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AN AGGREGATED PROPERTY OF WHEAT STRAW BRIQUETTES

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ABSTRACT

The paper deals with a method for assessing the quality of briquettes as solid fuel, made from wheat straw biomass. There are presented the advantages of biomass from wheat straw used at a burning process, especially when straws are used in the form of briquettes. Method makes an aggregate of main properties of briquettes and proposes an appreciation of the importance of each property separately. As referencing values of briquette properties resulted from biomass were used some European standards, especially ÖNORM M7135, 2012 from Austria, which contains a specific part only for briquettes. Finally, an aggregated property, defined as value of quality obtained for wheat straw briquettes is compared with the values of woody briquettes obtained from beech and spruce biomass. A better value of aggregated property for straw briquettes quality is put in evidence.

KEY WORDS: Biomass, briquette, aggregated property, wheat straw.

INTRODUCTION

Biomass is one of the based renewable resources on future (Lakó et al. 2008; Omer 2012; Tabarés et al. 2000), that can be used both for small-scale in developing countries (Boutin et al. 2007; Ciubotă-Roşie et al. 2008; Jehlickova and Morris 2007) and large-scale human household for boilers with or without co-generation (Kazagic and Smajevic 2009; Pastor-Villgas et al. 2006). Usually, for heating system with fully automatizing, higher qualities of densified products are required (Obernberger and Thek 2004). The term biomass covers a wide range of products and waste from forestry and agriculture (straw, manure, residues of wine production) (Toscano et al. 2013), reed (Kuhlman et al. 2013) including livestock, municipal and industrial waste. All fossil fuels such as coal, oil and natural gas is actually a very ancient biomass, created over the years. Therefore, the compatibility between coal and fresh biomass is good. Biomass can be obtained from plant or animal, but regardless of its nature, it is part of the renewable energy resources.

Biomass has been used for energy since fire was discovered. The part of plant biomass is mainly wood, remaining also agricultural plants, including straw (Eurostat 2011; EC 1997). Cereal straw (wheat, rye, barley, oats and rice) is today a cheap source of raw materials and sustainable renewable biofuels (Demirbas 2001), used on the form of briquettes and pellets (Demirbas and Demirbas 2004; Kažimírová et al. 2013), or directly (straw waste), but in the latter case the calorific density is small. The CO_2 emission is closed to the wood value by 83.8 g.(MJ)$^{-1}$, lower than of coal 97.5 g.(MJ)$^{-1}$. The amount of straw depends essentially by the agricultural soil (Vilcek 2013); the highest energy production (22.2 MJ.m^{-2}) occurs in the very warm, very dry lands, in deeps clayed soils with a slope to 3 %, in arable lands. From this point of view only *Miscanthus giganteus* (Greenhalf et al. 2013), reed or sort-rotation coppice (poplar, willow, acacia) with a value of 4.3 t.(ha.year)$^{-1}$ exceeds the production of wheat straw t.ha^{-1} (Moya and Tenorio 2013).

Cereal straw remains neutral on greenhouse gas emissions, especially smoke with serious effects on human health. The amount of gas that is removed by combustion is equal to the quantity absorbed during vegetation (Kim and Dale 2003; Wilkins and Murray 2003). Straw biomass from wheat (*Triticum aestivum* L.) could contribute to reduction in environmental degradation in some developing countries (Okello et al. 2013). Carbon dioxide from the atmosphere and water from the soil, through the process of photosynthesis are combined, resulted the carbohydrates that form the building blocks of biomass (Dhillon and von Wuelhlisch 2013). Solar energy is stored by photosynthesis in chemical bonds of the structural components of biomass. When biomass is burned, oxygen from the atmosphere is combined with the carbon from plants producing carbon dioxide and water. The process is cyclic, so that enough carbon dioxide (CO_2) in the atmosphere is absorbed by the plant again, as it sees in Fig. 1.

