INFLUENCE OF PROCESS PARAMETERS ON THE IMPACT RESISTANCE AND PELLETING PRESSURE OF OIL PALM SHELL PELLETS

RINCON S.L., **GÓMEZ A. and ZAPATA A.J.**

Universidad Nacional de Colombia - Sede Bogotá- Facultad de Ingeniería–Departamento de Ingeniería Mecánica y Mecatrónica - Grupo de Investigación en Biomasa y Optimización Térmica de Procesos - Carrera 30 Calle 45-03, Bogotá, Código Postal 111321 - Colombia
E-mail: slrinconp@unal.edu.co

ABSTRACT

In the present work a study of the production process of oil palm shells pellets is performed. The influence of the system parameters water content, particle diameter and temperature of the raw material are evaluated and its influence on the impact resistance of the obtained pellets is quantified. Also, the influence of these parameters on the pelletizing pressure is determined.

The experimentation was done at a laboratory scale pelleting unit in which a ram (45 mm diameter, max force 152 kN) forces the biomass to extrude through a die with 14 holes of 6 mm diameter. The design was made to emulate the forces needed to introduce the biomass into and through the channels found in a commercial pellet mill. A preliminary experiment was executed to determine the necessary conditions to produce pellets in this particular pelleting unit by varying the parameters in the following ranges; temperature 60-100°C, particle diameter 0.25-1.00 mm and water content 10-25 % w.b. The experiment showed that the machine had not enough pressure to force the biomass into the die for particle sizes bigger than 0.5 mm with moisture contents below 20%, and pellets produced with moisture contents above 20 % w.b. crumbled easily. With this information a factorial experiment was executed to evaluate the effect of each parameter and their interaction on the impact resistance of the pellets, as well as the influence of these parameters on the pressure required to force the biomass through the die. The results showed that all of the parameters have a significant influence on both the impact resistance of the pellets and the pressure.

Keywords: Oil Palm Shell, Solid Biofuel, Pellets.

1. Introduction

Oil palm shells constitute one of the residues of the extraction process of palm oil being its worldwide production 15600 kt in 2014 (USDA, 2014). Colombia is the fourth largest producer of palm oil with a production that has increased by 47 % in the last five years (USDA, 2014). The use of oil palm shells is limited; small quantities are used together with oil palm fibers as fuel for combustions processes and as filling material for paths within the own plantations. The use of oil palm shells as fuel or as raw material for the production of activated carbon can be enhanced by the production of pellets. In the pelleting process the biomass is densified by mechanical means into cylinders of diameters less than 25 mm and with lengths of less than 50 mm. Pelletized material has many advantages compared to the untreated residue; it has a higher bulk density which lowers transportation and storage costs, an increased energy density and a regular shape that minimizes flow problems in processing equipment and allows the implementation of simpler automated feeding systems.

Mechanical durability represents the ability of densified biofuels to remain intact when handled and delivered (CEN/TS 14588:2005). It is measured by the resistance of densified fuels towards shock and/or friction. Therefore, durability is an important quality parameter with regard to handling and transportation processes (Carone *et al.*, 2010). A literature review by Kaliyan and Morey (Kaliyan & Morey, 2009) found that biomass feedstock variables such as particle size, moisture content and steam conditioning/preheating temperature affected the density and durability of densified products such as pellets and briquettes. They concluded that particle sizes of geometric mean diameters of 0.5 to 1.0 mm, moisture contents of 8 to 20%wet basis, and preheating temperatures of 65 to 100 °C produced high quality (i.e., high density and durability) densified products for a variety of biomass feedstocks such as corn stover, alfalfa, wheat straw, sawdust and animal feed materials.

Most pellets today are produced in pellet mills of the ring die type (Bhattacharya et al., 1989). The acting forces in a press channel of a ring die type pellet mill have been reviewed in detail in earlier studies (Holm et al., 2006)(Stelte et al., 2011), and it was shown that under steady state conditions the pelletizing pressure is dependent on the friction coefficient between the material and the die, the length and diameter of the pellet in the die. Additionally (Stelte et al., 2011) proposes that there is also an influence of the moisture content in the pelletizing pressure.

