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A mathematical model of chopped Miscanthus briquetting process

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Abstract

This article presents the experimental results of working regime and products obtained from chopped Miscanthus in order to ensure a high energetic capitalization of this plant. The technological system of obtaining briquettes of powdery Miscanthus compressed and at the same time, their qualities are presented. At the same time, notations on Miscanthus briquettes behavior during the time are made. A formula, expressing the quality of product obtained in terms of working process characteristics, is given. Presented material offers suggestions and new directions of continuing the experiments on improving the technological process and briquettes quality.

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Keywords: briquettes; green energy; Miscanthus x Giganteus; mathematical modelling.

1. Introduction

Renewable energy resources represent one of the priority directions in all domains of research, an emphasis being lately put on agriculture. Valorization of high energetic potential plants, easy to cultivate and maintain is a source of assuring the local energy requirements, both in terms of heating and of performing different technological small processes, which are run in small farms (drying plants, smoke houses, etc.), [1]. Miscanthus being one of the most spread plants used for this very purpose. Miscanthus species used in the experiments was Miscanthus X Giganteus,

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culture exists in the experimental land of INMA Bucharest. The culture is harvested using a specialized equipment driven by the power take-off of a 60 kW agricultural tractor. (Fig. 1). Attempts of transforming this plant in briquettes frame within a wide range where different wood sawdust and wood chips were studied by [2].

Fig.1. Miscanthus X Giganteus

Biomass represents the whole vegetal agricultural production which can be converted in different forms of energy, [3]. The agricultural production comprises the principal production and the secondary production.

Main agricultural vegetal production is converted to bio alimentary energy and secondary agricultural vegetal production represents the principal source of biomass to be transformed in thermal energy.

According to European Union regulations, biomass represents the biodegradable share of products and wastes from agriculture, forestry and related industries, as well as biodegradable fraction from municipal and industrial wastes.

Main chemical composition of biomass is:

- lignin ($C_{40}H_{44}O_6$) = 15 – 30%;
- cellulose ($C_6H_{10}O_5$) = 40 – 45%;
- hemicellulose= 20-35%.

Variation limits of the main three components are determined by respective species. Cellulose long polymers are used by plants for creating fibers, which offer the plant solidity, and lignin acts as a binder for cellulose fibers, [4]. In order to manufacture the pellets the lignin content has to be as high as possible. For a high caloric power it is necessary that ratios O/C and H/C be as small as possible.

Researches try to answer the questions upon which the scarce content of lignin would make this plant briquetting impossible. During tests, chopped Miscanthus briquettes (powdery material) with a rather good stability have been obtained and which could be used by [5], if they were packed within a couple of days after manufacturing. This paper will provide estimations of period of time within which briquettes keep their stability and methods to be used, such as different packing techniques, possible biodegradable materials (paper of polymers coming from food industry waste), which could prolong this period. Transformation of Miscanthus powdery material in pellets has already been tackled at world level.

2. Materials and methods

Starting from the raw material made of chopped Miscanthus (powdery material) of 1.6 mm granulation, it is aimed to obtain cylindrical briquettes in a compacting (pressing) matrix by means of a piston cylinder (Fig. 2).

At the beginning of compressing process, the compressed biomass exit end is maintained closed till reaching piston limit pressure [6], after which, the exit end is opened and the briquette slowly leaves the tube. The bench used in obtaining Miscanthus briquettes is represented by an universal traction-compression machine, model MDW-100, assuring a maximum force of 100 kN and giving the possibility of control through its own computer (Fig. 3). For driving the piston, a mechanical traction/compression machine electrically operated is used, its measuring (working) domain being of 0-100 kN; the installation is endowed with a computerized system allowing to command and control the piston displacement speed, as well as register the diagram of force-deformation of briquette in course of being formed.

Inlet material (raw material, chopped Miscanthus) has a value of mass density of 132.69 kg/m^3. Particle density of the sample was measured by a method adopted by [7]. This chopped matter (powdery material) is obtained by Miscanthus stems and leaves finely broken up. Powdery material has been introduced in briquetting at 10% humidity and a constant temperature of 15^{o}C, the length of initial column of material subdued to compacting process being of 0.3 m, with a total mass of 0.05 kg. Mass of material processed is preserved during briquetting.

