IMPACT OF PRESSING CHAMBER CONICALNESS ON THE QUALITY OF BRIQUETTS PRODUCED FROM BIOFUELS IN BRIQUETTING MACHINES

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In this paper we analyze the impact of conicalness (an important structural parameter of pressing chambers) on the quality of briquettes made from solid biofuels. Besides the known impacts of the technological parameters of the pressing process on the quality of the briquettes, it is also important to pay attention to the structural parameters of the pressing chamber. A theoretical analysis of pressing chamber conicalness is presented. An experiment aimed at detecting the impact of conicalness on the quality of the briquettes was performed. The results show that increasing the conicalness of the pressing chamber improves the quality of the final briquettes. The conicalness of the pressing chamber influences significantly the construction of briquetting machine.

Keywords: biomass, briquetting, pressing chamber shape, pressing chamber conicalness

Received 25. 6. 2012, accepted 17. 12. 2012

1. Introduction

Briquetting is a complicated biomass treatment. Many parameters influence the process and the quality of the final briquettes. Briquette quality is evaluated by mechanical and chemical-thermic indicators that are defined by EU standards.

The most important quality indicator is the briquette density. Briquette final density is influenced by many parameters. On the basis of the experience that we have acquired and the analyses that we have made, we can divide the parameters into the following three groups [3]:

- material parameters of the pressed biofuel
- technological parameters of the process
- structural parameters of the pressing chamber

2. Decisive parameters of the briquetting process

The material parameters emerge from the properties of the pressed material, i.e. material moisture, chemical composition, fraction size, etc.

Among the technological parameters belong pressing temperature, compacting pressure, compacting speed, holding time, etc. These parameters can be changed in the course of the pressing according to the capabilities of the briquetting machine.

The structural parameters of the pressing chamber are also very important. For successful pressing of high-quality briquettes, all the parameters have to be in synergy. For an engineer, it is very important to know the behaviour of all parameters. We know that pressing temperature, material moisture, compacting pressure and fraction size are very important for briquetting. We can obtain briquettes of suitable quality by adjusting the optimal values of these parameters according to the material that is to be pressed. We know that we can achieve better results by changing some of the structural parameters of the pressing chamber. It is very desirable to optimize the geometry of the pressing chamber. The main structural parameters influencing the final briquette density are [2, 6]:

- the diameter of the pressing chamber
- the length of the pressing chamber
- the conicalness of the pressing chamber
- the friction coefficient between the chamber and the pressing tool
- the length of the cooling channel
- the counter pressure in the pressing chamber (created in various ways).

We have designed an experimental pressing stand (see Fig. 1) with which we are able to perform experiments to detect the impact of each of the parameters listed above.

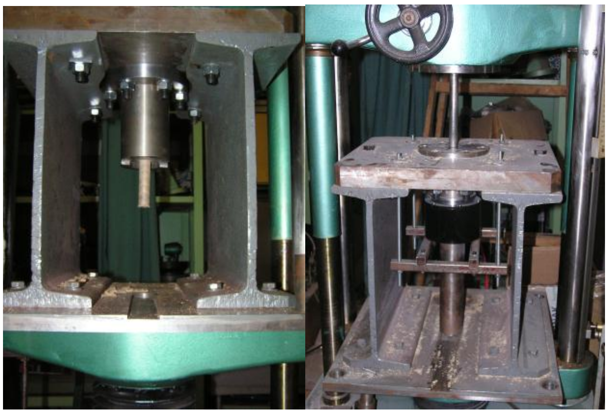


Fig. 1 Experimental pressing stand [3]

In this paper, we present our findings on the impact of changes in the conicalness of the pressing chamber on the density of the briquettes. A pressing chamber with a conically-shaped wall is very often used in briquetting and pelleting machinery.

However, we know of no studies that clearly show the interaction between the changes in pressing chamber conicalness and the changes in the final density of the briquettes.

3. Theoretical analysis of the impact of conicalness of the chamber on the pressing process

The geometry of the pressing chamber is very important in briquetting. However, few studies of the briquetting process have shown the influence of individual parameters of this process, taking into account the pressing conditions in the pressing chamber during briquetting. The results presented in this paper are based on our experience, and on a comparison between our experimental results and analyses, on the one hand, and the existing mathematical model of pressing, on the other.

