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TESTING MODEL FOR ASSESSMENT OF LIGNOCELLULOSE-BASED PELLETS

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ABSTRACT

This paper aims to find a simple testing and assessment model applicable to lignocellulose-based pellets, for the purpose of making the appropriate selection from the market. It is analysed the main tests of pellets, as density, caloric value and shear strength, for three different types of pellets bought from the competitive market. Afterwards is detailed the method of operation for the shear strength due to its not so frequent use. Finally, based on the tested values and limits required by the existing standards, it is determined a simple method for assessing for pellets, pointing out the closeness of each tested value to the standard limits.

KEYWORDS: Pellet, testing model, density, shear strength.

INTRODUCTION

The pellets are leading edge energetic lignocellulose-based products (Kažimírová et al. 2013; Omer 2012; Toscano et al. 2013; Okello et al. 2013; Yeniocak et al. 2014), obtained from small-sized lignocellulose-based biomass (dust, sawdust, and fine chips) compacted as cylinders with usual diameter of 6-10 mm (Demirbas 2001; Nielsen et al. 2009; Rahman et al. 1989; Lu et al. 2014). When the diameter exceeds 10-12 mm, the resulting aggregate is called briquette (Demirbas and Demirbas 2004; Junginger 2008; Tabarés et al. 2000). The compaction is made without any other adhesives or additives, the whole process being based on the feature of lignin existing in wood structure to activate and glue together the aggregate at temperature over 120°C. The pellets are ecological product (Eurostat 2011, EC 1997; Kim and Dale 2003) which does not produce additional polluting emissions (other than those of the solid wood it was obtained from) during combustion. They are successfully used both in developing (Boutin et al. 2007; Gavrilescu 2008; Jehlickova and Morris 2007; Kazagic and Smajevic 2009) and developed countries.

Pellets are engineering combustible products which incorporate a high technology and the uniformity of dimensional, density and other mechanical properties makes possible the automation of combustion process and provides autonomy of 12-24 hours for the heating unit. This is the reason why most of the heating unit producers provide their customers with the optional pellet use kit, with burner, supply snack, silo and own automation system. Moreover, some countries subsidize the use of pellet heating units, as one of the systems for obtaining the "green energy" (together with the solar panel energy), with zero contribution in terms of toxic gas emissions into the atmosphere (Dhillon and von Wuelhlisch 2013). Although pellets are apparently more expensive than briquettes (sometimes the price being double) and firewood, the benefits of their use are clear, as it follows:

- reduction of the fossil combustibles dependence, i.e. oil, coal and natural gas;
- they are renewable combustibles, obtained from small-sized lignocellulose-based biomass currently resulted in different processing sectors, waste and rests being thus significantly reduced;
- no degradation during storage, thanks so the low content of humidity and to the fact that they are supplied and kept packaged in plastic sheet (around 10 %);
- good energy value, over to the raw materials they are obtained from;
- they can be obtained from torrefied sawdust (Chen et al. 2011; Shang et al. 2012), in order to increase their calorific value;
- effectiveness in terms of costs of use, thanks to low humidity, but especially to high density of over 1,100 kg.m^{-3}, which leads to a very high energy density, significantly higher than those of solid wood and briquettes.

The disadvantages of pellets are minor, especially when compared to lignocellulose-based briquettes. But if the pellets are compared to fossil combustibles or firewood, there are some disadvantages, among which there are mentioned the followings:

-more difficult processing of raw materials for the purpose of obtaining the final product, as compared to fossil combustibles where the only process to be done is their extraction;

-additional investments for combustion, as compared to firewood use;

-necesity of collection and processing the ash resulted from combustion, as compared to oil or natural gas use, where amounts of ash are zero.

