OPTIMAL FEEDSTOCK PARTICLE SIZE AND ITS INFLUENCE ON FINAL BRIQUETTE QUALITY

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Abstract

Present paper monitored one of most important feedstock property, specifically particle size, and its influence on briquette quality. Six different types of briquettes were produced; two conifer tree barks (pine and spruce) with three different particle sizes (<6; 6 – 12; >12 mm) were used as feedstock materials. Investigated briquettes were subjected to gross calorific value, ash content, volume density, mechanical durability and rupture force determination. Evaluation of measured values stated particle size 6 – 12 mm as most suitable for spruce bark briquettes, followed by <6 mm and >12 mm. Within pine bark briquettes a particle size equal to <6 mm exhibited best results, then 6 – 12 mm and >12 mm. Generally, most suitable particle size was attributed to 6 – 12 mm, however, results did not prove one unambiguous optimal particle size. In conclusion, results values did not support prevailing opinion that smaller particle sizes are more suitable for briquette production.

Key words: solid biofuel, mechanical durability, rupture force, quality testing, particle size.

INTRODUCTION

Until recently, the biomass has not been widely utilized as renewable source of energy due to its relatively low energy efficiency when compared to fossil fuels. However, concern over climate changes and global inappropriate waste management caused increasing effort to use biomass and waste materials for energy production (MCKENDRY, 2002). Currently, briquetting is one of suitable evolving technologies of waste materials conversion to solid biofuels for energy purposes. Great amount of waste materials proper for briquette production are produced every day and one of them is tree bark. Bark is ordinarily used as a mulching material for greater soil evaporation (ZRIBI ET AL., 2015), nevertheless, there is a potential to use it as a feedstock for briquette production (KESLEY ET AL., 1979).

Two most important feedstock properties are particle size and moisture content (MITCHUAL ET AL., 2013). Optimal level of moisture content is defined by mandatory technical standard EN 18134–2 (2016): Solid biofuels – Determination of moisture content – Oven dry method – Part 2: Total moisture – Simplified method and it ranges between 8 – 12% (EN 18134–2, 2016). Despite the fact that particle size is also considered as great influencer of final briquette quality (SAPTOADI, 2008) there is no mandatory technical standard to define optimal range of particle size. According to previous researches, there is prevailing opinion that finer grind of feedstock material causes higher quality of solid biofuels (KALIYAN AND MOREY, 2009; KARUNANITHY ET AL., 2012). MacBain (1966) asserted that larger particles accept less moisture which causes fractures in solid biofuels in contrast with finer particles.

Thus, according to previous researches briquette quality increases with decreasing of feedstock particle size, but this trend is limited. Extremely small particles exhibit negative influence and decreasing of mechanical durability, which is main indicator of mechanical quality of briquettes, as well as disproportionately large particles (KALIYAN AND MOREY, 2009). Previous research of MITCHUAL ET AL. (2013) focused on briquettes produced from tropical hardwood sawdust proved that best particle size ranges between 1 – 2 mm. However, other authors exhibited that suitable particle size ranges between 10 – 15 mm for briquettes from municipal solid waste (YOUNG AND KENNAS, 2003) or ranges between 6 – 8 mm size for briquettes made from combination of three hardwood species (EMERHI, 2011). Different research done by TUMULURU ET AL. (2015) which was focused on briquettes produced from wheat, oat, canola, and barley straw proved best particle size between 25 – 32 mm (TUMULURU ET AL., 2015). Choice of optimal particle size apparently partially depends on concrete feedstock material but in general, it is not disputed that overall optimal particle size is not defined yet.

Main aim of this paper is to determine optimal particle size (fraction) of two feedstock materials – pine and spruce bark - used for the briquette samples production to optimize briquetting process by preventing material loose during briquette production, transportation and storage which can be directly caused by inappropriate particle size.

MATERIALS AND METHODS

Two different types of barks which were used as feedstock material for briquette sample production originated from pine tree and spruce tree. Both materials were acquired by cooperation with the Arboretum FFWS Kostelec nad Černými lesy. Raw unprocessed materials occurred in an unacceptable form for briquette production (moisture content above 40%, particle size above 100 mm) therefore preproduction preparation was executed. Material was primarily dehydrated in heated laboratory followed by drying in laboratory dryer LAC type S100/03 (LAC, Czech Republic) to proper moisture content in accordance to mandatory technical standard EN 18134–2 (2016): Solid biofuels – Determination of moisture content – Oven dry method – Part 2: Total moisture – Simplified method (EN 18134–2, 2016). Dried material exhibited following values of moisture content: pine bark equal to 14.02% and spruce bark equal to 11.91%. In next step were two mentioned feedstock materials crushed by shredder AL–KO New Tec 2400 R (Dolpima, Czech Republic) and subsequently divided by sieves according three different fraction size: <6 mm, 6 – 12 mm and >12mm.