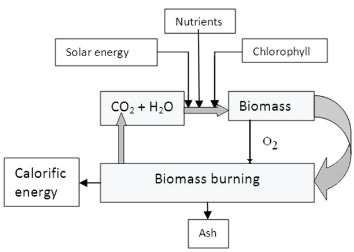

Fig. 1: Closed cicles of straw biomass generation and burning.

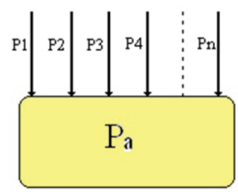

Fig. 2: Aggregated property of straw briquettes.

The cyclic process of carbon in nature is also found within biomass decomposition in nature. Therefore it is strongly recommend exploitation of biomass fuel to give a benefit to people by burning, because the amount of released CO_2 is always the same.

Specifically to the cereal straw compared to wood is its high silica content, higher in rice and lower in oats. This has a negative influence on the moving bodies of press machines in contact with chopped straw, i.e. the extruder, which will have a lower lifespan. Presence of silica leads also to a high ash content during combustion than in case of solid wood. Calorific value is lower in the straw than from wood (this due to lower carbon content, i.e. 40-46 %, compared to 50 %). The calorific value is different depending on the type of straw, respectively higher for barley straw and lower from corn stalks. There are lots of research works about wheat straw biomass, for obtaining ethanol or bio oil (Hansen et al. 2013) in pure stare, or co-firing with coal, in order to increase heating value and obtain a low tar amount. Generally, the determination modality of the calorific value and ash content were investigated thoroughly (Aebiom 2013), but less for straw.

Advantages of agricultural biomass when straw is used, in order to obtain energy, are manifold and can be summarized:

- Use of straw briquettes helps to replace and/or conservation of conventional sources of fossil fuels and decrease dependence on imported energy carriers and fossil fuels.
- Exploitation of agricultural biomass helps to reduce climate change by reducing or keeping constant the effects of greenhouse gases.
- Reduce waste disposal problems, the risk of disease of the earth, caused by problems in the farm work of straw residues, additional costs for agricultural work because of residues spread.

There are lots of properties for woody briquettes, usually grouped into physical, mechanical, chemical and technological. In order to define all these properties there are many standards in the Europe, some of them individualized only on pellets and other both on pellets and briquettes. For example, the main features that are determined in the case of briquettes (according to European standards ÖNORM M7135 from Austria) are the following (Plištil et al. 2005; Verna 2009): Moisture content, bulk and unit density, ash weight and calorific value of dried briquettes.

Elements of practice quality definitions of woody briquettes are few (Lunguleasa 2012) even if for other products are numerous in the scientific literature, but each of they have small particularities and limitations, specific on working conditions. Quality is an important attribute of briquettes, which in most cases are not visible with the naked eye even for the specialists and in a greater extend for common people. The buyer sees only the briquettes appearance and price, possibly the firm name and seldom some physical characteristics. In addition the buyer cannot evaluate the quality, because the briquettes are usually foiled. To list all the briquettes features on the quality bulletin will confuse more the buyer. Quality of wood pellets must be investigated before. By example, if it takes each property and applying for all standard limiting's of analysed samples, considering that the group has a good quality when all limitations are met. This analysis does not take into account the importance of each feature, putting on the same place, for example, the density and the chloride content of briquettes.

Main objectives of this paper is to obtain an aggregate property of briquettes made from wheat straw, in order to classified all types of briquettes related to their quality. In this way the customer is more informed and selection of woody briquettes is more comfortable.

