quality briquettes nowadays to interest general public and expand the scope of this environmental friendly renewable biofuel [4]. Secondary product of other renewable biomass based biofuel-biogas-called digestate [7] presents about 90 % of initial feedstock thus the need of subsequent utilization is requested [2]. Processed digestate was successfully used as a feedstock for briquette production before [8; 9]. Specific digestate properties as well as properties of all feedstock materials used as a feedstock for briquette production can be influenced by using various additives [9]. Type or amount of additives is not generally defined and both are carefully chosen according to specific chemical (lignin content) or mechanical (particle size) properties to achieved highest improvement of briquette quality [2]. Lignin leaves cells structures during pressing and act like a glue to bind different components of material into the form of briquette. It implies that additives are finding between materials with high content of lignin [10]. Results of previous research related to feedstock particle size exhibits higher mechanical durability for briquettes contain smaller particle than bigger one. Thus feedstock materials which contain big particles can be improved by an additive with a small particle size [11]. Example of frequently used additive material is sawdust which presents suitable combination of lignin content and small particle size additive [3; 10; 12; 13]. A countless representatives of commonly used additives can be find between plant origin material [14], animal origin material [12] and chemical or mineral substances [11; 12]. Selection of proper additives and its ratio in feedstock was scientifically investigated in many previous researches. It is important to realize that to every specific feedstock material suit different additives added in certain ratio which forms unique mixture which causes improvement of final briquette quality. Consequently all briquettes produced from unique mixed feedstock must be subjected to tests to define overall appropriateness of additive and proper suitable ratio in feedstock.

Many varieties of different additives and their influences were investigated in previous researches. Research which studied influence of cassava starch and wood ash additives on final quality of briquettes produced from tropical hardwood sawdust concluded that highest improvement exhibit briquettes with cassava starch additive [14]. Other papers handled for examples with the lignite additive in palm sawdust feedstock [11], waste of biodiesel production - raw glycerol additive in sawdust briquettes [15], caustic soda (NaOH) [16] or denatured rice husk additive [17] added in various biomass feedstocks. Influence of peat additive mixed with common reed and reed canary grass feedstock materials was also studied. Results showed the highest increase of mechanical durability for mixtures which contain 30 % of peat for common reed grass and 20 % of peat for reed canary grass [18]. Study focused on dry cow dung additive in briquettes made from raw mango and acacia leaves and saw dust expose the best mechanical durability of combination with 10 % of dry cow dung additive [12]. Other research proved highest mechanical durability for briquettes from Miscanthus straw with 20 % of algae additive [19]. Mentioned randomly selected additive materials reflect the wide scope of additive utilization in briquette production in attempt to improve quality of final products across various manufacturing sectors.

The aim of this study was to define the level of physical quality of briquettes produced from pure digestate and digestate with two different additives (zeolite and dolomitic limestone) by determination of mechanical durability. Subsequent evaluation of binder function of used additives and its influence on the final briquette quality was monitored.

Materials and methods

Proper feedstock preparation, briquettes production and subsequent testing were performed according to mandatory technical standards, namely an International Standard EN ISO 17225–1:2015, EN 15234–1:2011, EN 14918:2009, EN 14775:2010, EN 14774–2:2009 and EN 15210–2:2011, which describes methodology of mechanical durability testing [17]–[22].

Material and sampling

The digestate was obtained from the biogas plant placed in Central Bohemia region, Czech Republic with following composition of feedstock: 60 % beef manure, 20 % corn silage and 20 % grass silage. The raw material was mechanical dehydrated, dried naturally under the sun at first and subsequently dried to the finally content of 85-90 % of dry matter. Processed material was used as a feedstock for the briquetting press type BrikStar CS 50 (Malšice city, Czech Republic) which operates with working pressure 18 MPa, operating temperature 60 ºC, feedstock moisture content 8-15 % and the density of final products approximately 900-1100 $kg \cdot m^{-3}$. All briquettes were produced under the same conditions into the cylindrical shape with diameter 65 mm, length from 30 to 100 mm and weight from 27.4 to 257.1 g.

For the purposes of this paper three different types of briquettes were produced and divided into the groups according to composition and additives used: first type contained the pure digestate briquettes only (Group A), the second type contained briquettes made of digestate with addition of zeolite in ratio 6:1 (Group B) and the third type was digestate briquettes with dolomitic limestone added in ratio 6:1 (Group C). All samples were stored in laboratory with constant air temperature equal to 23 ºC in average and relative air humidity between 45-60 % for 92 days. Pure digestate material used as a feedstock for production of briquette samples for this paper was tested to determine its main physical properties. Standard analysis measured gross calorific value (wet basis) equal to 17.02 $MJ \cdot kg^{-1}$, moisture content 9.21 % and ash content 15.71 %.