We have attempted to find equations or mathematical models that can be used for calculating the pressing conditions in the pressing chamber. In [1], Horrighs offers a clear description of the pressing conditions in a cylindrically-shaped pressing chamber. This theory is represented by the following mathematical model:

$$p_G = p_k . e^{-\frac{4.\lambda.\mu.H}{D_k}} \quad \text{[MPa]} \qquad (1)$$

where p_G is the counter pressure in the chamber, p_k is the axial pressure of the hydraulic press, λ is the ratio of the main strains σ_r / σ_m , and μ is the friction coefficient, H is the length of a pressed briquette and D_k is the diameter of the pressing chamber.

The situation regarding the pressing conditions in the conical chamber is somewhat complicated. The pressed material in the chamber is subjected to multi-axial pressing. This increases the pressing quality: it increases the briquette density and also the mechanical properties of the briquettes. However, the tool wear is also increased. We have often replaced a cylindrical pressing chamber by a conical pressing chamber and obtained briquettes of higher density. However, there is no mathematical model for a conical pressing chamber. We are therefore attempting to design a mathematical model for a conical pressing chamber.

We base our model on the theory of forward extrusion [4] which is a basic metal volume moulding technology. Force and pressure distributions in forward extrusion are very close to the force and the pressure distributions in biomass briquetting. A simple scheme of the main parts of a conical pressing chamber is shown in Figure 2. This type of pressing chamber is often used in briquetting machines. The pressing chamber consists of three basic parts – a cylindrical part, a conical (reductive) part and a calibration part.

The material is filled into the cylindrical part and then starts to be compacted by the pressing piston. The main pressing of the material takes place in the conical part.

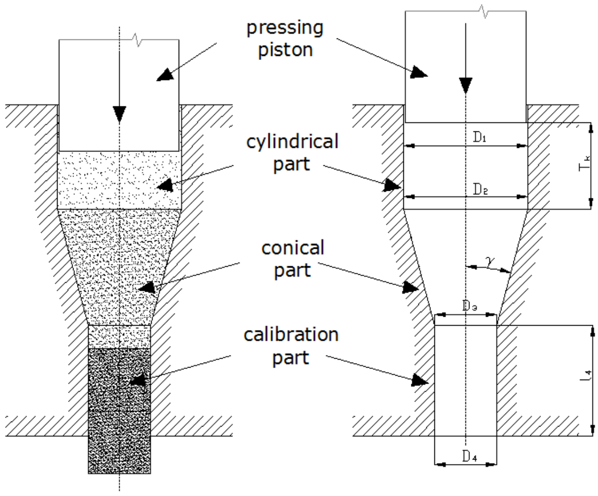


Fig. 2 Main parts of a conical pressing chamber [2, 4]

The pressure and the conical chamber cause a multi-axial pressing effect. Some holding time while the pressed briquette is under pressure is necessary in order to eliminate pressing expansion. The calibration part gives the final shape to the briquette and provides the holding time under pressure and temperature.

Figure 3 provides a better description of the pressing conditions in a conical chamber, and shows all the acting forces and pressures. The maximum attained axial pressure P_K depends on the length of the pressing chamber L, on the shape of the pressing chamber, on the size of the vertex angle of the conical chamber, and on the friction conditions between the pressed material and the wall of the chamber.

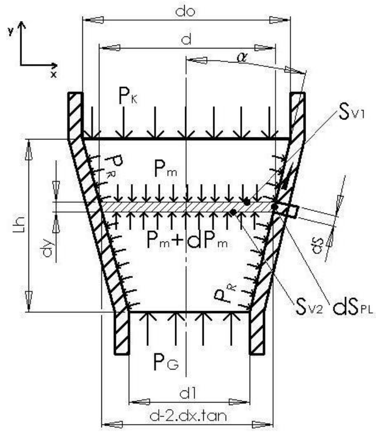


Fig. 3 The pressing conditions in a conical pressing chamber [5, 6]

P_K – axial pressure of press (MPa), P_G – counter pressure in chamber (MPa), P_R – radial pressure (MPa), P_M – axial pressure on the briquette (MPa), d_0 – input diameter of the pressing chamber (mm), d_1 – output diameter of the pressing chamber (mm), d - diameter of the pressing chamber in cross-section (mm), μ - friction coefficient (-), L - length of the conical part of the pressing chamber (mm)/

The surface friction drag is given by the radial pressure P_R, by the cross factor of pressure P_M, which affects the wall of the chamber, by the friction coefficient μ, and by the length of the pressing chamber L. The diameter of the chamber decreases linearly according to the length of the chamber L.