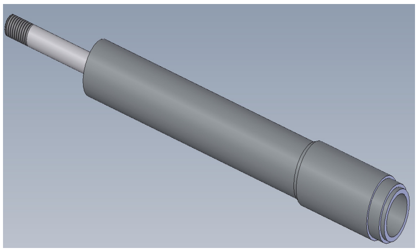

Fig 2. Cylinder with piston for compressing biomass

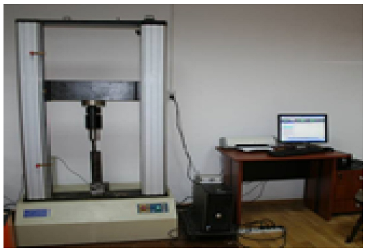

Fig. 3. Aspects of the roadway

Within the briquetting tests, the pressing force (the piston pressure, implicitly), the loading speed, the material flow granulation and humidity have been varied, reaching pressing forces between 40 and 90 kN. Piston driving speed is framed within 1 and 6 mm/s, the piston pressing force and driving speed being the two parameters used for the process. Within the compacting process there are lots of control parameters, which can be varied according to working conditions (compacting temperature, lubrication, etc.), the parameters taken into consideration being the above ones, which influence the most the process. Parameters which give the obtained briquettes quality are: height, density,[8] Shore hardness, (at lower and upper part) and loosening in time. For establishing the technological process basis, the qualitative parameters variation related to command parameters has been aimed.

3. Results

Running the experiments under the conditions described above we have obtained chopped Miscanthus briquettes. The initial raw material from which we obtained the briquettes has the granulation obtained through sieving with plane sieves and is represented in figure 4. In figure 5 is presented a detail of a Mischantus chopped briquette for a visual presentation of the Miscanthus particles cohesion.

Fig. 4. Initial material and briquette obtained

Fig 5. Detail of a briquette from Miscanthus powder

Variation of qualitative parameters referring to command parameters

One of the most important problems in substantiating a technology is to establish theoretical relations or theoretic-empirical relations between product quality parameters and control and command parameters, possibly the material initial parameters too. Another important component in technology substantiation is to establish the relations characterizing the process in terms of mathematical and energetic background. These relations together with the qualitative parameters form a mathematical ensemble enabling to estimate the performances of process of compaction of technology. The results which can be obtained using this mathematical ensemble enable the comparison of this technology and its results with similar goods producing technologies.

Graphs performed in compliance with experimental data are not recommended, because many tests: 78 were made and several parameters (4) were varied, sorting by classes being not advisable. Only a simple statistic characterization of experimental data should be done, and then the interpolation, the diagrams are established on interpolation formulae grounds.

The first conclusions on the relation between different categories of parameters can be obtained by studying the correlations between control parameters and quality or performance parameters. A list of values regarding the command parameters(piston force and movement speed) correlation and quality vectors of the process (density upper and lower part hardness and loosening after. 1 and 4 days) are shown in table 1.

Table 1 Values of corelations between experimental vectors of initial parameters of control and command and process quality vectors.

	Density	Hardness at upper part	Hardness at lower part
Pressing force	0.699	0.654	0.619
Piston displacement speed	0.005	0.029	0.057
Granulation	-0.059	-0.061	-0.179
Humidity	0.484	0.324	0.434

Correlation values show that the pressing force is the main active parameter in Miscanthus briquetting, the density and hardness acquired during the process directly depending on pressing force applied. Piston displacement speed is a weaker parameter related to quality parameters, but nevertheless significant. Granulation influences relatively little the process, but correlations have shown that a greater granulation leads to lower quality briquettes, and humidity [9], is also significantly involved in briquettes final quality.