Thus three different types of each bark feedstock materials were made within what six different types of briquettes were produced by hydraulic piston press Briklis type BrikStar type 30–12 (Malšice city, Czech Republic) under the same manufacturing conditions into cylindrical shape with diameter equal to 50 mm. Used briquetting press operates with pressure equal to 18 MPa, temperature equal to 60°C and proper feedstock moisture content varieties between 8–15%. Feedstock preparation and subsequent briquette samples production were performed according to mandatory technical standard EN ISO 17225–1 (2015): Solid biofuels – Fuel specifications and classes – Part 1: General requirements (EN ISO 17225–1, 2015).

< 6 mm 6 – 12 mm > 12 mm

Fig. 1. – Briquette samples produced from different particle size feedstocks

Length of produced briquette samples was equal to 55.86 mm in average (min. 38.41 mm; max. 73.57 mm) for pine bark and equal to 55.62 mm (min. 40.87 mm; max. 68.61 mm) for spruce bark. Variety of briquette weights exhibited following values: pine bark briquettes equal to 116.32 g (min. 74.20 g; max. 146.10 g) and spruce bark briquettes equal to 110.56 g (min. 63.40 g; max. 137.40 g). Volume density which is considered as important indicator of densification process efficiency was monitored and calculated within overall briquette quality. Detail ranges of volume density of all briquette samples are exhibited in Fig. 2 and Fig. 3.

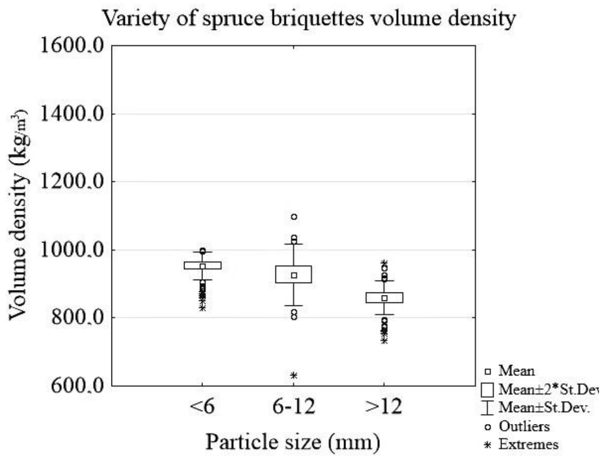


Fig. 2. – BoxPlot of volume density varieties within different particle sizes

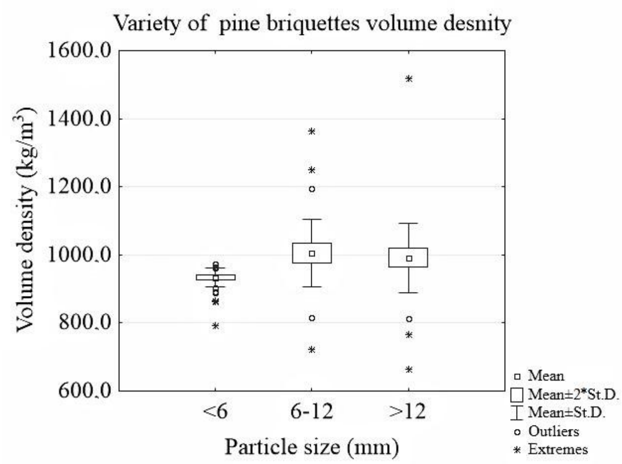


Fig. 3. – BoxPlot of volume density varieties within different particle sizes

Experimental methods

Experimental testing performed within briquette samples quality determination was conducted to mandatory technical standard EN 15234–1 (2011): Solid biofuels – Fuel quality assurance – Part 1: General requirements (EN 15234–1, 2011). Within analysis of chemical properties of mentioned feedstock a gross calorific value (GCV) and ash content (A_c) were determined. Measurements of GCV were performed according to mandatory technical standard EN 14918 (2010): Solid biofuels – Determination of calorific value (EN 14918, 2010). Adiabatic calorimeter Laget MS – 10 A (Laget, Germany) was used for experimental testing and subsequent result values were calculated by using of following formula (1):

$$GCV = \frac{dTk \times Tk - \left(c_1 + c_2\right)}{m} \tag{1}$$

Where:

GCV – Gross calorific value ($J \cdot g^{-1}$)

dTk – Temperature jump (°C)

Tk – Heat capacity of calorimeter ($J \cdot °C^{-1}$)

c_1 – Repair of benzoic acid (J)

c_2 – Repair of burning spark wire heat (J)

m – Weight of material sample (g).

