

## LOADS, TENSIONS AND DEMANDED ENERGY IN THE BRIQUETTE MANUFACTURE

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### ABSTRACT

Brazil produces around 960 thousand metric tons of briquette, originated from 620 thousand metric tons of wood and 340 thousand metric tons of agricultural waste. However, the engineering of the briquette machines is obsolete. This study aims to present a theoretical formulation and a case study for loads and tension in the work of sawdust densification for the manufacture of wooden briquette with pulse piston machines. It was motivated by the increasing briquette market in Brazil and all over the world, as well as the absence of modern engineering for these obsolete machines with 60 years old know-how without much improvements. For the two machines examined in this study, the dynamic axial loads of impact were 4.31 tf and 10.19 tf. The axial tensions of impact for sawdust compression were 24.73 MPa and 14.10 MPa. For the static tests of the briquette in its lateral resistance, the breaking loads were 2,224 kgf and 2,337 kgf, and the axial breakage tensions were 3.843 MPa and 3.233 MPa. The relation between manufacturing energy and thermic energy stored in one metric ton of briquette is 10.8%. Some suggestions are presented for the modernization of machine engineering and manufacturing conditions, with the purpose of getting better technical quality briquette and commercial viability.

**KEYWORDS:** energy, biomass, briquette machine.

### CARGAS, TENSÕES E DEMANDA DE ENERGIA NA FABRICAÇÃO DO BRIQUETE

#### RESUMO

O Brasil produz 960 mil toneladas de briquetes sendo 620 mil de madeira e 340 mil de resíduos agrícolas. No entanto, as máquinas de briquetagem são de obsoleta engenharia. Este trabalho apresenta formulação teórica e estudo de caso para cargas e tensões no trabalho de adensamento de serragem para a fabricação de briquete de madeira com briquetadeiras de pistão a pulso. Foi motivado pelo crescente mercado de briquetes no Brasil e no mundo, assim como pela ausência de moderna engenharia nessas antigas máquinas com *know-how* de 60 anos sem aperfeiçoamentos. Para duas máquinas em estudo, as cargas dinâmicas axiais de impacto foram 14,31 tf e 10,19 tf, as tensões axiais de impacto para compressão da serragem foram 24,73 MPa e 14,10 MPa. Para os ensaios estáticos do briquete em sua resistência lateral, as cargas de ruptura foram 2224 kgf e 2337 kgf e a tensão de

axial de ruptura 3,843 MPa e 3,233 MPa. A relação entre a demanda de energia de fabricação de uma tonelada de briquete e o seu conteúdo energético em poder calorífico superior é de 10,8%. São sugeridos itens para a modernização da engenharia das briquetadeiras, assim como especificadas as condições de fabricação de um briquete de melhor qualidade técnica e viabilidade comercial.

**PALAVRAS-CHAVE:** energia, biomassa, briquetadeira.

## INTRODUCTION

The wood fuel importance grows in the worldwide market due to high prices or uncertainties related to energetic fossil supply, and to the environmental conditions of firewood and briquette. Brazil produces around 960 thousand metric tons a year of briquette, originated from 620 thousand metric tons of wood and 340 thousand metric tons of agricultural waste (GENTIL, 2008).

The wooden briquette is a product used to generate heat or power in ovens and in agroindustry boilers, and also in service business like bakeries, pizza shops, hotels and restaurants. It is a self-sustainable, renewable fuel, of low price, with plenty of raw material and production growing 4.4 % a year (PEREIRA, 2006; GENTIL, 2008). In general it is composed of cylindrical parts, with diameter around 10 cm, length of 30 cm and made of densified sawdust. In this process, machine temperature rises up to 300°C, interfering in the chemical and physical structure of wood lignin, making it denser (ROWELL, 1987; PAULRUD, 2004).

On the other side, the wooden briquette is a compact portion of sawdust or shavings, pressed with an average load from 6 tf to 8 tf, tension from 90 kg/cm<sup>2</sup> to 145 kg/cm<sup>2</sup>, what generates temperatures in the range 170°C-270°C in the briquette production camera due to partial decomposition of the lignin (thermoplastic effect) (ROWELL, 1987). The conventional moisture content wet basis is from 5% to 15 %; when the best value is 8 %. Wooden briquettes are produced with density between 1.0 t/m<sup>3</sup> and 1.5 t/m<sup>3</sup>, presented in cylindrical or hexagonal pieces with diameter between 70 mm and 100 mm and length from 10 cm to 40 cm (ROWELL, 1987; PAULRUD, 2004).

After studying several types of biomass, BEZZON (1994) found for sawdust briquettes, average values for high calorific value (HCV) of 20.2 GJ/metric ton, apparent density from 1,120 kg/m<sup>3</sup> to 1,080 kg/m<sup>3</sup> and compression pressure of 20 MPa. This author also registered that the temperature for the biomass thermoplastic effect in the phase of briquette production varies, as in the case of sawdust, from 20.0 GJ/metric ton to 20.4 GJ/metric ton, while temperature rises from 200°C to 250°C.