For a description of the pressing process, we have to start with a description of the pressures acting on an element of dx thickness cut in a conical shape (see Figure 4). In the vertical direction, the axial compacting pressure P_M, acts in the opposite direction to the elicited pressure P_M+dP_M. Friction increases the pressure perpendicular to the wall of the chamber P_R.

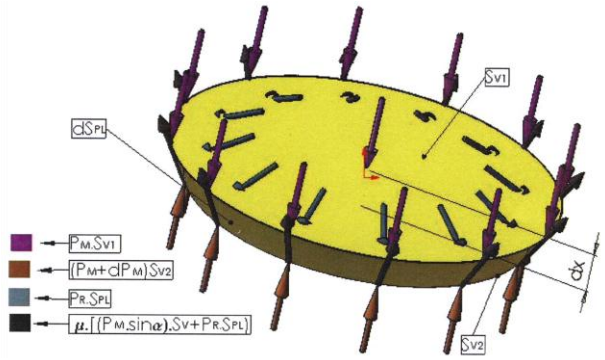


Fig. 4 Pressure distributions in space [7]

To make a balanced equation, we will need to know the sizes of the surfaces on which the pressures act. On the basis of the plane pressure distributions (see Figure 5), we were able to write the following equation (2):

$$P_M.S_{V2} + P_M.S_V - (P_M + dP_M).S_{V2} - \mu.(P_R + P_M.\sin\alpha).dS_{PL}.\cos\alpha = 0 \quad (2)$$

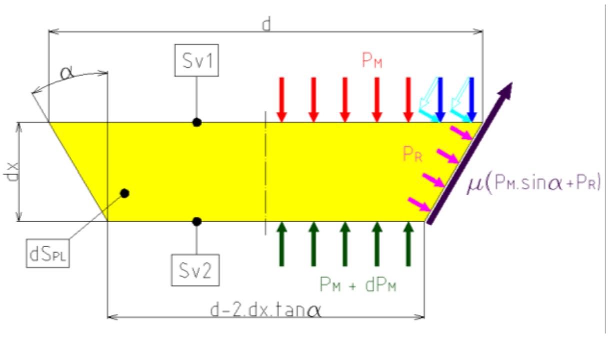


Fig. 5 Plane pressure distributions on a conically-shaped element [7]

In order to implement equation (2) it will be necessary to define the boundary conditions and to define the final shape of a mathematical model suitable for optimization methods. This mathematical manipulation has not yet been finalized, so we are not yet able to present a mathematical model for a conical pressing chamber.

4. Experiments to measure the impact of conicalness on the density of the briquette

We attempted to measure the relationship between changes in pressing chamber conicalness and the final briquette density. For this experiment we used an experimental pressing stand. It was necessary to prepare some new components: new chambers with different wall conics (see Figure 6).

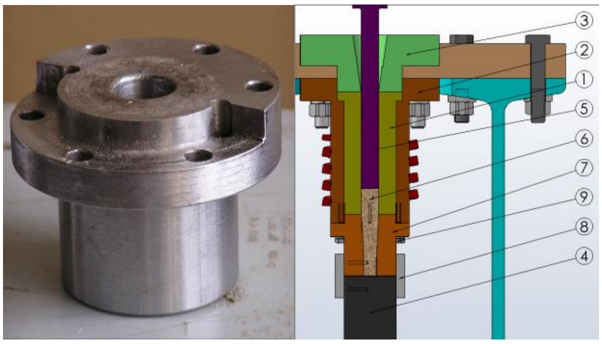


Fig. 6 Example of a new chamber with a conical wall (left), and the cross-section of pressing stand (right)
1 - pressing chamber; 2 - flange; 3 - start-up chamber; 4 - counter plug; 5 - piston; 6 - pressed material; 7 - chamber with a conical wall; 8 - sleeve connector; 9 - mounting screw/

For the experiment we prepared three new chambers with 1°, 2° and 3° degree conic walls. The results were evaluated in terms of the final briquette density. We compared briquettes pressed in a conical chamber with briquettes pressed in a cylindrical chamber under the same conditions.

Fig. 7 Negatives of internal chamber space representing different geometries

We chose the following conditions for the experiment: pressed pine sawdust material, material moisture 8 %, fraction size 1 mm, compacting pressure 159 MPa. The pressing was done without the use of additional heating equipment, i.e. without a pressing temperature effect. The measurements were carried out in laboratory conditions, at a temperature of 20 °C. For each setting we pressed 7 briquettes. These were measured, and then we were able to calculate their density. Table 1 shows the results, with only the average briquette density value. The average values were compared.