Content of ash was investigated by using of laboratory muffle furnace LMH (LAC, Czech Republic) in accordance to mandatory technical standard EN 14775 (2009): Solid biofuels – Determination of ash content. Final result values were calculated by formula (2):

$$A_c = \frac{\left(m_3 - m_1\right)}{\left(m_2 - m_1\right)} \times 100 \times \frac{100}{100 - M_{ad}} \tag{2}$$

Where:

A_c – Ash content (%)

m_1 – Mass of empty crucible (g)

m_2 – Mass of crucible + sample (g)

m_3 – Mass of crucible + ash (g)

M_{ad} – Water content in a sample (%) (EN 14775, 2009).

Within mechanical quality determination a mechanical durability of all specific briquette types was tested. Whole preparation, testing and used equipment were conducted to mandatory technical standard EN 15210–2 (2011): Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 2: Briquettes (EN 15210–2, 2011). Experimental measurements was performed in special dustproof rotating drum (see in Fig. 4) and for subsequent mechanical durability calculation following formula was used (3):

$$DU = \frac{m_A}{m_E} \cdot 100 \tag{3}$$

Where:

DU – Mechanical durability (%)

m_A – Mass of sieved briquettes after the drum treatment (g)

m_E – Mass of pre-sieved briquettes before the drum treatment (g).

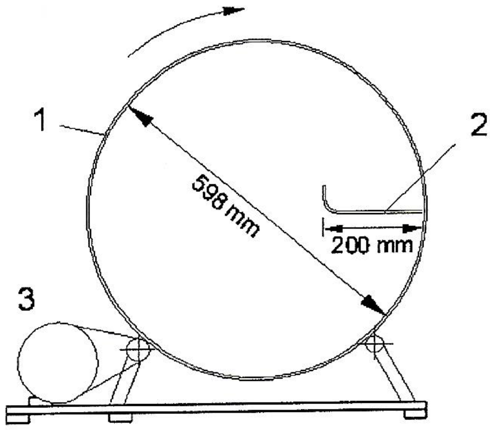
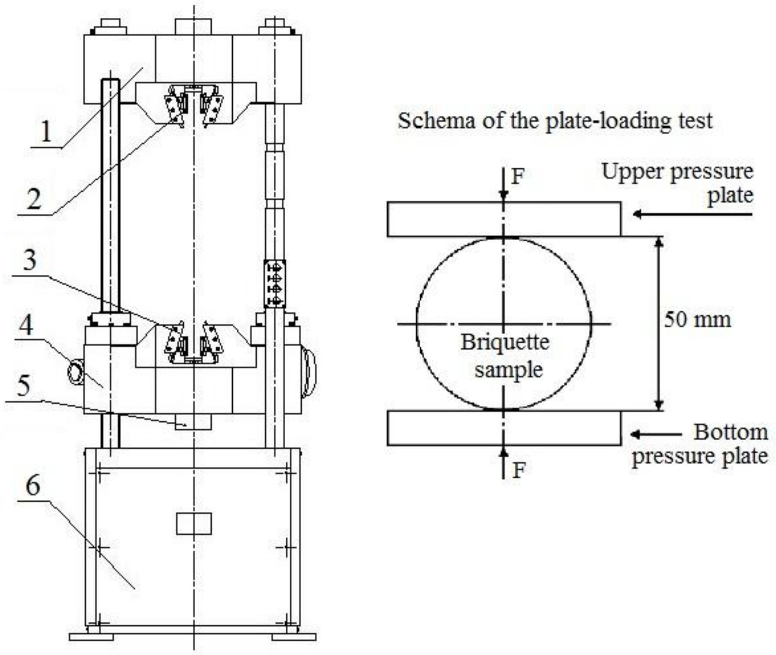


Fig. 4. – Special dustproof rotating drum: 1 – drum, 2 – partition, 3 – motor

A hydraulic universal tensile compression testing machine type ZDM 50 (VEB, Dresden, Germany) which operates with loading speed 20 mm/min. and maximal force 500 kN was used for performance of second mentioned quality test. Drawing of machine ZDM 50 and used principle of special plate-loading test are expressed in Fig. 5. There are no mandatory technical standards to define process of rupture force determination and evaluation of result values. Nevertheless, investigated briquette samples were loaded by application of force produced by ZDM 50 machine and maximal force which briquette sample was able tolerated before it broke down was measured and noted as a rupture force in Newton.