2. Materials and methods

2.1. Material preparation

The Oil palm shells from *Elaeis guineensis* obtained in a local oil producing plant were grinded in a hammer mill and then sieved in American standard sieves series E11:95 No. 100, 80, 60, 35, 25 and 18 (0.149, 0,177, 0.25, 0.5, 0.707 and 1 mm respectively), on a standard shaker machine, batches of 100 g where sieved for 10 min until all of the biomass was sieved.

2.2. Moisture determination and adjustment

Moisture content of the sieved biomass was determined using EN 14774-3. For each particle size 3 samples where dried to determine the average moisture content of the untreated material, the results can be seen in Table 1.

Table 1: Average moisture content of oil palm shell by different particle sizes.

Particle size (mm)	Mad w.b.(%)
0.5-0.25	8.41
0.25-0.17	8.43

Samples of different water contents were prepared by the addition of a measured amount of water to each sample, the samples were stirred until visual homogenization was attained and stored in sealed containers for 24 h at room temperature (20 °C) before performing an experiment. 11 levels of moisture contents were accomplished by adding different amounts of water to each sample, from 1 to 11 ml with a difference of 1 ml between samples. Moisture content of the samples was calculated as follows (Mahapatra et al., 2010):

$$M_f=\frac{W_iM_i+100A}{W_i+A} \quad (1)$$

Where M_i is the initial moisture content of the sample (%) taken from Table 1, W_i is the total weight of the sample before conditioning (g), A is the amount of water added (g) and M_f is the final moisture content.

2.3. Pelleting unit

Pellets where made using a laboratory ram extrusion press with a ram diameter of 43 mm stroke length 110 mm and a die with 14 holes of 6 mm diameter and 30 mm length, as shown in Figure 1.

The assembly is mounted on a hydraulic press which pushes the ram with a maximum force of 186 kN at an average speed of 10 mm s^{-1}, a data acquisition system was implemented to register the position (resolution 1 mm) and pressure of the ram (resolution 0.5 MPa) every 0.1 seconds. The material is preheated to the desired temperature in a microwave oven prior to loading into the machine, an electrical resistance heats the chamber to a fixed temperature of 120 °C to avoid heat loss during the pelleting process. Finally, after the ram has reached the end of the stroke the remaining material still in the die is removed and the die is cleaned before the next experiment; this remaining material produced at the end of the stroke with the maximum achieved pressure is considered as the pellets.

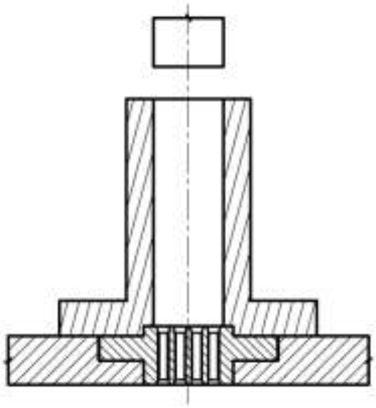

Figure 1: Ram die assembly.

2.4. Impact resistance of pellets

The amount of pellets produced in this laboratory scale machine is not enough to determine the durability of the pellets by performing a tumbling test. The impact resistance of the pellets was determined as an indirect measure of durability using the drop test method with a similar procedure as (Adapa *et al.*, 2010) where a single pellet was dropped from a height of 1.85 m on a ceramic tile. The larger intact portion of the mass retained is expressed as the percentage of the initial weight using a digital balance (resolution 0.001 g). This procedure is applied to every pellet of one batch and the averaged result is reported as the impact resistance (I.R.) of the particular test.

2.5. Correction of moisture content

In order to evaluate the influence of the material temperature on the pressure and impact resistance, the samples where preheated in a microwave oven prior to being loaded on the pelleting machine. A reduction of the moisture content of the samples after this process was observed and a statistical analysis estimating the real moisture content loaded on the machine was performed.

A full factorial experiment 3^2 with two replicates was executed were three levels of residence time in the microwave oven (t : 10, 35, 70 s) and three levels of water added (A: 0, 5, 11 g) were evaluated. This experiment showed that the two factors and their interaction were statistically significant as shown in Table 2.

Table 2: Anova of factorial experiment.