Theoretical elements

The method that is presented in the paper defines the quality of briquettes as the solid fuel. As a starting point it can use the multi criteria analysis technique, which although old can be successfully used nowadays, too. This method contains as the main stages: Establishing the criteria and the share of each, giving a rate for each version and according the final mark. From all technical variants, the *TOPSIS* (technique for order by similarity to ideal solution), defined firstly by Hwang and Yoon (1981) and then by Olson (2004) is the nearest, because is based on the idea that the best option should have minimum distance from the ideal solution. In light of the foregoing idea, to define the cumulative property of woody briquettes, it can be also used an old definition of quality that summarize as percentage all properties of products. According to above concepts, it is considered that there were n properties for appreciation of woody briquettes, noted by *P1, P2, P3*, ... *Pn*, expressed in points (Lunguleasa and Budău 2010) Fig. 2. The sum of all points will be the aggregate property *Pa*:

$$P1 + P2 + P3 + \ldots + Pn = Pa \quad (1)$$

If all properties of woody briquettes are very good, their total value will be high. In reality not all properties are great, there are some weak or very weak.

Also, some properties are not visible (calorific value and ash content), therefore is better for customers to view a quality index on the label batch of briquettes. Moreover, some properties are very good, some less good, but overall it is not known how to evaluate overall briquettes. The analysis of each property is done by comparing the real value with the reference value (usually taken from standards). Value is always one limiting, usually maximum or minimum. Inside of each property there are also lots of appreciations. If the measured method is used for assessing the performance of each property, it is quantified each attribute score areas, such as for instance: total acceptable, partially acceptable, partially unacceptable and total unacceptable.

It is considered, however, that each property has a different importance and will have a different score. From this point of view there are two types of properties: Primary (density, compressive strength and calorific value) and secondary (ash content, moisture content, additive etc.), with different category of points.

MATERIAL AND METHODS

Three types of cylindrically woody briquettes obtained on a mechanical and hydraulically briquetting machine will be analysed. Briquettes with high density over 1100 kg.m^{-3} are obtained on mechanical press, in comparison with hydraulic one of 900 kg.m^{-3} (Lunguleasa 2010). All briquettes are prepared for testing by sanding of ends, in order to correctly measure of briquette length and then its volume. Three primary properties (unit density, calorific value and compressive strength) and other three secondary properties (moisture content, ash content, coefficient of compaction) are taken into consideration.

Tab. 1: Score of each properties.

	Properties	Limitative values (reference)	Own value	Total points
Primary properties	Unit density (g.cm^{-3})	-over 1, ÖNORM M7135 -1-1,4 g.cm^{-3}, DIN 51731 -over 0.527 g.cm^{-3}, CTI - R 04/5	Over 1	100
	Calorific value (MJ.kg^{-1}), dry basis	-over 18, ÖNORM M7135 -over 16.9, SS 18 71 20 - 17,5 - 19,5, DIN 51731 -over 16,9, CTI - R 04/5 -over 16.7, Britisch BioGen/UK	Over 18	100
	Compressive strength, (MPa)	-1.8-2 MPa [61] -3-5 N/mm [62, 63]	Over 2.5	100

Secondary properties	Moisture content (%)	-under 18, ÖNORM M7135 -under 12, SS 18 71 20 -under 12, DIN 51731 -under 10, CTI - R 04/5 -under 10, Britisch BioGen/UK	Lower 12	50
	Ash content, (%)	-lower 6,0%, ÖNORM M7135 -lower 1,5 %, SS 18 71 20. -lower 1,5 %, DIN 51731, -lower 1,5 % , CTI - R 04/5 -lower 3 %, Britisch BioGen/UK	Lower 1.5	50
	Coefficient of compaction	-Lower 2-5 (Lunguleasa 2010)	Lower 5	50

As there is observed in Tab. 1, the moisture content should not exceed the maximum of 12 %, effective density should not exceed the minimum of 1.12 g.cm^{-3} and calorific value - HHV should not be less than 18000 kJ.kg^{-1}. Appreciation of each property is made referring to a reference one, as there is visible in Tab. 2.

Tab. 2: Appreciation of real properties related to referee ones.