1 – up crossbeam, 2 – up jaw, 3 – down jaw, 4 – down crossbeam, 5 – platen, 6 – configuring

Fig. 5. – Schema and principle of rupture force testing machine

RESULTS AND DISCUSSION

Level of briquette samples volume density expressed efficiency of briquetting process and appropriateness of used feedstock material for briquette production. Fig. 2 and Fig. 3 shows result values proving highest volume density for fraction <6 mm for spruce briquette samples. If compared differences between individually fractions of spruce feedstock, very small differences were proved. However, decreasing trend was observed with increasing of particle size. This trend corresponds with the common opinion that biofuel quality increases with decreasing of particle size as stated by SAPTOADI (2008). On the contrary, result values of pine briquette samples testing did not confirmed this trend. If compare differences between individually fractions of pine feedstock the highest level of volume density was observed for middle fraction 6 – 12 mm, following by largest fraction >12 mm and then lowest level was observed for fraction <6 mm. It implies that it cannot be represented that smaller particle size always indicated higher briquette quality.

Result values of GCV were stated equal to 18.6 MJ kg^{-1} in average for pine bark material and equal to 19.3 MJ kg^{-1} for spruce bark material. Present

result values corresponded to mandatory minimal requirement (>17 MJ·kg^{-1}) according to appropriate standard. In compare with wood of those conifer trees, previous researches proved GCV of pine wood equal to 16.3 MJ·kg^{-1} and equal to 20.5 MJ·kg^{-1} for spruce wood (KRATZEISEN ET AL., 2010; RHEN ET AL., 2007). Ash content determination exhibited following result values: 1.87% for pine bark material and 5.15% for spruce bark material. Mentioned values presented very high level of ash content if compare with pine wood (0.31%) and spruce wood (0.48%). This inequality could be caused by external contamination and pollution of bark during tree lifetime (RHEN ET AL., 2007).
Evaluation of mechanical durability result values proved that feedstock material which contains smallest particle size not always ensures best briquette quality results. Briquette samples produced from pine bark exhibited best result for middle particle size briquette samples (6 – 12 mm), following by smallest particle size briquette samples (<6 mm) and worst result was achieved by largest particle size briquette samples (>12 mm). Result values obtained for spruce bark briquette samples corresponded to prevalent opinion about improving of briquette quality with decreasing of particle size as visible from Fig. 6 (SAPTOADI, 2008). Overall evaluation of mechanical durability determination proved positive influence of decreasing of particle size on briquette quality. However, this evaluation is not unambiguous for all investigated briquette types as well as volume density result values indicated. In any case, overall evaluation of mechanical durability of all investigated briquettes samples indicated high level of this quality indicator (>90%) according to appropriate mandatory technical standard (EN 15210-2, 2011).

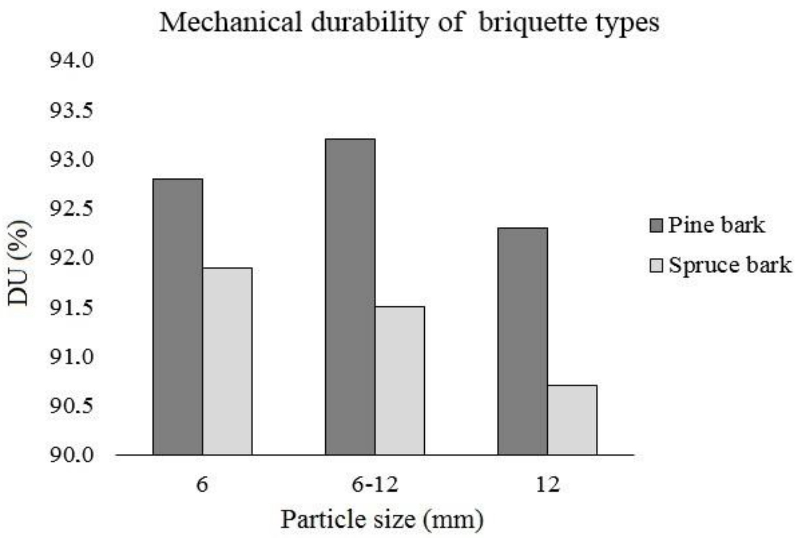


Fig. 6. – Comparison of mechanical durability of investigated briquette sample types

Within rupture force testing a highest level of this mechanical quality indicator was proved by pine bark briquette samples with largest particle size (>12 mm), followed by middle particle size (6 – 12 mm) and worst result exhibited briquette samples with smallest particle size (<6 mm).
Investigated spruce bark briquette samples exhibited best result for middle particle size (6 – 12 mm), then for smallest particle size (<6 mm) and worst results proved briquette samples with largest particle size (>12 mm). Comparisons between specific particle sizes of concrete feedstock materials are expressed in Fig. 7 and Fig. 8.

