USING INFESTANT SHRUBS TO BIOENERGY- PRELIMINARY RESULTS

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Abstract. *The Portuguese broom weed "Cytisus multiflorus" is the shrub species that occupies the largest area of abandoned Portuguese agricultural land. In a moment when finding alternative energy sources to reshape the energy mix is a major concern for all economies looking for some degree of energetic independence, bioenergy can represent a decisive CO_2 neutral opportunity. The need for quality energy consumption in biomass conversion leads to the need to increase its density and volumetric heating value. The energy balance of such densification process is of the upmost importance as it allows assessing the benefits of the operation. In this exploratory study the emphasis is on determining the effective amount of energy used per unit of biomass for its densification, i.e., the net value of the compression work required to pelletize a particular local shrub species, a leguminous highly efficient N_2 capturer that has been studied in the USA for its ability to be harvested in very short cycles. A specially designed piston-chamber pelletizing device was instrumented and used in a universal testing machine. Pellets were produced by pure compression in standard sizes 6, 8 and 10 mm in diameter using compression speeds of 0.5 to 1.5 MPa/s, with pressures ranging from 75 to 125 MPa. The experimental results included an evaluation of the specific work of compression; additionally, three quality tests were performed, mechanical resistance, durability and water resistance, which enable comparing their performance with existent commercial pellets, under BioNorm II WPIV guidelines.*

Keywords*: Bioenergy, Pelletizing, Portuguese broom*

1. INTRODUCTION

Biomass resources can be divided into three broad categories: wastes, standing forests and energy crops. World production of biomass is estimated at 146 billion tons a year, mostly wild plant growth (Demirbas, 2001). Short rotation crops are planted in some European countries but commercial use for energy production is still negligible, because dedicated biomass production is more expensive per unit of energy produced than the use or available wastes (Faaij, 2006). Sometimes threats become opportunities: *Cytisus multiflorus* is an autochthon infestant shrub, also named 'Portuguese broom'. It was recently pointed out as a valuable species for restoration of degraded soils, especially due to drought tolerance and root symbiosis with nitrogen fixing bacteria (Estabrook, 2006; Estabrook, 2008); it is also the major structural component of arid-land plant communities in the center and north regions of Portugal. This leguminous is an highly efficient N_2 capturer that has been studied in the USA for its ability to be harvested in very short cycles.

To generate heat, electricity and other forms of energy with low greenhouse and acid gas emissions, biomass has become a really important renewable energy resource (Li and Liu, 2000), but the value of a particular type of biomass depends on the chemical and physical properties of the large molecules from which it is made (Mckendry, 2002a). For instance, in the combustion process of lignocellulosic fuel, only a small amount of air is needed when in comparison with other kind of solid biofuels; however, an homogeneous mixture air fuel is practically impossible to achieve using biofuels and the densification is a way to improve its behavior as a fuel (Tabarés *et al.*, 2000). Therefore, before rendering definite judgments on the evaluation of the efficiency of conversion of the different biomass types, it is essential to have gathered data on physical and chemical properties, such as density, moisture and ash content, fixed carbon, volatiles, cellulose/lignin ratio, alkaline and metallic contents and finally heating values. These are the factors that, due to their intrinsic nature, influence the parameters of the technological processes of conversion and pre-conversion (Mckendry, 2002).

Being the biomass a cellulosic material its properties change according to the vegetable species under analysis and for a given species the properties are even dependent upon particular characteristics of such species (Ngohe-Ekam *et al.*, 2006). Because of this, before using the biomass as an energy source or energy conveyor, it must be previously dried and densified. These biomass preparation stages are required steps to improve the handling, transportation and combustion performance (Mckendry, 2002). On the other hand, the moisture content of the biomass can be intrinsic, i.e., independent of the atmospheric conditions, and extrinsic, depending only of the atmospheric conditions during harvesting (Mckendry, 2002). This means that those characteristics determine the biomass performance during the energy conversion process as well as during the pre-processing phase, drying, densification for pelletizing or briquetting, Mani *et al.* (2006). Drying the material also alters the crystalline the structure of the cell walls of the lignocellulosic biomass, (Rayirath *et al.*, 2008).

The main objective of the present study was to calculate the consumption of energy per unit, *i.e.*, the work of compaction, when manufacturing Portuguese broom pellets.