One of the most important goals aimed by the authors was to find a calculation formula or several calculation formulae which connect the inlet and outlet parameters of briquetting process. Otherwise said, the main goal of theoretical-empiric study, [10] is mathematical modeling for applicative purpose of briquetting process. Final stage of mathematical model is represented by its utilization for process command and control in order to achieve an optimum process, namely a product of appropriate quality and minimum energetic consumption. For the time being, the mathematical model is built following elementary experiences and, in fact this model will grow during the time, but any other superior model should include this elementary model, if it is valid.

Biomass briquetting is defined by many random factors, being a process working with an initial material hard to be framed in a certain category (solid, gas, etc.) Furthermore, the materially changes its density during the process, or processes of this kind are less modeled in specialty literature, the density modification being important, because it grows by 6 – 7 times up to the end of process.

As a result of these physical features of briquetting process, which, in fact is a process reverse to wood destroying process by chopping, process irreversible in nature, mathematical modeling by classic models of mechanics and thermodynamics is difficult to access. Knowing the rheological behavior of powder, determination of constitutive equation should require an ample and costly experimental study. Furthermore, once determined an approximate constitutive equation there is the possibility that it could be redundant because its complex form or instabilities coming from its presence in numerical processes of solving the mathematical model.

Taking into account the reasons above, we have chosen a simple model, suggesting a mathematical relation of the form:

$$\rho = \rho_0 \left(\frac{F + F_0}{F_0} \right)^{\alpha} x \left(\frac{v + v_0}{v_0} \right)^{\beta} x \left(\frac{\phi}{\sqrt{rh}} \right)^{\gamma} u^{\eta} \tag{1}$$

Where:

- ρ (in kg/m^3) is current density of briquette,
- ρ_0 (in kg/m^3) is initial density of briquette raw material,
- F (in N) is the pressing force,
- v (in m/s) is piston displacement speed,
- ϕ is granulation (in m),

- u is material humidity (in decimal fractions),
- $\alpha, \beta, \gamma, \eta$ non-dimensional exponents,
- F_0 and v_0 are a force (in N) and a speed (in m/s) conventionally formed from process parameters in order to make the product (1) parameters relative according to power α and β.

Relativity is made for allowing to exponents α and β to take real values without influencing the formula dimensional consistency. For force F_0 we considered the expression of force of gravity of Miscanthus powdery mass introduced, and for speed v_0 we considered the speed value of a particle of powdery matter in a resistant environment which is, in fact the powder itself:

$$F_0 = mg \quad , \quad v_0 = 0.1 \tag{2}$$

Where:
- m is the mass of powder introduced in the process,
- g is local gravity acceleration,
- h is the powder column height initially introduced in the pressing tube.

Using the experimental results and minimizing the functional:

$$\Im(\alpha, \beta, \gamma, \eta) = \sum_{i=1}^{N} \left(\alpha \ln \left(\frac{F_i + mg}{mg} \right) + \beta \ln \left(\frac{v_i + v_0}{v_0} \right) + S_i \right)^2$$
$$S_i = \gamma \ln \frac{\phi_i}{\sqrt{rh}} + \eta \ln u_i + \ln \rho_0 - \ln \rho_i \tag{3}$$

Where N (for this case 78) is the number of briquetting tests performed, and ln is the symbol of natural logarithm, for the four exponents, the following values are obtained: α= 0.183, β= 0.248, γ= -0.006801, η= 0.184. These exponents are non-dimensional.

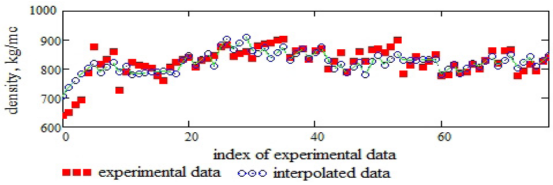

Fig. 6. Distribution of data interpolated in comparison with experimental data

Distribution of data interpolated by the least square method, as it was described above, in relation with experimental data, is shown in figure 6. If one takes into account that:

$$m = \pi r^2 h \rho_0 \tag{4}$$

Then, the formula (1) may be written in a form which also contains the compressing cylinder data:

$$\rho(F, v, \phi, u, \rho_0, r, h) = \rho_0 \left(\frac{F + \pi r^2 h \rho_0 g}{\pi r^2 h \rho_0 g} \right)^{\alpha} x \left(\frac{v + v_0}{v_0} \right)^{\beta} x \left(\frac{\phi}{\sqrt{rh}} \right)^{\gamma\gamma} x u^{\eta} \tag{5}$$