	SS	df	MS	F	P-value	F crit
t (s)	5.071503	2	2.535752	1086.259	1.86E-11	4.256495
A (g)	16.05985	2	8.029927	3439.841	1.05E-13	4.256495
Interaction	4.464563	4	1.116141	478.1298	1.8E-10	3.633089
Within	0.02101	9	0.002334			
Total	25.61693	17				

A least squares linear regression was performed on the data to find the coefficients of the following model to predict the water lost (A_l) in the preheating process. The results can be seen in Table 3.

$$A_l = \beta_0 + \beta_1 t^2 + \beta_2 A + \beta_3 A^2 + \beta_4 At + \varepsilon \quad (2)$$

Table 3: Regression coefficients.

	Value
β_0	0
β_1	-0.00259
β_2	-0.01874
β_3	0.000597
β_4	0.004398

A comparison of experimental results and the results given by the model can be found on Figure 2.

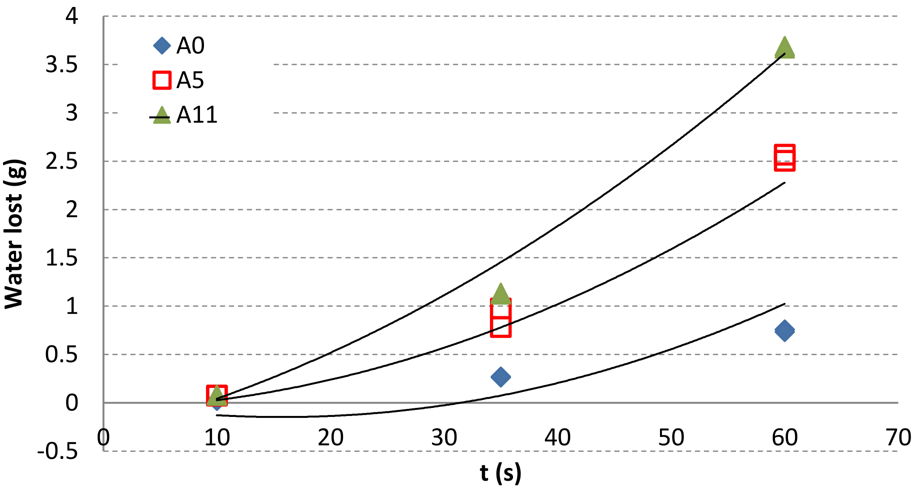

Figure 2: Experimental data and model for water lost during preheating in the microwave oven.

3. Results

By the experiments made with the bigger particle size (1 – 0.75 mm) without any additional water and at room temperature the ram compressed the material until the maximum pressure generated by the machine but the material did not flow into the die's chambers. A series of tests where then executed starting with the bigger particle size to determine the required moisture content to extrude the material through the die's chambers for each particle size until an adequate particle size was found. Pellets with particle sizes bigger than 0.5 mm could not be extruded using the pelleting unit used in the present study.

Two levels of particle sizes were selected, 0.5 - 0.25 mm and 0.25 - 0.17 mm. For these two particle sizes tests 11 levels of moisture contents were executed with the same temperature. The results found in Figure 3 showed that the pelleting pressure decreases as the moisture content increases and the particle size decreases. The same trend can be observed for the impact resistance as can be seen in Figure 4. The results of the tests in which the ram jammed before the material started to extrude outside the die are taken as failed tests and therefore not shown in the results.

As the particle size of the material increments the pelletizing pressure and impact resistance for similar moisture contents diminishes as previously stated. This contradicts the results found by (Stelte *et al*., 2011) in which the pressure required to push the material in the chamber increases as the particle size decreases. An explanation for this discrepancy is theorized to be found by concluding that the pressure reported by the author only takes into account the pressure required to force the pellets through the die channel and an additional pressure not contemplated by the author in his work is needed in the particular experimental setup used in this project because of the sudden area reduction encountered when the material flows from the chamber into the die channels.

In order to evaluate the effect of the sample temperature two levels of temperature (55 and 100 °C) were selected. The results are presented in Figures 5 and 6 were the data corresponds to two replicates. From these figures it can be stated that as the temperature increases the pelleting pressure decreases but the impact resistance increases.

Pellets made with moisture contents greater than 20% started to exhibit longitudinal cracks and crumbled very easily. To illustrate this, the photograph found in Figure 7 shows pellets made with the same particle size and temperature but with different moisture contents.