For that goal a piston-chamber pelletizing instrumented device was designed and pure compressed pellets were obtained using a universal testing machine. Additionally, an evaluation of the quality of pellets was performed, under the specifications guidelines of the BioNorm II.

2. MATERIAL AND EXPERIMENTS

2.1. Substance characterization

Cytisus multiflorus and *striatus* are two varieties of the commonly designated 'Portuguese broom' (or '*giesta',* white and yellow, in Portugal), Fig.1, a deciduous shrub of the *leguminosae* (*Fabaceae*) family (UTAD, 2007). It grows up to 10 feet tall, although the frequent size is usually smaller. There are many stems, which are sparsely covered with dark green leaves. The leaves are more numerous towards the ends of the stems and each leaf is composed of 1 to 3 leaflets. Portuguese broom has pale yellow or white pea-like flowers in the spring. Seeds are borne in an inflated pod (¾ to 1¾" long), which is densely covered with whitish hairs. After drying, the pods split open and the seeds are ejected from the plant. Portuguese broom form dense thickets, replacing native vegetation. Like other brooms, this plant burns readily and the seeds remain viable for years.

Figure 1. White and yellow Portuguese broom– *Cytisus multiflorus* and *Cytisus striatus*, respectively.

For the present work, white *Cytisus multiflorus* shrubberies were harvested in a forest situated at the north of Portugal. Some of the crop material was used for experimental characterization and the other matter was dried naturally, in air exposition under the sun until being ready to be used on the experimental compaction processes. The proximate analysis and the higher heating values were determined experimentally at laboratory facilities of INEGI, an interface institute from the Faculty of Engineering of the University of Porto, for both slim and raw parts of the substance, according to standard methodologies (NFP, 1975). The obtained values are shown in Tab. 1.

Table 1. Some examples of composition and Higher Heating Value (HHV) of known biomass species (Martinez, 2009), *Ulex europaeus L.* (furze), *Sarothamnus scoparius (L.)* Link (broom) (Núñez-Regueira, 2004) and experimental results for two specimens (slim and sturdy) of *Cytisus multiflorus*.

Composition and Properties (%wt)	Moisture (%wt)	C (%wt)	H (%wt)	O (%wt)	N (%wt)	S (%wt)	Ash (%wt)	HHV (kJ/kg)
Sugar cane bagass	7	46	5	40	0	0	1	16200
Pine sawdust	9	45	5	39	0	0	1	16400
Almond shells	12	41	5	39	1	0	3	16000
Grape stalks	8	41	6	40	0	0	5	16700
Ulex europaeus L.	47.7	50.54	6.50	40.91	1.73	0.32	0.36	20049
Sarothamnus scop.(L.)	51.8	49.94	6.39	40.16	2.99	0.52	0.28	19760
Cytisus (slim)	-	-	-	-	-	-	-	18000
Cytisus (sturdy)	-	-	-	-	-	-	-	15000

2.1.1. Material preparation

Biomass samples for compaction were ground using a Fritsh hammer mill, model P19, with two different screen sizes: 0.5 and 2 mm. To obtain samples for moisture content and heating value assessment, some of the plants that were previously cropped were divided into two groups: larges and median branches, hereby designated by 'sturdy', and the remaining very thin branches, flowers and leafs, named 'slim' material. For slicing the fat branches used on moisture content determination samples a band saw woodworking machine ELU-EBS 306 was utilized.

2.1.2. Average particle size

Since the dimensions of the particles could have some relevance in the compaction (Mani *et al.* 2006), a determination of its mean diameter (d_{gw}) was made. Using a RETSCH analytical sieve shaker, model AS200 Control, a sample of 82 g of material obtained by a 2 mm hammer mill screen size was placed in the stack of sieves arranged from the largest to the smallest opening, for the application of the gravimetric method (Hartmann *et al.*, 2006). The duration of sieving was 10 min and the amplitude 1.50 mm, to ensure achieving adequate sieve acceleration. After sieving, the mass retained on each sieve was weighed. The particle size was determined according to ISO 3310-2 1999-01, resulting in a mean diameter of 427 µm.