Function of density of briquette becomes a function of process and control parameters, F, v, and of initial material parameters, ρ_0, ϕ , u and parameters of cylinder where the compressing process takes place r (cylinder radius) and h, the height of material initial column. If, both the numerator and denominator of factor are raised to α power, then the final density can be expressed as depending on the current pressure on briquette upper surface.

$$\rho(F, v, \phi, u, \rho_0, r, h) = \rho_0 \left(\frac{p + h \rho_0 g}{h \rho_0 g} \right)^{\alpha} x \left(\frac{v + v_0}{v_0} \right)^{\beta} x \left(\frac{\phi}{\sqrt{rh}} \right)^{\gamma\gamma} u^{\eta} \tag{6}$$

Where p is the pressure exercised by piston on upper surface of briquette in course of being formed. A similar function can be obtained for briquette hardness, both at upper part and lower part.

We can get a similar result for Shore hardness at upper part or lower part of briquette. Thus, for lower part hardness, we obtain the formula:

$$\delta_i\left(F, v, \phi, u, \rho_0, r, h\right) = d_{0i}\left(\frac{F + \pi r^2 h \rho_0 g}{\pi r^2 h \rho_0 g}\right)^{\alpha i} x \left(\frac{v + v_0}{v_0}\right)^{\beta i} x \left(\frac{\phi}{\sqrt{rh}}\right)^{\gamma \gamma i} x u^{\eta i} \quad (7)$$

Where $\alpha_i, \beta_i, \gamma_i, \eta_i$ are non-dimensional exponents calculated by the least square method, similarly to calculation formula designed to briquette density, (5), δ_i is briquette hardness at lower part, and d_{0i} is average experimental value of Shore hardness on briquette lower part. Values of four exponents of formula (7) are: 0.055, 1.176, -0.028, 0.372, and average value of experimental hardness, d_{0i}, is 69.449 Shore degree. For the upper part hardness of chopped Miscanthus briquettes a similar formula to (7) is obtained, exponents taking one after the other the values of: 0.054, 0.854, 0.012, 0.296, and average experimental value which appears for the first factor, is of 55.372 Shore degree. Comparison between the experimental data and data interpolated in relation to formulae above (7), for upper and lower hardness, can be estimated by graphic representations in figure 7 and figure 8. From the two diagrams we can observe the high degree of correlation between the experimental and interpolated data.

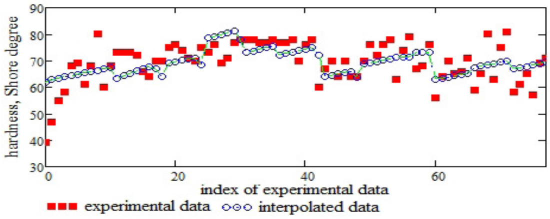

Fig. 7. Distribution of data interpolated in comparison with experimental data, in terms of briquette lower part hardness

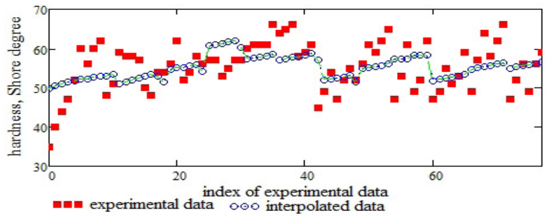

Fig. 8. Distribution of data interpolated in comparison with experimental data, in terms of briquette upper part hardness

In order to understand, the manner in which quality (performance) parameters vary, a few graphs are useful. In Appendix figure 9 - 12, are given one by one the dependences of final average density of the briquette on parameters: F, v, r, h, ϕ , u and ρ_0. Dependences are graphically represented for extreme values of pressing force during experiments, this being the main command parameter and the most important.