The properties of lignocellulose-based pellets may be divided into four groups: dimensional, physical, chemical and mechanical (Plištil 2005; Verna et al. 2009). Pellets' testing is made following specific, standardized methodologies (Van Dam et al. 2008), i.e. density according to EN 15103 (2009), mechanical durability according to EN 15210-1 (2009), general requirements according to EN 14961-1 (2010) and so on. These properties are limited by the European product standards, namely EN 14916-2 (2013). The limitatative technical characteristics of pellets stipulated by the European standard EN 14961-2 (EPC 2013, CEN/TC 335 2004, CTI-R 04/5 2004) are:

- diameter: 4-10 mm;
- length: less than 50 mm;
- bulk density: 650 kg.m^{-3};
- effective density: more than 1200 kg.m^{-3};
- humidity: less than 8 %;
- ash content: less than 1.5 %;
- caloric value: 16.9-19.5 MJ.kg^{-1};
- nitrogen content < 0.3 % (for A1 class), < 0.5 % (for A2 class), < 1.0 % (for B class);
- sulphur content < 0.03 % (for A1 and A2 classes) and < 0.04 % (for B class);
- chlorine content < 0.02 % (for A1 and A2 classes) and < 0.03 % (for B class);
- ash content determination at temperatures > 1200°C for A1 class and > 1100°C for A2 and B classes.

Tab. 1 shows the energy equivalency for different types of combustibles, totaling some data from multiple sources (Kaliyan and Morey 2009; Kers 2013).

Tab. 1: Energy equivalency of combustible.

Type	Caloric equivalent	Quantity	Price, Euro
Wood pellets	10 kWh	2 kg	80 Euro/ton
Firewood	10 kwh	2.5 kg	50 Euro/m^3
Woodchips	10 kwh	2 kg	40 euro/m^3
Natural gas	10kWh	12.5 m^3	380 Euro/MWh
Oil	10 kWh	3 litres	90 Euro/ barrel

The main goal of this paper is to create a pelllet testing model, an operation methdology for each test (especially in cases where there is no standardized method), an assessment model and possibilities to improve their properties.

METHOD AND MATERIALS

It is used three types of pellets available on the market, in order to analyse their characteristics. The type 1 of pellets is made of spruce and fir, type 2 of beech and type 3 of oak. It is used a foil-packed sack of 10 kg of each type of pellets. The main properties that there are analysed were: bulk and effective density, shear strength, loss of mass by pellets torrefaction, caloric value for simple and torrefied pellets.

Pellets' density was determined for the two forms, i.e. bulk and individual, for each type of pellet. In order to determine the pellets' bulk density, it is used a tapered vessel with the following dimensions: R =45.31 mm, r = 23.435 mm, h = 99.06 mm, in order to determine the density, considering the truncated cone volume and the mass m of the vessel's content, it was used the following relation:

$$\rho = \frac{3m}{h(R^2 + r^2 + Rr)} \quad (g \cdot cm^{-3}) \qquad (1)$$

For determining the pellets' effective density it took randomly over 20 pieces of pellets, their ends were sanded in order to obtain a surface perfectly perpendicular to their length and taking into consideration that each pellet is a right circular cylinder, it was used the following relation:

$$\rho_{ef} = \frac{4m}{\pi \cdot d^2 \cdot l} \quad (g \cdot cm^{-3}) \qquad (2)$$

where: ρ - effective density of pellets ($g \cdot cm^3$);
m - pellets' mass, (g) ;
d - pellets' diameter (cm);
l - pellets' length (cm).

Pellets' torrefaction process consisted in their insertion into an oven for heat treatment in oxygen environment (Obernberger and Thek 2004), at a temperature of 260°C, for 5 minutes. Before torrefaction, the over 20 pellets of each type to be treated were dried until the constant mass into a laboratory drying oven. In order to avoid any possible loss, the sample was permanently kept into a crucible made of nickel-chromium alloy. Based on pellets' initial mass, i.e. non-torrefied mass (mnt), and that after torrefaction (mt), the mass loss was determined (L_m) with the following formula:

$$L_m = \frac{m_{nt} - m_t}{m_{nt}} \cdot 100 \quad (\%) \qquad (3)$$

where: L_m - mass loss (%);
m_{nt} – non-torrefied mass, (g);
m_t- torrefied mass (g).

The caloric value both for torrefied and non-torrefied pellets was determined using a bomb combustion calorimeter, with sample of 0.6-0.8 g and a 30-bar oxygen pressure in the calorimetric bomb (Grîu 2014, ASTM 2000, Aebiom 2013, ISO 2009; DIN 2000). The formula used by the software was the following (Griu and Lunguleasa 2014):

$$CV = \frac{C \cdot (t_f - t_i)}{m} - q_s \quad (kJ \cdot kg^{-1}) \qquad (4)$$

where: CV - calorific value, in kJ·kg;
t_f – final temperature, read by the calorimeter's thermocouple (°C);
t_i – initial temperature, read by the calorimeter's thermocouple (°C);
q_s- amount of heat released by the nickeline wire and the cotton wire (kJ.kg);
m- pellets' mass (g).