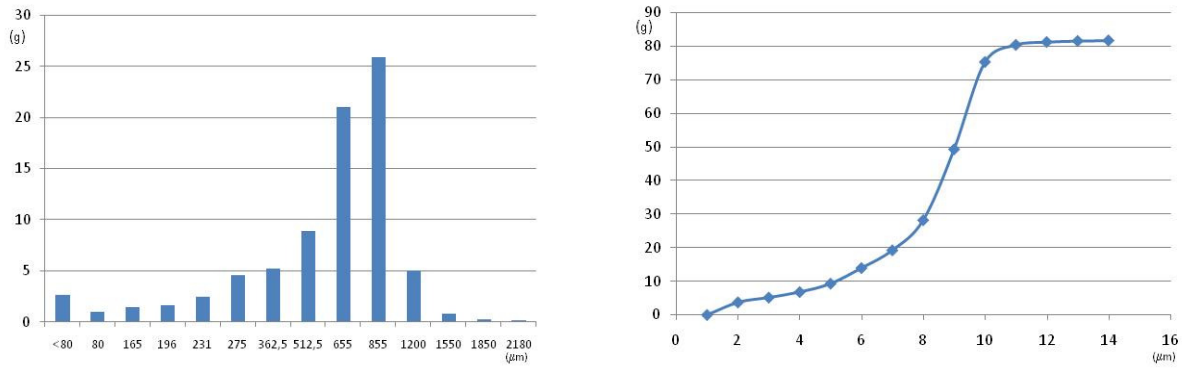

Figure 2. Particle discrete size distribution.

2.1.3. Moisture content

As explained in section 2.1.1., the collected material was divided in sturdy and slim portions. The samples were weighted and dried at 105° C in a Binder laboratory stove, model SDL115, until constant weight was reached (Samuelson *et al.*, 2006). They were then stabilized at ambient room temperature (21° C) inside a cooling silica chamber desiccator. Three general essays were done and in the third one the plants constituents were not separated before chopping took place, to emulate the industrial drying process. The samples were subsequently dried and stored in hermetic boxes until used in the compaction process. Then, a new control was made on the moisture content. Tab. 2 presents the moisture content values calculated by the following equations (wet basis and dry basis, respectively) for the three crops:

$$H_{wb} = [(m_w - m_d) / m_w].100 \quad (1)$$

$$H_{db} = [(m_w - m_d) / m_d].100 \quad (2)$$

where H_{wb} is the moisture content of the material, m_w the weight of the test sample before drying (wheat) and m_d is the weight of the test sample after drying until constant weight.

Table 2. Moisture content of the samples.

Samples		Initial mass before drying (g)	Final mass after drying (g)	Moisture content, H_{wb} (%)	Moisture content, H_{db} (%)
N 1	sturdy material	84.22	66.65	25.4	34.0
	slim material	88.89	74.37	19.6	24.4
N 2	sturdy material	196.97	114.58	45.3	82.7
	slim material	155.42	58.90	68.7	219.7
N 3	mixed	65.52	54.58	21.1	26.7

2.1.4. Bulk and particle density

Measurements of raw and piled bulk density change with applied pressure, simulating the increase in height of the stored material (Jirjis, 1995), is shown in Fig. 3:

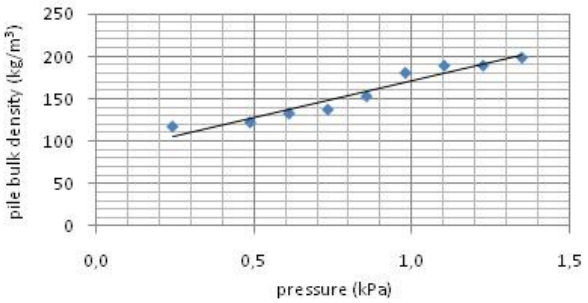

Figure 3. Pile bulk density versus applied pressure.

As for the bulk density measurements of ground/milled samples, a 0.5 l glass container was used (Mani *et al.*, 2006; Lam *et al.*, 2008). The sample was gently dropped at the center of the container, using a funnel and a glass stick to maintain the flow in a continuous way. The cup was gently leveled and weighed. The resulting value for the mass per unit volume gives the bulk density of the biomass in kg/m^3.