Determination of mechanical durability

Mechanical durability of briquettes belongs to very important tests of their mechanical resistance. This quality indicator specifies how the briquettes are resistant during handling, transporting and storage. The experiment was done at the laboratory conditions by using special rotary drum, see in Figure 1, according to the standard EN 15210-2 [22]. For the subsequent calculation of mechanical durability the standard formula noted below was used (1):

$$DU = \frac{m_A}{m_E} \cdot 100\,, \tag{1}$$

where DU – mechanical durability, %;
m_A – the mass of sieved briquettes after the drum treatment, g;
m_E – mass of pre-sieved briquettes before the drum treatment, g.

Every briquette was weighed before and after mechanical durability testing and obtained data were used for subsequent calculation of mechanical durability. STATISTICA10 software was used to final process and evaluation of measured data; other statistical methods, namely descriptive statistics, analysis of variance, Scheffé's method and Kruskall-Wallis test were applied to evaluate the dependency of monitored values. Totally four tests of mechanical durability were performed during the whole storage period. First test of mechanical durability was performed at first day after production of all briquette samples (thus at first day of storage). Subsequent tests were performed at 37th day, 64th day and 92nd day of storage.

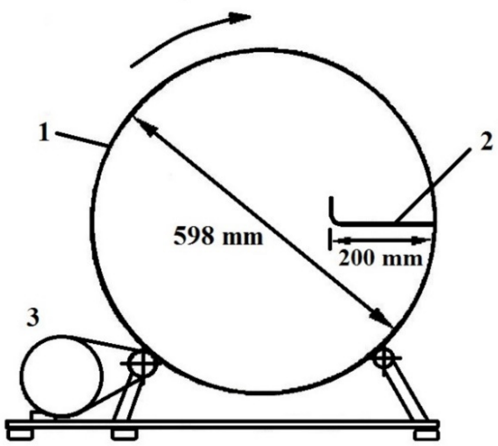

Fig. 1. **Rotary drum:** 1 – drum; 2 – partition; 3 – motor

Results and discussion

According to the European Standards EN 15210–2 measured values obtained from experimental part of this research have indicated that the highest mechanical durability was determined for briquettes produced from pure digestate equal to 98.91 % in average; the lowest values equal to 97.31 % in average were observed for briquettes made from digestate with dolomitic limestone additive. Third used feedstock material, digestate mixed with zeolite, exhibits average mechanical durability equal 98.16 %. Minimal and maximal values from all measured values for specific feedstock material are noted in Table 1.

Table 1

Mechanical durability of different feedstock briquettes

Material	*DU* average, %	Minimal *DU**, %	Maximal *DU**, %
Pure digestate	98.91	86.77	99.77
DGST+zeolite	98.16	72.58	99.71
DGST+limestone	97.31	81.09	99.73

*Minimal and maximal value of all tests; DGST – digestate

Result values of specific feedstock samples noted in Tab. 1 reflect fact that digestate material has great potential as a feedstock for solid biofuel production. Other authors which dealt with question of subsequent utilization of digestate proved suitable chemical and mechanical properties of both, briquettes and pellets from digestate. First study which was focused on digestate pellets tested primarily its chemical composition and according to the authors opinion there can be concluded sustainability of digestate pellets [9]. Next authors performed research focused primarily on mechanical quality of digestate briquettes. Result of this paper indicated that tested samples were sustainable secondary product of proper waste management and also potential solid biofuel with outstanding mechanical properties [8]. According to the European Standards EN 15210–2 which also contains precisely instruction for final briquette mechanical durability evaluation, all groups of briquette samples from different feedstock tested in this paper achieved to the highest grade of this quality indicator (> 95 %).

Process of mechanical durability change during storage period is expressed in Figure 2 which displays average result values of specific tests and increasing linear trend lines of mechanical durability issue with clearly visible difference between specific feedstock briquettes. Results of present paper proved that using of mineral additives namely zoelite and dolomitic limestone did not improve mechanical durability of tested briquette samples from digestate which is main purpose of using additives in briquette production. Worst mechanical durability level reached by briquettes from digestate mixed with dolomitic limestone was probably caused by mechanical properties of granules of dolomitic limestone which were used. Added granules could break inside or on the surface of briquettes during pressing or subsequent testing and bigger pieces of material could crumbled off for this reason.