Pellets' shear strength is mechanical feature indicating their internal compaction and adhesion (Lunguleasa et al. 2010; Lunguleasa 2010, 2011; Mitchual et al. 2013; Stelte et al. 2011). This strength occurs during storage stack, transport, handling and the feeding of thermal plants with snack conveyer. This test is already used in the case of animal feed in pellet form.

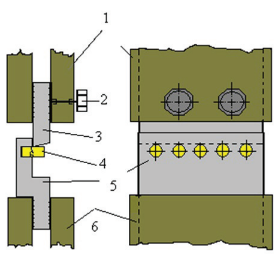

Fig.1: Pellets shearing: 1- upper bracket of testing machine; 2- screw for fixation ; 3- upper bracket of shear device; 4- pellets; 5-lower bracket of shear device; 6-lower bracket of testing machine.

Shear section in pellets was made by a device specially designed for such test, and the effect's amplification was obtained by shearing 5 pellets simultaneously. The cutting speed was of 4 $mm.min^{-1}$ (Sola and Atis 2012) (Fig.1).

RESULTS AND DISCUSSION

Pellets' bulk and effective density differs, their ratio being of 1/3 (Griu and Lunguleasa 2014), as it is shown in Tab. 1. Moreover, it may notice that values are different, i.e. higher for type 1 and lower than those provided in the effective standards for types 2 and 3.

After torrefaction, pellets' mass is diminished, as it may be seen in Tab. 2. Right after torrefaction, pellets' caloric value was determined in order to see the increase as compared to non-torrefied witness samples (Tab. 3).

Tab. 2: Pellets' density and shear strength.

Type of pellets	Bulk density ($g.cm^{-3}$)	Effective density ($g.cm^{-3}$)	Shear strength ($N.Mm^{-2}$)
1	0.2805	1.338	2.2357
2	0.3268	1.137	1.3029
3	0.306	1.103	1.1338

Tab. 3: Mass losses and calorific value of torrefied and non-torrefied pellets.

Pellet types		Mass (g)	Mass of torrefiated samples (g)	Mass loss (%)		Calorific value (kJ.kg)
Control sample	1	0.59085	-----	-----		18 262.667
	2	0.4339	-----	-----		18 534.333
	3	0.47375	-----	-----		17 546.333
Torrefied sample	1	0.468	0.412	11.9	Mean=11.3	18 653
	1	0.478	0.426	10.8		
	2	0.398	0.350	12.0	Mean=10.8	19 786
	2	0.350	0.316	9.7		
	3	0.408	0.360	11.7	Mean=11.0	23 673
	3	0.524	0.469	10.4		

The increase of caloric value may be graphically represented as well (Fig. 2), observed also by other reserchers (Kaliyan and Morey 2009; Mitchual et al. 2013).

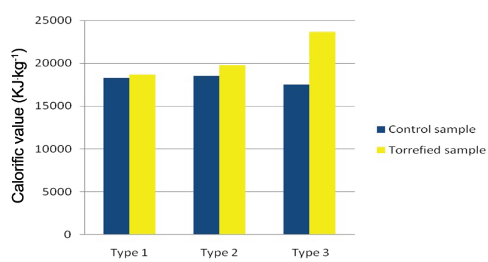

Fig. 2: Calorific value increase in torrefied samples of pellets.

It may notice a weak dependence of pellet density on shear strength values (Fig. 3). Spreading range of all values and very low values of Peason coefficient R^2 comes once again confirming that between density and shear strength is not a very clear dependence, as exists in the case of solid wood.