Some uniform branch sticks used in moisture content determination were also measured to define the corresponding particle density following the Lam *et al.* (2008) dimensional measurement procedure. A 150 mm digital caliper, with a precision of 0.01 mm, was used to measure the length and three diameters (extremities and middle) per branch. The volume of each sample was calculated through the knowledge of the average diameter of the stick, based on the three mentioned diameter measurements, and the length of the stick. The samples were weighted and some very different values of the material density were obtained. The uncertainty of the methodology was apparent while using the Archimedes Principle for the hydrostatic method proposed by Rabier *et al.* (2006). Tab. 3 shows the differences on the volume of the samples as well as on the corresponding densities obtained under the two methodologies. However the order of magnitude of the results is coherent.

Table 3. Differences of volume calculation under two methodological approaches.

Sample number	Dimensional measurement		Hydrostatic method	
	volume (10^{-6} m^3)	particle density (kg m^{-3})	volume (10^{-6} m^3)	particle density (kg m^{-3})
1	4	705	6.0	495
2	4	746	5.0	590
3	4	753	5.0	546
4	8	659	6.0	865
5	10	761	11.5	639
6	6	734	5.5	791
7	4	705	6.0	495

Though there is some degree of coherence in the results, the hydrostatic method presents a large data scattering, especially when the same samples are compared to the geometrical measurements corresponding density results. Therefore, only the densities calculated by means of the dimensional measurement were considered.

The effective volume of particles was determined applying the hydrostatic method of Rabier *et al.* (2006). Thus, twelve similar samples of branches of Portuguese broom were sliced in similar lengths and weighed using a Kern centesimal scale, model 'ew', with a precision of 0.01 g. The samples were subsequently dried inside the lab stove until constant weight was attained (Samuelson *et al.*, 2006). For the volume determination of the samples, a graduated test tube with 50 cm^3 capacity with water placed inside it was used. The samples were introduced one by one in the test tube without touching its internal wall and the volume of water dislocated, as well as the correspondent weight, was simultaneously registered. Once the volume was determined, the particle density ρ_u was estimated using the following equation:

$$\rho_u = (m_u / m_{w.dis})\, \rho_w \tag{3}$$

where ρ_w is the density of the liquid water at a given temperature, m_u the weight of the test sample in air and $m_{w.dis}$ the weight of liquid water displaced by the test sample. The results are presented in Tab. 4:

Table 4. Particle density of twelve branches of Portuguese broom.

Sample nr (-)	Test sample, m_u (g)	Displaced water, $m_{w.dis}$ (g)	Particle density, ρ_u (kg m^{-3})
1	4.49	4.74	998
2	3.35	3.58	1000
3	1.09	1.21	983
4	4.56	4.95	994
5	2.40	2.51	1036
6	1.29	1.49	1007
7	3.75	3.97	1003
8	2.80	2.97	1013
9	1.49	1.65	988
10	6.89	7.14	1020
11	3.66	3.76	1037
12	2.23	2.41	992

2.2. Compression tests

To perform the tests, a piston-chamber of 200 mm length was designed to manufacture three single pellet matrixes, Fig.4, with three diameters: 6, 8 and 10 mm. The compression chamber end was adapted to fit a cylindrical plate where a K type thermocouple was installed to measure the temperature variation during the pellet production; the thermocouple was logged in a computer using aPico Log® software. Biomass samples with 0.5 mm mean diameter particle size and 8 to 15 % (wb) moisture content were selected because they were close to the range of values found in the industrial sector and at the same time they were close to the optimum range of moisture content (6 % to 12 %) values convenient for the pelletizing process (Li and Liu, 2000). The mean bulk density of the raw material, in the 150 to 229 kg/m^3 range, was used to estimate the weight for the volume of the material needed to fill the compaction chamber.

The compressive movement was performed by the universal test machine Instron 4206, fitted with a 100 kN load cell. The preset loads used for the tests were from 4 to 20 kN, and an increase ratio from 14 to 117 N/s was used. These compression ratio values are connected to the chosen values for the compression speed values of 0.5, 1.0 and 1.5 MPa/s, adopted in the experiments as suggested by Li and Liu, (2000). These authors indicated that for compression speeds below 3 MPa/s the density of briquettes diminished with the increase of the compression ratio. The sample was fed into the chamber and compressed up to the specified preset load and then held until the load decrease stabilized (Li and Liu, 2000; Mani *et al.* 2006). The pellet formed was removed using the same compressive piston. The force-deformation data were logged in the computer. The compressive work, *W*c, was calculated with the data recorded. The mass, length and diameter of the pellet were measured. Each compression process was repeated twice.