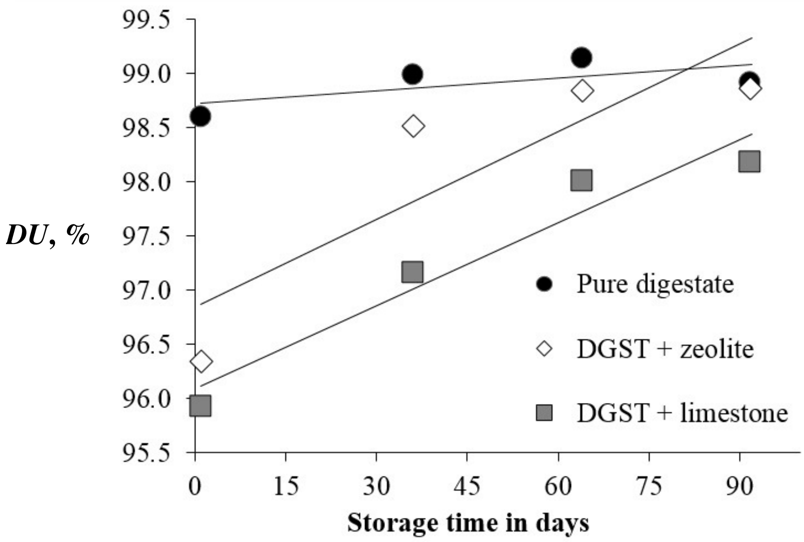

Fig. 2. **Process of mechanical durability change during storage time**

Previous mentioned research focused on mechanical quality of digestate briquettes proved mechanical durability of briquettes made from pure digestate and stored in constant laboratory conditions equal to 99.44 % in average. Mentioned research also shows level of mechanical durability of briquette samples stored in outdoor conditions equal to 99.45 % [8]. Resuls of present and previous mentioned researches indicated very high mechanical durability of digestate briquettes without using any binders or additives.

Comparison of mechanical durability of specific tests indicated that the largest difference was observed between first and second testing. All subsequent tests of specific feedstock material exhibited approximately constant increasing values with minimal changes. Only inequality was observed in the pure digestate case during last testing where the mechanical durability level decreased. This slight inequality may be caused by the disintegration of one briquette sample. Described differences and increasing trend of mechanical durability is visible at Figure 3 which express specific tests of specific feedstock groups.

This phenomena could be explained by relation between mechanical durability and shape of briquettes. During first testing sharp edges of briquettes were abraded and during subsequent testing those edges have been already smoothed and did not caused further abrasion. This fact was not proved by statistical analysis but according to visual evaluation. This phenomenon related to difference between specific testing was also observed in previous mentioned research focused on the briquettes made from digestate. Result of mentioned paper also indicate biggest difference in DU between first and second testing and exhibit subsequent testing approximately constant [8].

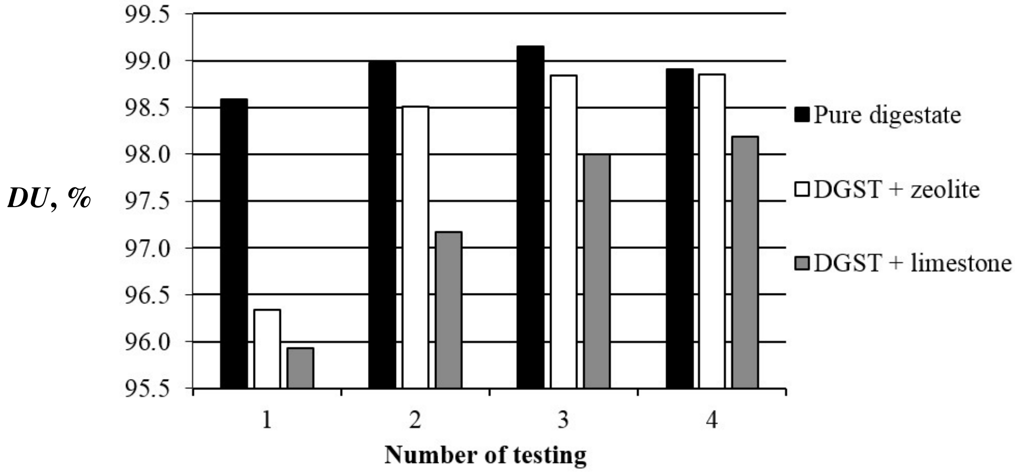

Fig. 3. **Mechanical durability during specific tests**

Conclusions

In general, obtained results of mechanical durability together with chemical properties results exhibited high level of final quality of tested briquette samples according to appropriate technical norms and standards. Values measured in this paper indicate difference between level of mechanical durability of briquettes produced from pure digestate and briquettes from digestate mixed with mineral additives, despite all briquette samples were produced under the same conditions. Statistical analysis proved that composition of feedstock material used for the briquette production has significant impact on the level of mechanical durability with 95 % of probability. Therefore the findings of this research imply that using of mineral additives in digestate briquettes production is not nessesary, even more it decreases mechanical durability of final product thus it is not recommended. Awareness of subsequent utilzation of digestate as a solid biofuel production was not exproled and monitored sufficiently yet but results of this paper indicated its great potential and evaluated unproper using of additives. By publication of this paper can raise awareness about digestate material and can increases the interest of solid biofuel producers about it. However more experimental reaserches are recommended especially focused on the influence of biogas plant station feedstock diversity to final briquette quality.

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