No	Differences (%)	Points	
1	Total acceptable	No differences	Total (100 for primary or 50 for secondary properties)
2	Partial acceptable 1	Up to ±10 %	80 % (80 or 40)
	Partial acceptable 2	Between ±10-20 %	70 % (70 or 35)
3	Partial unacceptable 1	Between ±20-30 %	50 % (50 or 25)
	Partial unacceptable 2	Between ±30-40 %	30 % (30 or 15)
	Partial unacceptable 3	Between ±40-50 %	10 % (10 or 5)
4	Total unacceptable	Over ±50 %	0

Unit or effective density is determined as a ratio between mass and volume of each briquettes, at the same moisture content - MC of 10 % (usually mass and volume is determined successively at short time, when the moisture content is not changed), expressed in kg.m^{-3} or g.cm^{-3}. Calorific value of woody briquettes is determined with calorimeter bomb for small pieces of 0.6-0.8 g from briquettes with 10 % moisture content (DIN 510900, 2000; ISO 1928, 2009, Kers et al. 2013). There are three types of calorific value (high, low and for 0 % moisture content), but only calorific value (for 0 % moisture content) is taken for comparison. Increasing the calorific value of biomass is generally made by torrefaction (Chen et al. 2011) when the carbon content is increased.

The compressive strength quantifies consistence and compaction of woody briquettes. In time of testing the pressing force acts perpendicular on the briquette's symmetry axis. A universal machine for testing had to be used. The superior and inferior plateau of testing machine is flat, usually used for Brinell or Janka hardness, with gradations up to 20 mm right and left side. Each wooden briquette was subjected to compressive force, until the briquette was broken and the rupture force decreased quickly (Lunguleasa et al. 2010; Mitchual et al. 2013). The compressive strength was determined as a ratio between the maximum force of rupture and the double area of compressed surface (the superior and inferior one, when both surfaces are equals).

Moisture content is determined with classical method, by determining the moist and oven-dry mass of a little piece from briquettes. For determining the oven-dry mass, the prepared samples were dried in a laboratory oven at 103±2°C. Moisture content influences strongly the calorific value (Nielsen et al. 2009).

Ash content of briquettes is determined as a ratio between calculated mass and oven-dry mass of grinded piece from briquettes (using a 1.6×1.6 mm sieve for sorting). When a certain moisture content of briquettes is used, the final relationship for ash content (Eq. 2) can be obtained. Before the samples are entered in the furnace, they are burned up outside, in order to eliminate smoke from it, for protecting furnaces.

$$A_s = \frac{m_c}{m_s}(100 + MC) \quad (\%) \qquad (2)$$

where: A_s - ash content (%);
m_c - mass of calculated ash (g);
m_s - mass of moist sample (%);
MC - moisture content, dry mass (%).

Compaction coefficient of briquettes takes into account that comes into the briquettes and what results as a final product as it can see in Fig. 3. Using the density in expand state of chips and the main physical characteristic of briquettes (which is density), the compaction coefficient can be obtained, as a ratio of the above mentioned densities.

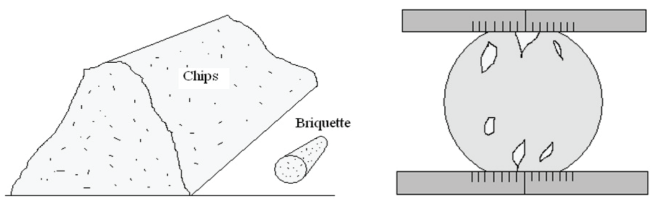

Fig. 3: Coefficient of compaction and the compressive strength of briquette.