For pressing without additional heating (under laboratory conditions) we did not obtain any briquettes. The first column in Table 1 (20 °C) therefore only shows the briquette density obtained by pressing with a cylindrically-shaped chamber. The problem was the very high friction force between the pressed material and the chamber wall.

Table 1 Experimental results – density of pressed briquettes, in kg/dm^3

	T_1 = 20 °C	T_2 = 85 °C	T_3 = 120 °C
α = 0 °	0.852	1.152	1.207
α = 1 °	-	1.221	1.216
α = 2 °	-	1.236	1.224
α = 3 °	-	-	-

* *α represents the conicalness of the chamber*

The pressing forces in the pressing chamber are distributed as a laminar flow in a cylindrical pipe (see Figure 8, left). The maximum axial pressing force is applied in the axial axis of the pressing chamber, see Figure 8, right.

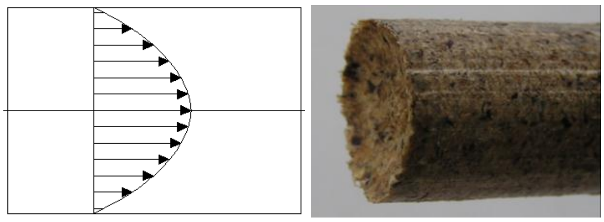


Fig. 8 Pressing force distribution across the pressing chamber

The experimental pressing stand is inserted into the hydraulic press, which can exert a maximum pressing force for 10 tons. In our case, this corresponds to the compacting pressure of 318 MPa. We used also the maximum pressure, but without success.

From our experience, we know that the friction force for briquetting can be reduced by lignin plastification. The friction force can be reduced by increasing the pressing temperature. For this purpose, we used heating equipment affixed to the pressing chamber. The heating equipment was controlled by a regulator that worked on the basis of a signal coming in from the temperature sensor. Lignin is a material component of all types of biomass. In the briquetting process, it has the function of a gluing medium, strongly joining the particles of the material into a compact briquette.

We then decided to repeat the experiment at a different pressing temperature. The results are presented in Table 1. With a higher pressing temperature we were able to obtain briquettes. The data show that at each temperature level the briquette density increases as the wall angle in the chamber increases. We also proved that increasing the pressing temperature has a positive impact on the friction forces between the pressed material and the chamber wall. However, we found that a chamber with a 3° wall cannot be used in our conditions. The experiment with this chamber was not successful, because the mounting screws were destroyed during pressing. The maximum strength of the hydraulic press was also insufficient to extrude the pressed briquette from the conical chamber. During the second squeezing, the screws were destroyed.

Another interesting finding during the experiment was that we were able, during pressing, to recognize three compacting pressure values. The first value represents pressing, the second represents overcoming the friction force, and the third represents extruding the pressed briquette from the chamber. The following figures present a graphic record of these three pressure values, as recorded by the hydraulic press.

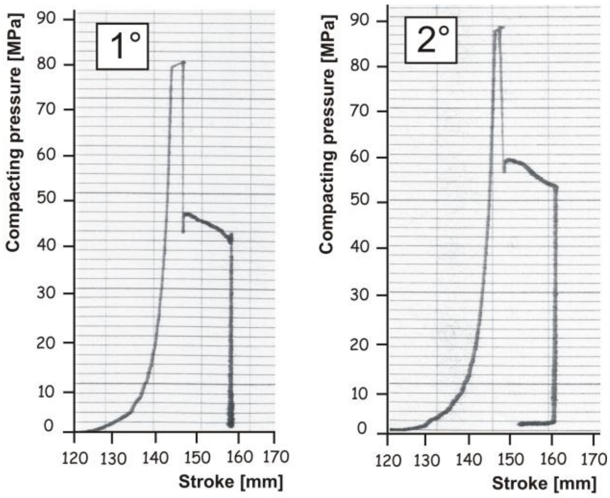


Fig. 9 Graphic record of briquette pressing in conical chambers at 120 °C pressing temperature

