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Effects of Compressing Pressure on Briquettes Made from Woody Biomass

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Biomass, in particular wood, has become a fundamental renewable energy source that can replace fossil fuels in many applications, from eating to electricity production. Wood chips are one of the most popular biomass fuel in latest cogenerating plants and in small heating systems. This fuel has low bulk density and needs large volumes in handling and transport operations. These obstacles, common to many biological residues, can be overcome by densification.
This study reports the effects of the compressing pressure on the demand of energy required in briquetting, final bulk density and durability of briquettes manufactured from wood chips.
An hydraulic press was used to produce briquettes in controlled conditions. Five pressure levels (20, 30, 50, 80 and 110 MPa) and three different types of wood chips (PC - hybrid poplar, CC - chestnut, and MC - mixture of spruce white pine) were investigated.
The study shows that the different pressures adopted significantly affect the specific compression energy, the final density and the durability of the compacted samples. Equations were developed to predict compact density and the specific compression energy required by the densification process. The specific compression energy values obtained in this study (18-58 kJ kg^{-1}) were significantly lower than the specific energy required to manufacture pellets made from biomass feedstock (typically 19-90 kJ kg^{-1}). Furthermore, chestnut wood chips with pressure at 110 MPa resulted in the maximum briquettes bulk density and durability.

1. Introduction

Biomass products used as energy source can offer an important alternative to fossil fuel (Bernedes et al. 2003) that are the principals damaging factors for the ozone (Quadrelli and Peterson, 2008) and their availability is guaranteed for few years. Biomass, in particular wood, has became a fundamental renewable energy source that can replace fossil fuels in many applications, from heating to electricity production (Krausmann et al. 2008).
One fundamental step in the biomass energetic exploitation is the comminution process that usually is performed with different kinds of chippers adopting various cutting technology that affect the overall process efficiency (Spinelli et al., 2012). In order to optimize the entire wood fuel supply chain, is useful to reduce the cost of harvesting, processing and transportation. One of the most penalizing wood chips characteristics is the final low density (150-250 kg m^{-3}) that increases the handling and transportation costs. One possible solution to this problem is densification of wood chips. Densification has been shown to increase the biomass bulk density from an initial bulk density of 40-200 kg m^{-3} to a final one higher than 800 kg m^{-3} (Mani et al. 2003). Thus, densification of biomass materials could reduce the costs of transportation, handling and storage (Kaliyan and Vance Morey, 2009).
The initial characteristics of the biomass significantly affects the final physical and mechanical properties of the produced compacts (Facello et al. 2014). In this context, Pampuro et al. (2017) considered pellet density and durability as two important physical properties of the produced pellets. Ishii and Furuichi (2014) reviewed the studies on the production of solid fuel from agricultural residues, highlighting the factors affecting the strength and durability of densified biomass products. Stelte et al. (2011) evaluated the fundamental forces keeping the biomass of the pellet together to improve the strength and durability of different biomass

resources. Moreover, as reported by Young et al. (1963), densified products must meet consumer requirements and market standards and must withstand the rigors of handling and transportation. The same authors divided the forces that cause damage (i.e., fragmentation and abrasion of pellets) on pellets (or any densified product) during handling, transportation, and storage into three general classes: compression, impact and shear. Compression forces result in a crushing action. Impact forces result in shattering the surface of the pellet and along any natural cleavage planes of the pellet, and shearing forces result in the abrasion of pellet edges and surfaces.

This study addresses the effects of different woody biomass and compressing pressure on the mechanical properties of woody briquettes. The study focused on the energetic demand required by the briquettes production and on briquettes density and durability, being the properties that mostly affect briquettes quality during handling, transportation and storage.

2. Materials and Methods

2.1 Feedstock preparation

Three types of woody materials – hybrid poplar (*Populus x euramericana Guiner*) (PC), chestnut (*Castanea sativa* L.) (CC) and a mixture of spruce (*Picea abies* L.) and eastern white pine (*Pinus strobus* L.) (MC) were studied. Wood chips used for the trials were G40 quality class. The average moisture content of PC, CC and MC were respectively 7.1, 7.9 and 8.1 % (wb). The moisture content was determined drying the samples at 103 °C for 24 h.

2.2 Bulk density

The initial bulk density of PC, CC and MC were 119, 212 and 152 kg m^{-3}, respectively.