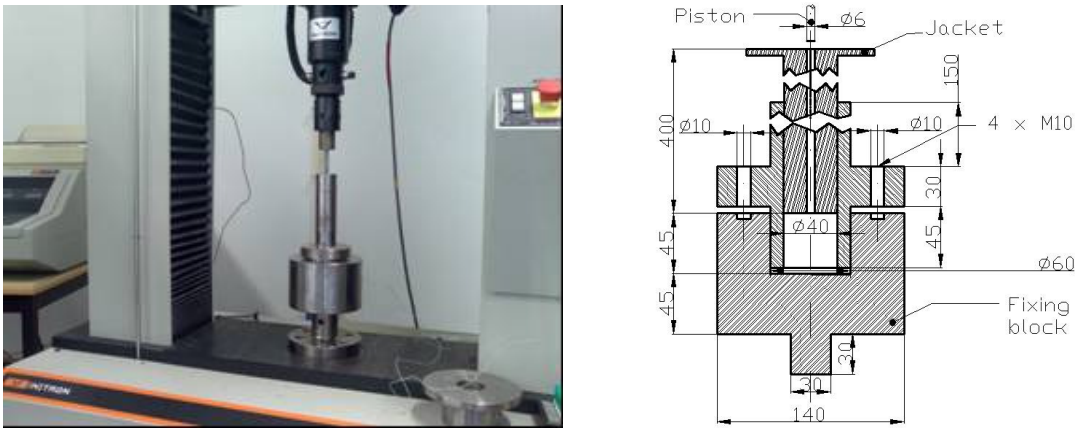

Figure 3. Instron machine and drawing sectional view of the pellet compression chamber.

The production of pellets took place in a conventional solid mechanics laboratory facility, using the universal test machine after fitting the device shown on Fig. 3 to produce pellets on a one by one basis. Figure 4 shows a typical displacement, load and strain test results. The initial slightly curved line that initializes the offset adjustment, approximately until 1 kN is reached, represents a feed-back load adjustment, a machine response to the existence of unexpected resistances, such as those that result from intermittent blockage from very small fibers that are caught lengthwise between the piston and the jacket.

Once the offset period is over, *i.e.*, once the initial adjustment of the bar head is done, the displacement increases with practically no force needed and the association between the variable displacement and the constantly increased force employed is noticeable. It can be observed that, until approximately 1 kN, a displacement mode control is in place, imposing a set constant pre-load velocity of 30 mm/s.

From 1 kN and beyond, until the end of the test, there is always a resistance increase and the machine will, as a consequence of that resistance, increase the strength up to the situation for which it had been programmed. The mode of controlled load takes place with a previously defined value, 1,5 MPa/s (7065 kN/min for the case of the test shown in Fig. 4). In this region of controlled load velocity, its value can be found, if otherwise not available, by the slope of that line. The test ends when the 15.7 kN value is reached.

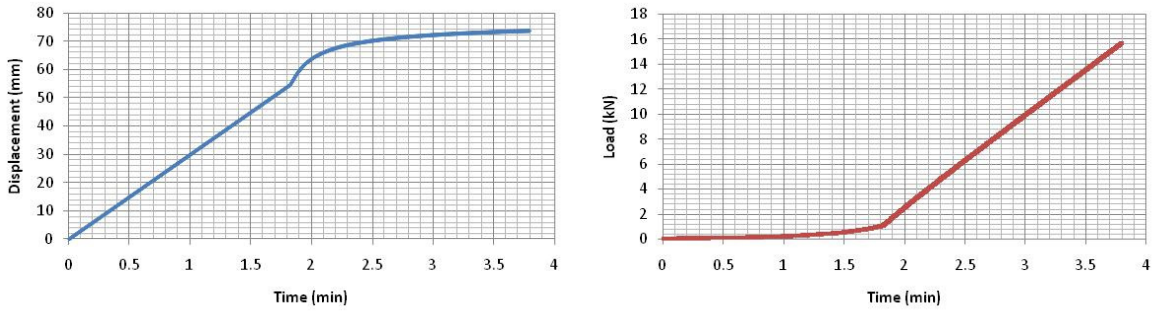

Figure 4. Displacement and load change with time during a 10 mm diameter pellet test manufacture.