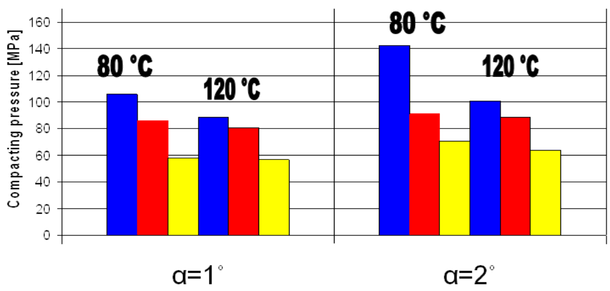


Fig. 10 Comparison of recognized pressures for pressing in conical chambers

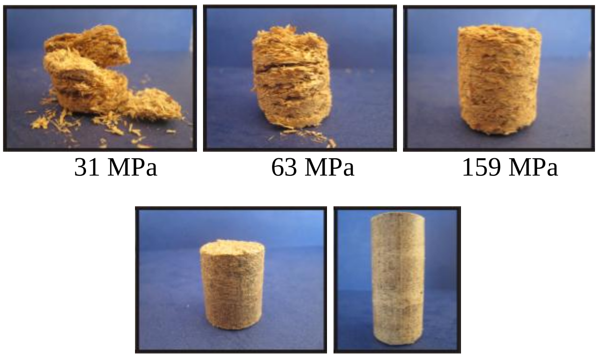
Blue columns represent the pressure needed to overcome the friction force, red columns represent pressing, and yellow columns represent the pressure needed to extrude the pressed briquette from the chamber

These figures show that during pressing in a conical chamber the acting pressures are higher than acting pressures in a cylindrical chamber. This proves that higher briquette density can be obtained by pressing in a conical chamber. We can state that it is possible to increase the pressures acting in the chamber by increasing the degree of conicalness of the chamber. However, it can be seen that in a conical chamber with a higher degree of conicalness, higher friction forces are generated. The friction forces can be reduced by using a higher pressing temperature. As the pressing temperature increases, the compacting pressure action decreases.

5. Conclusion

The main aim of this paper has been to present the results of our experiment to detect the impact of the conical shape of pressing chambers on the density of the briquettes. We also wanted to show the importance of this type of parameter for the briquetting process. In the near future, we aim to design a mathematical model for a conically-shaped pressing chamber. Of course, more experiments will be needed. With this model, we will be able to calculate the optimal length of a conical pressing chamber in accordance with the standards for the final density of briquettes.

Solely for a demonstration see the following Figure 11 where you can see the impact of applied compacting pressure. Below of each briquette is the value of the compacting pressure with which was the briquette pressed. These briquettes were made in a cylindrical pressing chamber.



31 MPa 63 MPa 159 MPa

191 MPa 254 MPa

Fig. 11 Impact of resizing of applied compacting pressure [2]

Nowadays, there are not many sources and analyses dealing with the mathematical description of the briquetting process, dealing with the influence of various parameters on the final briquettes quality. It is clear that the impacts of constructional parameters of the pressing chamber on the briquetting process are complicated and require a detailed analysis.

Figure 12 shows geometries of pressing chambers which are usually used in compacting machines.

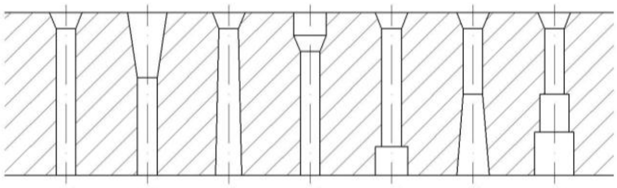


Fig. 12 Various geometries of pressing chambers used at biomass compacting
a) normal, b) deep, c) flat, d) water well, e) cylindrical, f) spherical, g) stepped/

Each geometry has its own specific shape that affects the distribution of the pressures in pressing chamber and the final quality of briquettes. Each shape of pressing chamber is suitable for a specific type of pressing material. Therefore it is necessary to research the influence of pressing chamber constructional parameters on the biomass compacting process and on the quality of the resulting briquettes. Research and optimization of the pressing chamber geometry for biomass briquetting will enable to design an energy efficient briquetting process that will produce high quality briquettes.

Acknowledgment

This paper is an outcome of the project “Development of progressive biomass compacting technology and the production of prototype and high-productive tools” (ITMS Project code: 26240220017), on the basis of the Operational Programme Research and Development support funding by the European Regional Development Fund.

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Summary

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Impact of Conical Pressing Chamber on the Final Quality of Solid Biofuels in Briquetting Machine

In this paper, we will present the impact of the conical shape of a pressing chamber, an important structural parameter. Besides the known impact of the technological parameters of pressing chambers, it is also very important to pay attention to their structural parameters. In the introduction, we present a theoretical analysis of pressing chamber conicalness. An experiment aimed at detecting this impact was performed at our institute, and it showed that increasing the conicalness of a pressing chamber improves the quality of the final briquettes. The conicalness of the pressing chamber has a significant effect on the final briquette quality and on the construction of briquetting machines. The experimental findings presented here show the importance of this parameter in the briquetting process.