The bulk density was determined using ASABE Standard S269.4 (ASABE, 2007).This method involves pouring the bulk solid into a cylindrical container with a diameter of 380 mm and an height of 495 mm (volume of 0.05615 m^3). The material was leveled across the top of the surface of the container and weighed. Mass per unit volume gave the bulk density of the biomass in kg m^{-3}.

Bulk density measurements were repeated five times and the average value was reported.

2.3 Durability

Durability represents the measure of shear and impact forces that a briquette could withstand during the handling, storing and transportation process (Kaliyan and Vance Morey, 2009). In general, it can be stated that the higher the briquette durability, the higher the briquette quality.

The durability of the samples was assessed according to ASABE Standard S269.4, using a tumbling device with the outside dimensions of the iron frame of 460 x 300 x 300 mm. The covering is 12.5 mm mesh hardware cloth applied to the outside of the frame. The box is mounted on a diagonal axis (2 planes) with two stub shafts terminating at the exterior of the angle iron frame. The axis of rotation is horizontal.

When the box is rotating, the briquettes abrade and produce fines due to the impact of the shearing of the briquettes over each other and against the wall of the box itself. The durability (%) was then determined as the ratio between the weight of the sample after and before the above-mentioned operation, multiplied by 100.

The durability measurements were repeated five times, and the mean value was reported.

2.4 Compression equipment

The press used to obtain the compressed material has two opposite hydraulic cylinders. The unit, fitted with an oil-hydraulic unit, can deliver up to 297 kN in a time variable from 0 to 210 seconds. The press can be equipped with different compressing chambers as needed. In order to obtain the test samples, a chamber with a diameter of 45 mm and a volume of 440 cm^3 was used.

Upper and lower cylinders are fitted with load cells (model TMT–HY–C/PS, max rated load 200 kN) that give signals proportional to the compressing force. The top of the plunger is connected with a potentiometric displacement sensor (model Gefran LT-M-0500-S 500 mm full stroke) giving the exact position and volume of the compressing chamber. The oil feed line has a pressure transducer (Gems sensor 3100 series, 0-250 bar).

These signals are processed by a pc-based acquisition system (DS-NET with BR8 module) capable of acquiring up to 10 ks s^{-1}. For this application the sampling rate was fixed to 1 ks s^{-1}. All the collected data were recorded with properly configured software (Dewesoft 7.0) for post-processing operations.

2.5 Compression tests and energy calculation

The mass of samples used for making compacts was 50.00 g. Five preset pressures of 20, 30, 50, 80 and 110 MPa corresponding to loads of 31.5, 47.3, 62.3, 126.1 and 173.4 kN, were used to compress samples in the chamber. For each woody material investigated, 10 samples were produced at of the each pressure levels.

After compression, the base plate was removed and the compact was ejected out of the chamber using the plunger. A digital caliper was used to measure the length and the diameter, while a digital balance with to 0.01

g accuracy was used to measure the mass of densified material. The densities of the samples were calculated from the ratio of mass to volume (obtained from length and diameter measurements). As reported by Li and Liu (2000), the densities of the briquettes were measured 2 minutes after the samples were ejected from the mold.

During the compression of individual briquette, force-displacement data were recorded. Specific compression energy (SCE) was calculated following the methodology of Pampuro et al. (2013). The area under the force-displacement curve was integrated using the trapezoid rule (Santamarta et al., 2012); when combined with the briquette mass, it yielded the specific energy values in kJ kg^{-1}.

2.6 Data analysis

Regression analysis was performed using the proc reg function in SPSS statistical software package (Version 17.0) and plotted with the experimental data using Microsoft Excel (Microsoft Office 2007). Significance testing was carried out using one way analysis of variance (ANOVA) in the SPSS statistical package.

3. Results and Discussion

3.1 Bulk density

The bulk density of briquettes should be taken into account when designing or adopting handling and storage procedures to preserve briquette integrity. The results from the experiments showed average bulk density values ranging from 546 to 898 kg m^{-3}, from 589 to 1.082 kg m^{-3} and from 543 to 913 kg m^{-3} for PC, CC and MC, respectively (Figure 2).