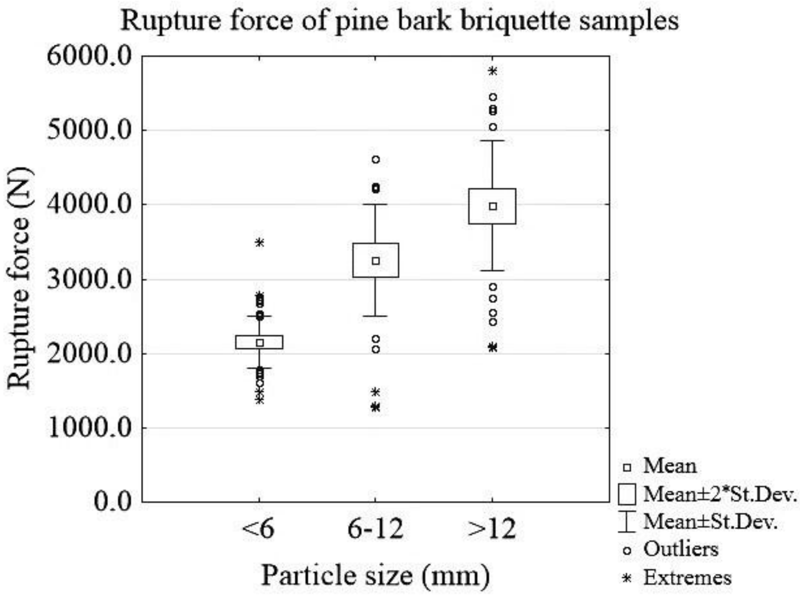


Fig. 7. – Boxplot of rupture force variety within different fractions of pine bark feedstock

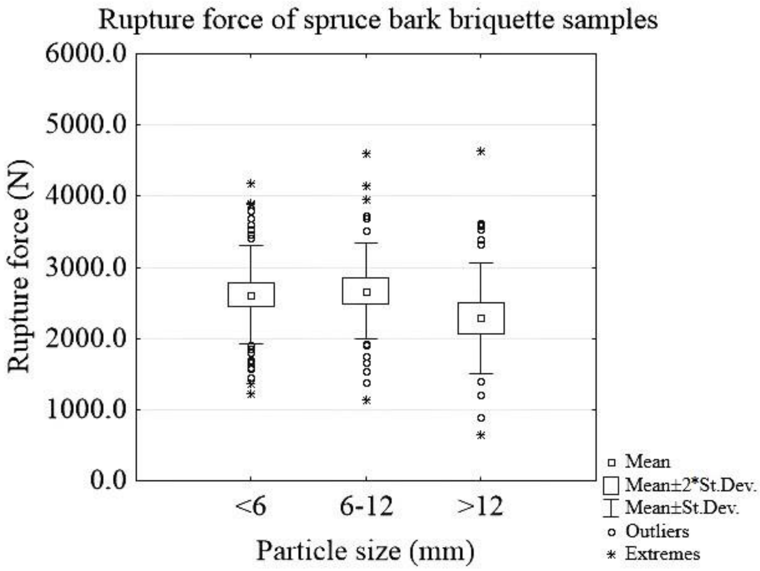


Fig. 8. – Boxplot of rupture force variety within different fractions of spruce bark feedstock

As is visible from Fig. 7 and Fig. 8 in neither case was highest result values reached by briquette samples made from smallest particle size. It can be concluded that smallest particle size (<6 mm) influences rupture force negatively.

CONCLUSIONS

Overall evaluation of investigated quality indicators did not prove unambiguous result. According to the Tab. 1 which expressed all result values (best results are emphasize by bold font) there was low difference between specific feedstock material and in case of specific particle size the results exhibited best values out of sequence.

Thus it can be concluded that one unique optimal particle size was not proved but if compare all best result values the middle particle size (6 – 12 mm) expressed most of them. Within explored influence of different particle size on final briquette quality it can be recommended to continue in future researches in attempt to define unique optimal particle size for different types of biomass.

Tab. 1. – Result values of quality indicators of different feedstock briquette samples

	Pine bark			Spruce bark		
Particle size (mm)	<6	6 – 12	>12	<6	6 – 12	>12
Volume density (kg/m^3)	933.9	**1005.6**	991.1	**953.3**	926.7	859.7
Mechanical durability (%)	92.8	**93.2**	92.3	**91.9**	91.5	90.7
Rupture force (N)	2155.54	3248.41	**3984.53**	2613.6	**2663.0**	2287.2

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