The high calorific value of briquettes varies according to the type of raw material or other materials used in their processing. The most used sawdust and shavings in the State of Goiás come from coniferous such as the *Pinus sp* with HCV of approximately 21.77 GJ/metric ton and broadleaf trees as the *Manilkara sp*, of approximately 19.26 GJ/t. As an average value for wood calorific value it is considered the value of 19.72 GJ/metric ton (ROWELL, 1987; CRISP, 1999; QUIRINO, 2002; SUAREZ & LUENGO, 2003).

According to GENTIL (2008), the high quality briquette is the slowest burning one, with maximum moisture of 10% wet basis, a maximum high calorific value, resistant to disintegration during transportation or handling, made of shavings and that demand less energy, lower expenses and shorter time for manufacturing.

Although the briquette production is a 148-year-old practice, there are not much information of loads and tensions during the process of compression in the briquette

machines. The result is machine weakness, industrial production interruptions, excessive expenses, and profit losses. For this reason, the goals of this study is to determine the loads and tensions of compression, as well as side efforts in the briquettes.

## MATERIAL AND METHODS

For the development of the calculations and accomplishment of the tests, it was used the Laboratory of Forest Products of the IBAMA in Brasília, the Institute of Physics and the Department of Forest Engineering of the University of Brasília, as well as the installations of the company Eco Industrial Ltd. The last one is situated in the state of Goiás, employing two pulsated briquette machines, for 800 kg and 1,200 kg per hour of nominal capacity, acquired between 15 to 40 years ago, where it is produced 650 metric ton/month of briquette using two pulsated briquette machines with steel made impact pistons diameters of 85 mm and 95 mm.

Two types of briquettes were considered in the study: B1, with the diameter of 85 mm and B2, with 95mm. Both produced from sawdust of *Pinus caribaeae*, var. *hondurensis* originated from a pencil factory in the State of Minas Gerais.

The following Table 1 and 2 presents the characteristics of the materials and methods used in this study.

**TABLE 1-** Characteristics variables of the materials and methods used in the study.

Item	Unit	B1	B2
Nominal flow of the briquette machines	kg/hour	800	1,200
Actual flow from briquette machines	kg/hour	883.9	1,042.7
Diameter of briquette pistons	mm	85	95
Installed source power	kW	50.75	62.52
Necessary power for the motors	kW	50.75	38.00

**TABLE 2-** Characteristics common of the materials and methods used in the study.

Item	Unit	Values
Monthly factory working hours	hours	308
Monthly factory interruption hours	hours	44(14.3%)
Monthly expenses with repair and maintenance	US\$/month	6,030
Monthly expenses with repair and maintenance	% of the cost	7.7
Monthly briquette production	t/month	650
Electric power demand for 2 motors and 2 briquette machines	kW/t	49.73
Total electric power demand for briquette processing	kW/t	65.42
Period for data collection	months	2006
Raw material moisture in the briquette processing	% moisture wet basis	11.11

To determine the impact loads, static and dynamic tensions of compaction, as well as the relation between the necessary energy and the one contained in the briquette, it was used the method developed by GENTIL (2008), according the following equations:

## COMPACTION LOAD AND TENSION IN THE BRIQUETTE PROCESS

In order to determine the necessary tension to convert loose and wet sawdust into solid and dense briquette, it was used the following equation:

$$\sigma_{cs} = \frac{P}{2\pi \times 10^6 f R^2 (D_0 - D_1)} \quad [1]$$

with:

$\sigma_{cs}$  = sawdust compaction tension (MPa).

P = electric motor power (W).

f = steering wheel rotation frequency of the briquette machine (rev/s).

R = briquette radius (m).

$D_0$  = course of the briquette machine piston (m).

$D_1$  = length of the compressed briquette (m).

For the determination of the impact load at the moment of the sawdust densification it was used the following equation:

$$C = 0.010197 \sigma_{cs} A \quad [2]$$

with:

C = impact load in metric ton-force (tf).

$\sigma_{cs}$  = compaction tension (MPa)

0.010197 = conversion factor for MPa $\times$ cm<sup>2</sup> into tf.

A = area of the briquette cross section (cm<sup>2</sup>).

## STATIC MECHANICAL RESISTANCE

For elaboration of charge and densification axial tension formulas in the pulsated briquette machines it was used principles of statics and kinematics. The static and transversal load and tension were determined by the Extended Planar Strength Method, according to ROCHA (2006).

It was found the briquette resistance to perpendicular compression stress along the longitudinal axle, based on the rule proposed by ROCHA (2006), with the following rupture tension formula:

$$\Sigma_{cl} = \frac{10^6 F}{A} \quad [3]$$

with:

$\sigma_{cl}$  = lateral compression tension (MPa).

F = applied load (N).

A = area of the briquette cross section (m<sup>2</sup>).

After considering 1 kgf = 9.80665 N or 1 N = 0.1019716 kgf

The statistic averages were analyzed through variance analysis with 5% of probability, where the load and tension will be considered treatments.