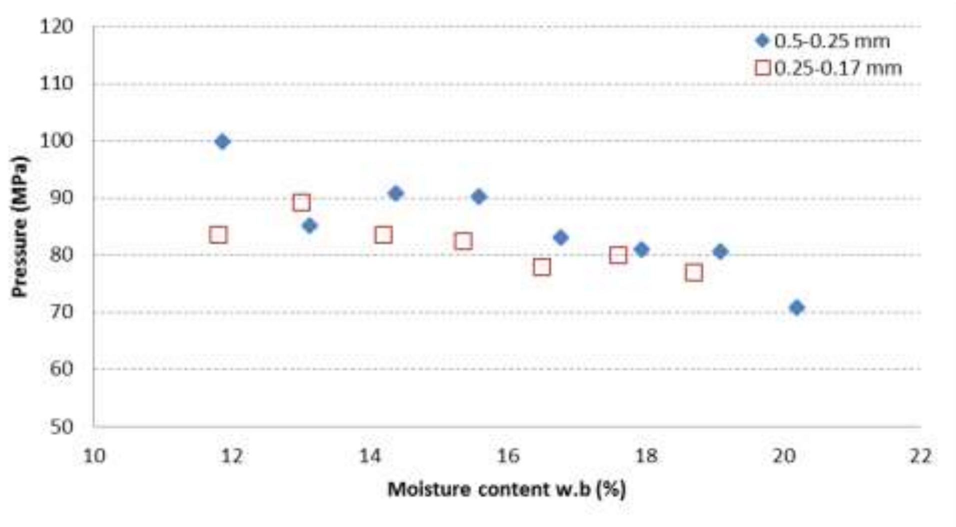

Figure 3: Effect of moisture content and particle size on extrusion pressure with average temperature of 92 °C.

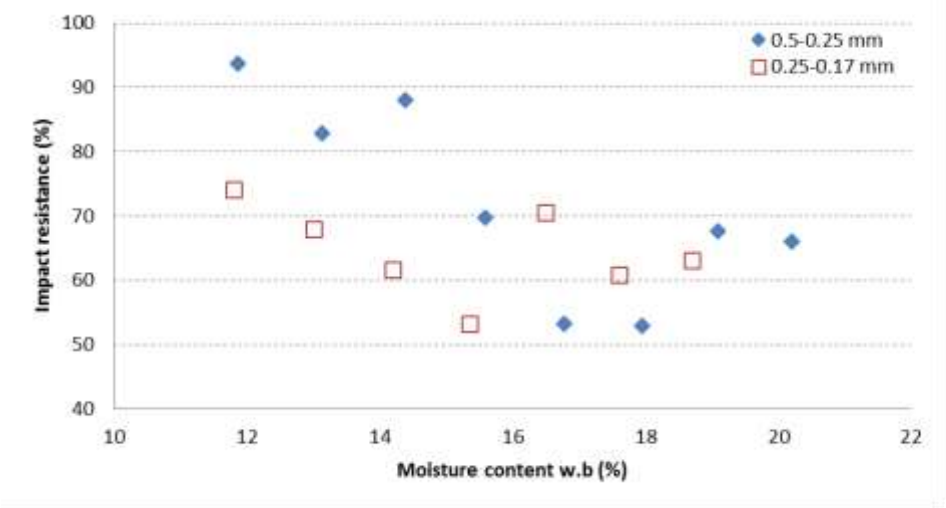

Figure 4: Effect of moisture content and particle size on impact resistance with average temperature of 92 °C.