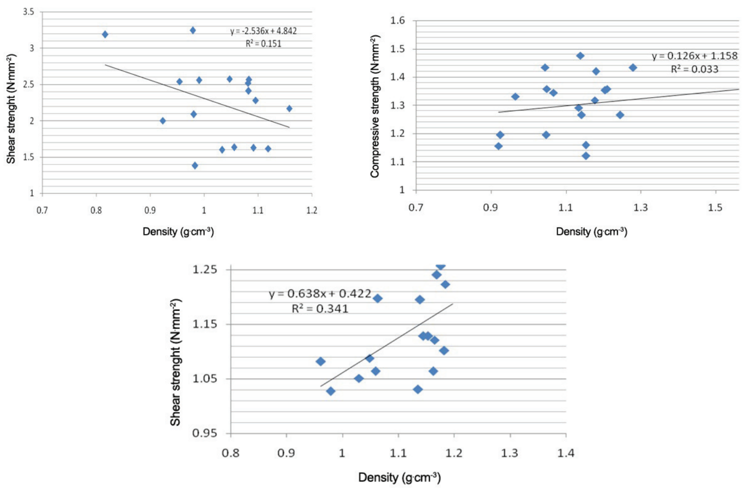

Fig. 3: Influence of density on shear strength for all three type of pellets.

As pellets have different densities and caloric values, it found that caloric density is a feature which better characterizes the energy they provide. The formula to determine the energy density is the following (Griu 2014):

$$CD = CV \cdot \rho_p \qquad (\mathrm{MJ \cdot m^3}) \qquad (5)$$

where: CV - caloric value ($\mathrm{MJ \cdot kg^{-1}}$);
ρ_p- density of pellets ($\mathrm{kg \cdot m^{-3}}$),

In order to compare different types of pellets, it is appropriate to find a method to point out various characteristics, to totalize such points and to determine the maximum of them. It is used the method of approaching or moving away from the limiting value provided by standard.

For example in the case of effective density, the limitative value of European standard EN 14961-2 (2013) is 1.2 $\mathrm{g.cm^{-3}}$ (Tab. 4). Pellet type 1 has an average density of 1.338 ($\mathrm{g.cm^{-3}}$), namely an increase of 11.5 % compared to the limiting value, that will add to the 10 points, yet 11.5 % more of the 10 points, ie a total of 11.1 points. If type 2 of pellets is taken in consideration, the average density is 1.137 ($\mathrm{g.cm^{-3}}$), ie a decreasing with 5.2 % as reference value, that will be deducted 0.5 points from the maximum score of 10, this type of pelletes will receive 9.5 points. It can continue in this manner until the Tab. 4 is fully completed.

Tab. 4: Appreciation of pellets related to limitative value.

Characteristics		Limitative value EN 14961-2 (2011)	Real value	Distances from the limiting value	Points, from 10
Bulk density (kg·m^{-3})	1	min 600	280.5	-40 %	6
	2		326.8	-45 %	5.5
	3		306.0	-49 %	5.1
Effective density (kg·m^{-3})	1	Min 1.200 (g.cm^{-3})	1.338	+11.5	11.1
	2		1.137	-5.2 %	9.5
	3		1.103	-8.0 %	9.2
CV of Non-torrefied pellets	1	Min 16.9 (MJ.kg)	18.262	+7.6 %	10.7
	2		18.534	+9.6	10.9
	3		17.546	+3.7	10.3
CV of torrefied pellets	1	Min 18.3	18.653	+1.9 %	10.2
	2		19.786	+8.0 %	10.8
	3		23673	+29.3 %	12.9
Shear strength, N·mm^{-2}	1	Min 1.5	2.2357	+49 %	14.9
	2		1.3029	-13%	9.8
	3		1.1338	-24.6%	7.6

Tab. 5: Centralized scores.

Characteristics	Scores, points		
	Type 1	Type 2	Type 3
Bulk density	6.0	5.1	5.5
Effective density	11.1	9.5	9.2
Calorific value	10.7	10.9	10.3
Shear strength	14.8	9.8	7.6
Total score	42.6	35.3	32.6

Next it proceed to analyze the types of pellets score, putting the analyzed characteristics on vertical and pellet types on horizontal (Tab. 5). It get a maximum score of 42.6 points for type 1 and a minimum of 32.6 poits for pellet type 3. It is determined that the best batch of pellets is type 1.

CONCLUSIONS

The tests regarding pellets' bulk density show that all batches are under the allowable limit, and in respect of the effective density, the batch no.1 passes over the minimum allowable limit. The caloric value of torrefied pellets is far higher than of non-torrefied pellets, thanks to the heat treatment and increase of lignin content. In respect of pellets shearing, batch 1, which had also a good density, surpassed the minimum allowable limit, and the other two were closely under this limit.The method of assessment of pellet batches based on the score obtained at each feature makes possible the informed selection of necessary pellets, especially when a large amount of pellets is ordered.

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