As stated before, Fig. 4 represents load and displacement values for 10 mm diameter pellets tests; other diameter values, namely 6 and 8 mm, show the same pattern of behavior. Figure 5 shows how strain changes with the applied load for the same test represented in Fig. 4.

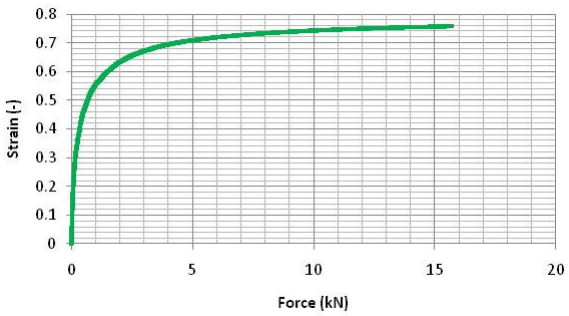

Figure 5. Strain change with load during a 10 mm diameter pellet test manufacture.

Strain is expressed as the ratio of total deformation to the initial dimension of the material that will give place to the final pellet, in which the forces are being applied. The normal strain of a material element axially loaded e, is expressed as the change in length ΔL per unit of the original length L_i of element:

$$e = (L_f - L_i)/L_i = \Delta L/L_i \tag{4}$$

where L_f is the final length of the pellet. Strain is positive if the material fibers are stretched or negative if they are compressed. Thus, as in the present situation there is compression process, to avoid minus signs the strain values are presented in modulus:

$$e = |\Delta L/L_i| \tag{5}$$

Multiplying and dividing Eq. (5) by the area of the cylindrical base of the pellet and by its mass, Eq. (5) is now written as:

$$e = |\rho_i / \Delta\rho^*| \tag{6}$$

where $\Delta\rho^*$ is the ratio between the mass and the change in volume. Eq. (6) is a recognizable way of expressing the densifying process that took place and that is one of the major goals of pellet production. The energy employed to attain a certain degree of densification is the purpose of the graphic shown in Fig. 6, which has naturally the same significance of the curve displayed in Fig. 5, but turns out to be a more explicit representation concerning the definition of a specific energy at stake in pellet production.

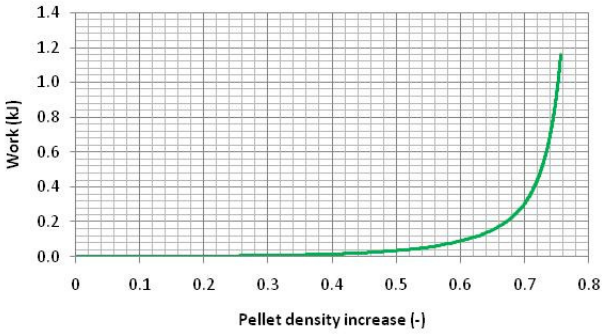

Figure 6. Diagram of the energy spent versus densification of a 10 mm diameter pellet to 76% .

2.3. Pellets quality

Durability (DU) and particle density are the main parameters describing the physical quality of densified solid biofuels (Temmerman *et al.*, 2006).

Since the amount of water contained in the sample is an important factor that influences the durability of the pellet, especially for values above 10 %, before testing durability the moisture content of pellets was calculated using oven drying in air at 105º C (Samuelson *et al.*, 2006). To determine the density of the pellets through the hydrostatic method, the sticks were coated with paraffin before being submerged under water (Rabier *et al.*, 2006, p956, Temmerman *et al.*, 2006, p967). After selection of a representative number of the pellets of 6, 8 and 10 mm diameter with moisture content below 10 %, they were tumbled in an ASAE drum with inner dimensions of 300×300×125 mm^3. The container was rolled on axis; which is centered perpendicular to the sides of the box. The rotation speed was fixed to 50 rpm and a 500 g sample was tumbled for 500 rotations before being sieved manually with a 3.15 mm round hole sieve according to ISO 3310.2 (Temmerman *et al.*, 2006, p966).

The durability obtained was expressed as the percentage in mass of the pellets remaining on the sieve to the total sample weigh and was calculated as the mean value of three replications.