Graphs of the same values characterizing the process performances are also possible in two dimensions, namely as surfaces. But, they are not very spectacular.

Similar graphs can be performed for briquette hardness and for their loosening in time. Knowing these properties of briquettes is essential for adjusting the technological process so that they resist during maneuvering and storage enough to the final use and commercialization.

Furthermore, the energetic consume required by briquetting and especially the mechanical work for compression, can be calculated and hence the costs.

4. Conclusions

Technological process for obtaining chopped Miscanthus briquettes can be mathematically modeled through models which connect the input parameters (density, granulation and humidity of raw material) to the output qualitative parameters (briquettes density, hardness and loosening) and geometry of briquetting matrix (cylinder diameter, height of raw material column when starting), respectively to control parameters of process (force and movement speed of the piston).

Interpolation functions found out have shown that briquettes density varies almost linearly with force, but also with piston movement speed (Appendix, fig. 9 and fig.10).

Final density of briquettes decreases while the pressing cylinder radius grows and column height of material to be pressed increases (Appendix, fig. 11 and fig.12). Final density also diminishes along with increment of raw material granulation, but by a less intensity rate than other reductions (Appendix, fig. 13). At the same time, briquettes final density increases along with humidity and initial density of raw material (Appendix, fig. 14 and fig.15).

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Appendix A.

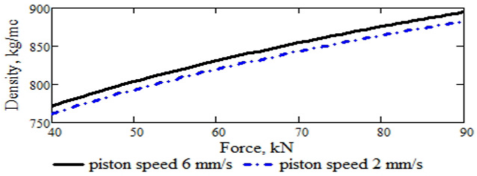

Fig. 9. Variation of briquette final average density with material pressing Force in cylinder

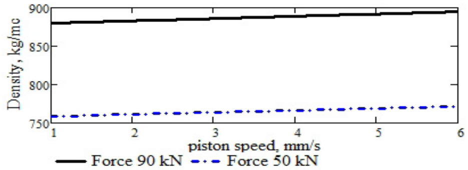

Fig. 10. Variation of briquette final average density with piston displacement speed

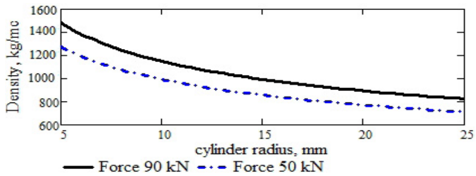

Fig. 11. Variation of briquette final average density with cylinder radius

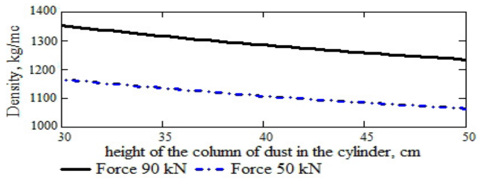

Fig. 12. Variation of briquette final average density with cylinder height

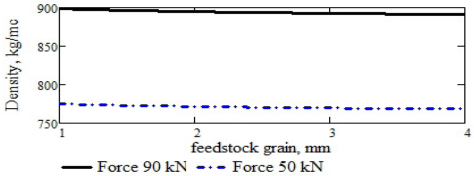

Fig. 13. Variation of briquette final average density with raw material granulation

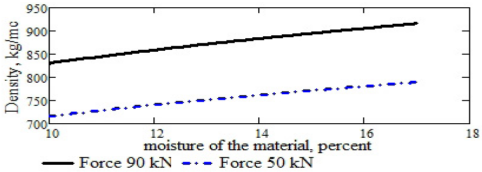

Fig. 14. Variation of briquette final average density with raw material humidity

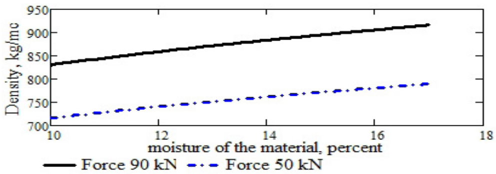

Fig. 15. Variation of briquette final average density with average density of raw material

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