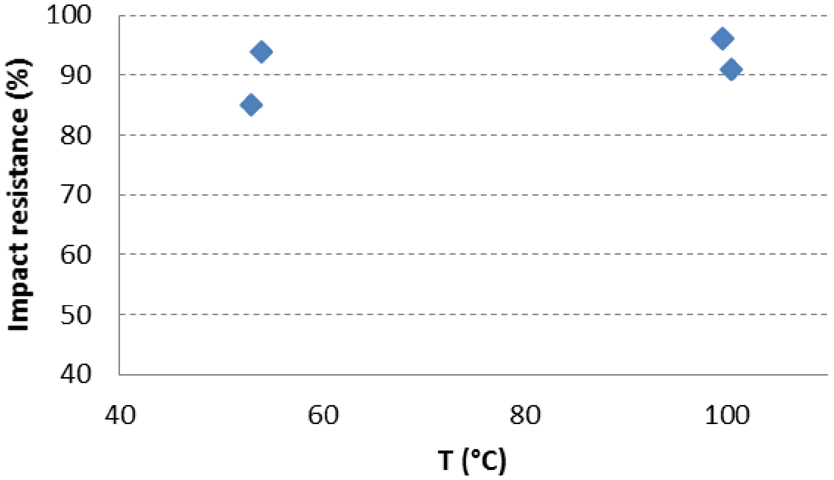

Figure 5: Effect of temperature on impact resistance with average moisture content 10.7 %. Particle size 0.5 – 0.25 mm.

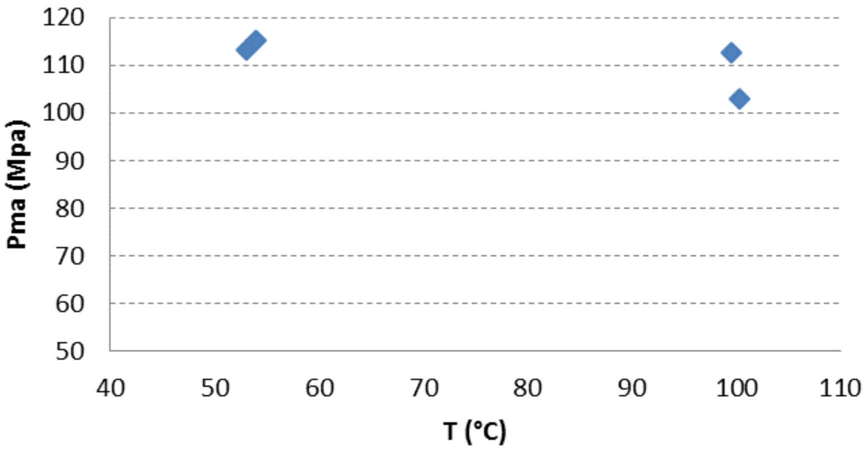

Figure 6: Effect of temperature on extrusion pressure with average moisture content 10.7 %. Particle size 0.5 – 0.25 mm.

Figure 7: Pellets produced with particle size 0.5-0.25 mm, temperature 92 °C, moisture content w.b. 10.6 % (top) 20.2 % (bottom).

4. Conclusions

As the pelleting pressure increments the impact resistance of the pellets increments and the factor with the most influence on the extrusion pressure is the moisture content of the sample. Temperature also has a statistical significance in both the pressure and impact resistance.

REFERENCES

1. Adapa, P., Tabil, L., Schoenau, G. & Opoku, A. (2010), Pelleting characteristics of selected biomass with and without steam explosion pretreatment, Int J Agric Biol Eng Open, 3, 62 .
2. Bhattacharya SC, Sett S, Shrestha RM. State of the art for biomass densification. Energy Sources 1989;11:161–82.
3. Carone, M. T., Pantaleo, A. & Pellerano, A. (2011), Influence of process parameters and biomass characteristics on the durability of pellets from the pruning residues of Olea, Biomass and Bioenergy, 35, 402–410 .
4. Holm JK, Henriksen UB, Hustad JE, Sorensen LH, (2006), Toward an understanding of controlling parameters in softwood and hardwood pellets Production, Energy Fuels, 20, 2686–94.
5. Kaliyan N., Morey R.V. (2009), Factors affecting strength and durability of densified biomass products, Biomass Bioenergy, 33, 337–359.
6. Mahapatra, A. K. et al. (2010), Effects of moisture change on the physical and thermal properties of sericea lespedeza pellets, Int. Agricutural Eng. J., 19, 23–29 .
7. Stelte W., Holm J. K., Sanadi A. R., Barsberg S., Ahrenfeldt J., and Henriksen U. B. (2011), Fuel pellets from biomass : The importance of the pelletizing pressure and its dependency on the processing conditions, Fuel, 90, 3285–3290.
8. UNI. UNI CEN/TS 14588:2005. Solid biofuels. Terminology, definitions and descriptions. 2005.
9. United states department of agriculture - USDA: Oilseeds: World Markets and Trade, 2014