## RELATION BETWEEN PRODUCTION AND RAW MATERIAL ENERGY

The following equation relates the demand of energy in the briquette manufacturing process and the energy obtainable from it:

$$\eta = \frac{100 \varepsilon_1}{\varepsilon_2} \quad [4]$$

with:

$\eta$  = relation between  $\varepsilon_1$  e  $\varepsilon_2$  (in percent).

$\varepsilon_1$  = energy used to manufacture one metric ton of briquette (kWh).

$\varepsilon_2$  = energy available from one ton of briquette (kWh).

## RESULTS AND DISCUSSION

### Impact load and tension of briquette manufacture.

The Table 3 shows that the compaction load upon sawdust to manufacture briquettes of 85 mm of diameter amounts 14.31 metric tons-force and for the ones of 95 mm, 10.19 metric tons-force. Likewise, the compaction tension for briquettes of 85 mm amounts 24.73 MPa, and for 95 mm, 14.10 MPa.

**TABLE 3** - Impact tension and load in the briquette processing.

Piston diameter	Impact load	Tension
(m)	(kgf)	(MPa)
0.085	14,310	24.73
0.095	10,190	14.10

The actual piston course (D0-D1) is 0.05 m in both briquette machines, while the frequency of the steering wheel of B1 is 3.1 rev/s and of B2 is 3.39 rev/s. The briquette machine B1 receives 75.39 % more tension than B2, and the load of B1 is 40.43% higher than that of B2. In other words, the briquette machine B1 is being overloaded both in dynamic tension (MPa) and in dynamic load (tf) for sawdust densification in the briquette manufacture. However, notice that briquette B1, of 85mm in diameter, supports 18.8% more lateral load in the static resistance test. So, briquette B2 demands less tension and impact load, suggesting a longer useful life and fewer machine repairs, though it has less resistance to static load.

The electric motor of briquette machine B1 operates in the limit of the power with a demand of 43.64 kW. The motor of briquette machine B2 operates in a 14 h/day regime. TRIPATHI et al. (1998) shows that the power demand for a briquette manufacture of fine and wet sawdust with production of 750 kg/h is of 41.5 kW, what is close to the value found in this work. The power demand of the B2 machine is already of 33.87 kW, which operates with a briquette flow 18% higher, suggesting that the new machine B2 has a better energetic performance than the B1.

### Mechanical Static Resistance

The Table 4 presents the average results for compression with respect to briquettes with diameters of 85mm and 95mm, expressed in kgf (breaking load) and MPa (tension).

The maximum breaking tension was of 3.843 MPa for the briquette with diameter

of 85mm and of 3.23 MPa for the one of 95 mm, showing that the smaller briquette is 18.86% more resistant to static load.

ROCHA (2006), through a similar method for wooden briquettes, found the value of 4 MPa for the maximum breaking tension, what is close to the one found in this work. Considering the delivery distance of briquettes to consumers, as well as the way in which briquettes are arranged inside the packages, it is reasonable to suppose that those with fewer diameters have stronger resistance to friability and therefore a higher fraction of undamaged product could reach the destiny. This would be a commercial advantage, as they could be delivered to more remote places.

**TABLE 4 - Results of lateral compression of briquette**

<b>Diameter</b>	<b>Lateral Load (kgf)</b>	<b>Tension (MPa)</b>
85 mm	2,224 (5,17)*	3.843 (23,56)
95 mm	2,337 (4,91)	3.233 (32,57)

\*valores entre parênteses – coeficiente de variação

Variance analysis shows no significant difference between briquettes of 85 mm and of 95 mm in diameter, in a level of 5 % of probability, to lateral load and tension.

#### **Relation between demanded energy for briquette production and briquette net calorific value (NCV)**

The energy consumption to manufacture one metric ton of briquette is of 435 kWh/t and the amount of net calorific value (NCV) obtainable from briquettes with moisture content wet basis of 12.9 % is of 4026.7 kWh/t. So, the relation between them is  $\eta = 10.8\%$ .

While evaluating wood in British Columbia-Canada, MANI (2006) found values of 22 % for the industrial energy necessary to manufacture one metric ton of pellet, with respect to the energy contained (NCV) in the sawdust used for its manufacture. This difference can be attributed to wood residue of less calorific value or to lower energetic efficiency in the industry. QUIRINO (2002) registers that for a caloric value of 5440 kWh, it is demanded 26.4 kWh, what represents a relation of 4.85%; HIRSMARK (2002) found 13 % for demand of energy, regarding to the wood energetic potential, though he did not mention which sawdust was used.

#### **CONCLUSIONS**

During the wood briquettes manufacturing, and for those with a diameter of 85 mm, the axial load impact briquetting machine was 70% higher compared to briquettes with a diameter of 95 mm and in the same industrial process. Regarding the lateral load impact tested between the briquettes, there was no statistically significant difference between the diameters of 85mm and 95mm.

The difference of briquette compaction tension in both machines, 24.73 MPa and 14.10 MPa, shows that the one with the highest value, B1, tends to break easier and more frequently. Likewise, the impact tension between both of them, of 14,310 kgf in B1 and 10,190 kgf in B2, confirms the tendency that one of them can break easier, since the briquettes have the same characteristics.

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