Table 5. Durability of the pellets produced under the 1.5 MPa/s load rate compared to a commercial product.

Pellets type	Diameter	Lenght	Unit mass	Sample initial mass	Sample final mass	DU
	(mm)	(mm)	(g)	(g)	(g)	(%)
Commercial	10.26-10.43	16.71-45.0	1.2-3.7	51.76	51.21	98.9
	10.26-10.43	16.71-45.0	1.2-3.7	50.71	49.96	98.5
	10.26-10.43	16.71-45.0	1.2-3.7	50.01	49.45	98.9
Lab samples	10.25	26.11	2.2	48.96	37.45	76.5
	10.27	24.95	2.2	50.82	39.15	77.0

3. RESULTS AND CONCLUSIONS

As referred in section 2.2, the test represented in Fig. 6 was made using a load velocity of 7065 N/min. Figures 7 and 8 correspond to experiments with a smaller load velocity of respectively 4710 and 2365 N/min.

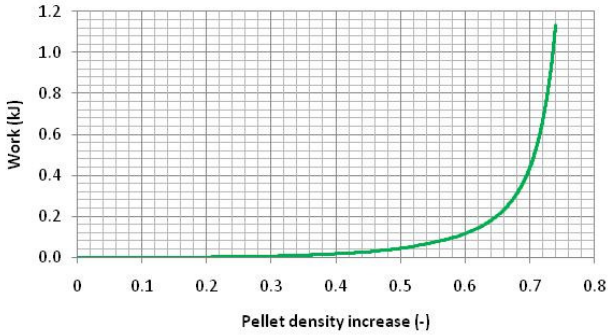

Figure 7. Diagram of the energy spent versus densification of a 10 mm diameter pellet to 74% using a load rate of 1.0 MPa/s (4710 N/min for a 10 mm diameter).

Changing the pellet load rate has an influence on the energy used and that effect is not directly proportional to the densifying outcome. Analyzing the diagrams of Figs. 6 to 8 and the results of Table 4, no recognizable pattern is detected, which suggests that more work is necessary to come to some coherent conclusions.

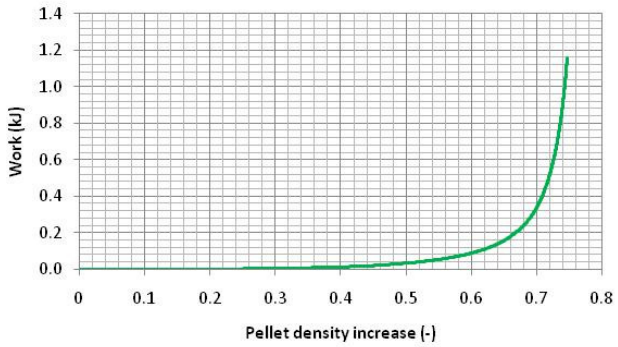

Figure 8. Diagram of the energy spent versus densification of a 10 mm diameter pellet to 75% using a load rate of 0,5 MPa/s (2365 N/min for a 10 mm diameter).

Though some authors report a consistent density reduction with a decrease of the compaction speed, namely Li and Liu (2000) for values lower than 3 MPa/s, the present results show no such regularity.

Table 6. Influence of the load rate on the work of compression for the tested sizes.

Sample diameter	Load rate	W_c	e
(mm)	(Pa/s)	(J)	(-)
6	0.5	17.3	0.66
6	1.0	17.7	0.65
6	1.5	14.6	0.64
8	0.5	52.1	0.63
8	1.0	58.6	0.68
8	1.5	51.4	0.67
10	0.5	85.7	0.75
10	1.0	99.7	0.74
10	1.5	89.4	0.76

However, some general trends can be detected from the experimental data obtained so far:

-There seems to exist a clear trade-off between the energy used and the densifying results. Energy spending becomes strongly exponential after reaching a 70% densification, for all the cases considered;

-The load rate has an influence on the quality of the pellets and, therefore, it is a factor to take into consideration when further analyzing the experimental data of a wider range of tests.

5. ACKNOWLEDGEMENTS

We want to thank Prof. José Salgueiro for his commitment with the strength essays. Without his skill, permanent availability and encouragement the results presented on this work would not have been possible. We also are indebted to Marco Sampaio for his contribution gathering data on bulk density.

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