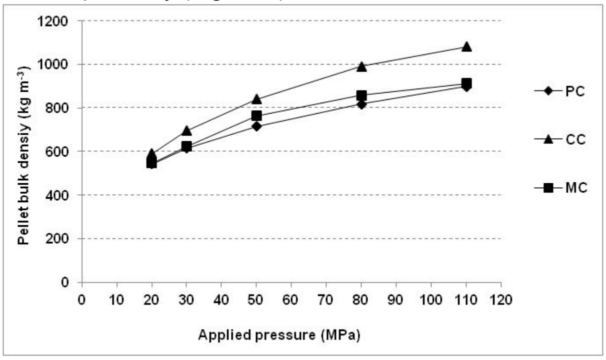

Figure 2: Effect of pressure levels applied on the woody biomass during the densification process on the final density of PC, CC and MC briquettes.

As seen in Figure 3, for each pressure level applied, CC showed higher ($p<0.05$) values of briquette bulk density, while PC presented lower values ($p<0.05$).

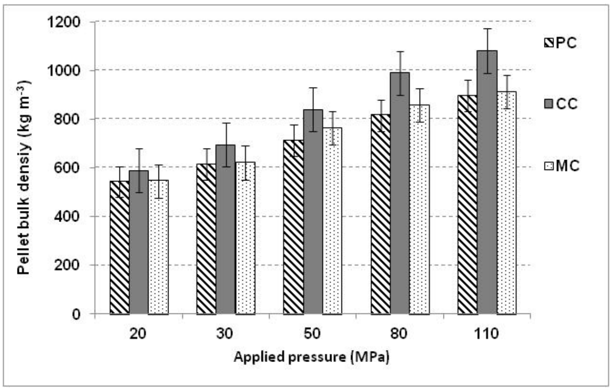

Figure 3: Average density values (kg m^{-3}) of PC, CC and MC obtained using five different pressure levels (20, 30, 50, 80 and 110 MPa). Error bars indicate standard error (n = 5).

The ANOVA showed significant effect ($p<0.05$) on briquette bulk density of the five levels of pressure applied during the experimental pelletizing process (20, 30, 50, 80 and 110 MPa).

Previous studies conducted by Demibras (1999) have shown a logarithmic relationship between applied pressure and resulting density of briquettes manufactured from waste paper and wheat straw mixtures and applied pressure. Even though considerably higher pressures were used in that study (300-00 MPa), the briquette densities obtained (50-850 kg m^{-3}) were lower than the densities obtained in this study. We suspect this is due to the different properties of the materials under test.

3.2 Durability

The statistical analysis showed significant effect ($p<0.05$) of pressure application levels (20, 30, 50, 80, 110 MPa) on briquette durability. The results of the durability tests performed with the manufactured briquettes are plotted in Figure 4 and Figure 5. In particular, Figure 4 shows the relationship between applied pressure and briquette durability. The results from the experiments showed average durability values ranging from 19.1% to 77.4%, from 29.1% to 87.7% and from 19.8% to 78.1% for PC, CC and MC, respectively.

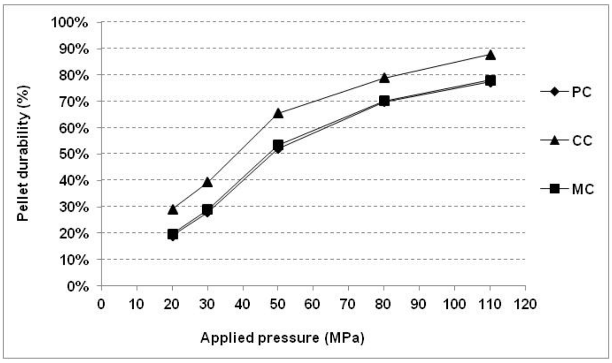

Figure 4: Effect of applied pressure levels on the woody biomass during the densification process and the durability of PC, CC and MC briquettes.

As reported in Figure 5, for each pressure level applied, CC showed higher ($p<0.05$) values of briquette durability, while the statistical analysis showed no significant differences ($p>0.05$) between MC and PC.

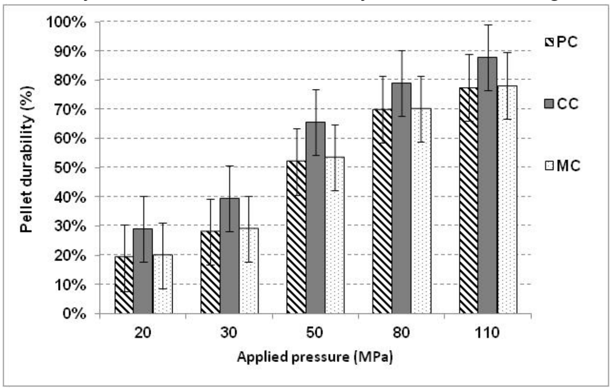

Figure 5: Average durability values (%) of PC, CC and MC obtained using five different pressure levels (20, 30, 50, 80 and 110 MPa). Error bars indicate standard error (n = 5).