Knowing this coefficient of compaction has a great importance in sizing of storage silos for raw materials and the clock supply with raw material for briquetting presses. The current value of compaction coefficient for good briquettes are about 3-5 and for bad wooden briquettes, a value of 5 rating can be took as limitative. This coefficient is directly influenced by density and compressive strength and therefore it should always studied in correlation with these. For instance, if the compaction coefficient is 3.5 the beech briquettes will have a compressive strength about 8.3 $N.mm^{-2}$ and if the coefficient is 17.7 the compressive strength will be only 1.7 $N.mm^{-2}$ (Lunguleasa 2011). Usually values of compressive strength are between 1.1-2.0 $N.mm^{-2}$ for density about 0.9 $g.cm^{-3}$ and over 2.0 $N.mm^{-2}$ for density about 1.1-1.2 $g.cm^{-3}$, a limitative value of 3 $N.mm^{-2}$ can be took. Determining compressive strength of woody briquettes, a better knowledge about compactness and consistence will occur, thus improving the quality of these products (Rahman et al. 1989). By adding some natural additives or improving the surface consistence of briquettes with thermal treatments or lignin activation, the quality of these products will be improved (Shulga et al. 2008).

RESULTS AND DISCUSSION

A data sheet for each batch of woody briquette was prepared containing volume, mass, density, width compression and compressive force, moisture content, ash content, masses of samples, masses for ashes, values of calorific value etc. Plištil et al. (2005) established only some of the above features to be analysed the briquettes. Medium values of each feature for all batches are visible in Tab. 3.

Tab. 3: Real values of all analysed properties.

Lots	Moisture content (%)	Unit density kg.m^{-3}	Compressive strength, N.mm^{-2}	Ash content (%)	Compaction coefficient	Calorific value kJ.(kg)$^{-1}$	
1	8.4±0.3	1145±60	4.6±0.2	9.2±0.4	5.4±0.2	HCV_{10}	17960
						LCV_{10}	17010
						CV_0	18480
2	7.9±0.2	1310±80	18.4±0.3	4.9±0.1	3.8±0.1	HCV_{10}	17570
						LCV_{10}	16990
						CV0	18200
3	8.2±0.3	1250±70	10.3±0.3	5.9±0.2	4.2±0.2	HCV_{10}	17830
						LCV_{10}	16790
						CV_0	18320

As it is observed from Tab. 3, all values of properties have a great range of distribution, because of press machines. During operation of the screw pressing, it takes a certain amount of chips to be pressed, which is not always the same. If the amount of chips is larger, the degree of compression of the screw will be higher. The same thing happens when the chips high from the silo is higher. Fetching for each type of property and briquettes all measured values and the reference value, it is then calculated the percentage difference and finally is determined the number of points awarded for each type, as seen in Tab. 4.

Tab. 4: The cumulative property for all three types of straw briquettes.

		Type 1	Type 2	Type 3
Moisture content (%)	Measured Value	8.4	7.9	14.2
	Reference Value	Under 12		
	Percentage difference	-30 %	-34 %	+31 %
	Place	Total Acceptable	Total Acceptable	Partial Acceptable 2
	Points	50	50	35
Effective density (kg.m^{-3})	Measured Value	1.45	1.31	1.25
	Reference Value	Over 1.0		
	Percentage difference	+ 45 %	+ 31 %	+ 25 %
	Place	Total Acceptable	Total Acceptable	Total Acceptable
	Points	100	100	100

Compressive strength, $N.mm^{-2}$	Measured Value	4.6	18.4	10.3
	Reference Value	Over 2.5		
	Percentage difference	+ 84 %	+ 636 %	+ 312 %
	Place	Total Acceptable	Total Acceptable	Total Acceptable
	Points	100	100	100
Compaction coefficient	Measured Value	5.4	3.8	4.2
	Reference Value	Lower 5		
	Percentage difference	+ 8 %	- 24 %	- 16 %
	Place	Partial acceptable 1	Total Acceptable	Total Acceptable
	Points	40	50	50
Ash content (%)	Measured Value	5.2	4.9	5.9
	Reference Value	Lower 1.5		
	Percentage difference	+ 246 %	+ 226	+ 293
	Place	Total unacceptable	Total unacceptable	Total unacceptable
	Points	0	0	0
Calorific value, ($MJ.kg^{-1}$)	Measured Value	18.48	18.20	18.32
	Reference Value	Over 18		
	Percentage difference	+ 2.6 %	+ 1.1	+ 1.7
	Place	Total Acceptable	Total Acceptable	Total Acceptable
	Points	100	100	100
Total points	390	400	385	
Classification		II	I	III

A first conclusion obtained after analysis of the results refers to the overarching values of briquette properties. Experimental briquettes made from wheat straw are made with powerful systems, getting a high density, as Toscano et al. (2013) also considered. Due to high densities (1.25-1.45 $g.cm^{-3}$), the other mechanical property (compressive strength) is also very high (4.6-18.4 $N.mm^{-2}$) (Lunguleasa 2011). For type 3 of woody briquettes a higher value of moisture content was obtained.