According to Adapa et al. (2003), durability is high when the computed value is above 80%, medium when the value is between 70% and 80% and low when the value is below 70%. Knowing that the studied material will be used as a renewable energy source, low briquette durability is not desirable since it can cause problems during briquette handling, storage and transportation.

3.3 Specific compression energy requirement

For applied pressures of 20, 30, 50, 80 and 110 MPa the average specific compression energy required to form the briquettes ranged from 22.5 to 58.1 kJ kg^{-1}, from 19.4 to 50.2 kJ kg^{-1} and from 18.8 to 43.3 kJ kg^{-1} for PC, MC and CC, respectively For each pressure level applied, CC showed specific compression energy values significantly ($p<0.05$) lower than PC and MC (Table 1).

Table 1: Specific compression energy values (kJ kg^{-1}) of PC, CC and MC obtained using different pressure levels (20, 30, 50, 80 and 110 MPa). Mean value and standard error (in parentheses) of 10 replicates. Values with different letters in each row are statistically different at p<0.05.

Applied pressure (MPa)	Materials		
	PC	CC	MC
20	22.5^a (1.0)	18.8^b (0.7)	19.4^b (1.0)
30	32.1^a (0.5)	22.7^c (0.4)	25.7^b (0.6)
50	42.5^a (1.0)	29.2^c (0.5)	37.1^b (0.6)
80	49.9^a (0.5)	38.1^c (0.4)	42.3^b (0.4)
110	58.1^a (0.3)	43.3^c (0.5)	50.2^b (0.4)

From the analysis of collected data is useful to obtain the relationship between density and specific energy required (Figure 6).

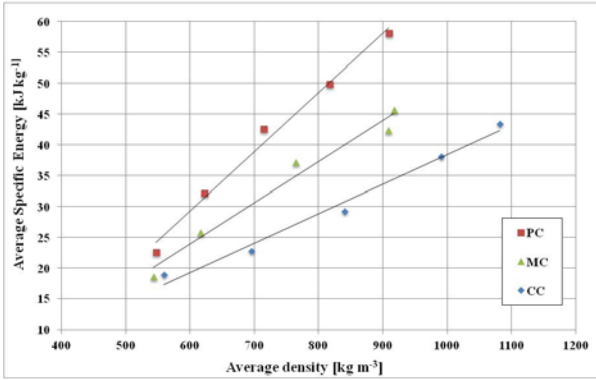

Figure 6: Relationship between specific compression energy and density to form the PC, MC and CC briquette.

For the three materials a linear regression was chosen in order to have the simplest model of the process. The general equation is reported below:

$$SCE = k \cdot \rho + c \qquad (1)$$

Where ρ is input value of density, k is a material-dependent coefficient and c is a constant offset value. For each material the characteristic components were computed and the results are showed in the following table:

Table 2: Parameters for the SCE linear equation.

Material	Parameter		
	k	c	R^2
PC	0.090	-23.3	0.938
CC	0.048	-9.2	0.933
MC	0.068	-16.0	0.874

The specific compression energies calculated for the densification of PC, CC and MC were higher than the values obtained by Santamarta et al. (2012). Using a moisture content of 10.8% and an applied pressure of 47.7 MPa, the specific energy required to form the oilseed rape (OSR) straw briquettes was 24.9 kJ kg^{-1},

compared to 42.5, 37.1 and 29.2 kJ kg^{-1} used to produce PC, MC and CC briquettes, respectively, when the applied pressure was 50.0 MPa and the moisture content ranged from 7.1 to 8.1% .
However the average specific compression energy values found with this trial were lower than the specific energy required to manufacture pellets from biomass feedstock (typically 19-90 kJ kg^{-1}) (Colley et al., 2006).

4. Conclusions

The results of this study indicate that pressure levels - in the range of 20 - 110 MPa - significantly affected the final quality of the briquettes: the higher the pressure, the higher the briquettes quality. Moreover, the study highlighted that the final density value is strongly affected by the kind of biomass and by the different properties of the materials. In particular, poplar and pine require more energy per unit of processed material to obtain the same level of final density. This suggest a lower efficiency of the process with low density woods. These data have to be paired with those coming from an economical analysis in order to evaluate the overall cost of the operation and design sustainable applications.

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