A second conclusion on wheat straw briquettes is that they have almost similar features, such as high ash content (4.9-5.9 %) and good calorific value - (18.2-18.4 $MJ.kg^{-1}$). Yeniocak et al. (2014) found a lower ash content of 2.8 %, in the case of wine stalks. High ash content of straw is due to the large quantities of secondary compounds (as oxalate and carbonate types), i.e. 6-8 % compared to 1-3 % in solid wood. Moya and Tenorio (2013) have set similar values. That is what there is needed a comparing with briquettes made from wood, softwood (spruce) and hardwood (beech). This also rises from the limiting values of ONORM standard, expressed for the entire range of briquettes, especially those made from wood, which are the most common in the world market. To do this, it takes some research data from several previous works (Lunguleasa and Budau 2010) for comparison with chips briquettes (*Fagus sylvatica* L.) and spruce (*Picea abies* L.), processed according to the above methodology. Methodology has similarities with the methodology used for the test joints (Yerlikaya 2014). New results are analysed similarly.

Tab. 5: Comparative data between briquettes of straw, spruce and beech wood.

No	Properties		Briquettes					
			***Triticum aestivum* L.**		***Picea abies* L.**		***Fagus sylvatica* L.**	
			Real value	**Points**	**Real value**	**Points**	**Real value**	**Points**
1	Primary	Effective density, $kg.m^{-3}$	1.45	100	878	70	921	80
2		Calorific value CV0, ($MJ.kg^{-1}$)	18.48	100	18.6	100	18.5	100
3		Compressive strength, ($N.mm^{-2}$)	4.6	100	1.5	10	1.6	30
4	Secondary	Compaction coefficient	5.4	40	3.5	50	4.8	50
		Moisture content, %	8.4	50	10	50	9	50
5		Ash content, %	5.2	0	0.8	50	1.4	50
Aggregate property, points			------	390 (I)	-----	330 (III)	-----	350 (II)

From the comparative study with briquettes made of wood and straw (Tab. 5), it follows that woody briquettes are less dense, which is why their compression is weaker. In conclusion the score obtained for them is smaller, being behind straw briquettes (no. II and III). The main cause of this gap is the equipment that press woody chips in briquettes (with hydraulic piston), which not allowed the increasing of density over the limit allowed, thus the compression strength not exceed the lower limit. If woody briquettes could be obtained on a mechanical press, the two main properties would have exceeded the minimum allowed, and the final score would be increased at 450 for spruce and 440 for beech, clearly surpassing value of wheat straw briquettes.

CONCLUSIONS

The briquettes market from straw in the world is in formation and there are now few settlements in this area. Therefore the method used in the paper comes to the aid of briquettes buyer/customer. The paper highlights the advantages of the method used by the concept of quality definition for straw briquettes by aggregated property *Pa*. By this paper, the briquette quality from wheat straw as a generic concept is gauged quantitatively.

Generally, from the study about briquettes made from wheat straw, it is observed that the residues of wheat straw remain a consistent source of organic fuel, with similar properties and uses woody chips. In accordance with the objectives, a value of aggregate property of wheat straw was obtained, defining in this way the quality of briquettes. This value was compared with that of beech and spruce woody briquettes, resulting that the values are appropriate. Therefore wheat straw briquettes remains joined those of beech woody residues, in order to increase market briquettes, as renewable products with zero carbon dioxide emissions.

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