Shape of the Briquetting Press Tool as an Important Parameter during Solid Biofuels Production

Peter Križan*, Miloš Matúš, Juraj Beniak, Jozef Bábics

Slovak University of Technology in Bratislava, Faculty of Mechanical Engineering, Nam. Slobody 17, 812 31 Bratislava

***Abstract*: The aim of the present paper is to present an analysis of the shape of a briquetting press tool on parameters in the pressing chamber that directly influence the resulting quality of solid biofuels. In nowadays the pressing tools and densification machines producers are step by step improving the theory of structural parameters effect. But each is dealing only with the individual situation regarding the producing tools. Meaning of this study is to present the general view on this important issue. Theoretical analysis points out the importance of dimensioning parameters of the pressing tools during briquetting and hence the necessity to consider in the engineering the direct influence of the tools shape and dimension design on the quality of solid biofuels. Authors would like to present the importance of volume-surface ratio which influence the tool wearing and production process. According to the knowledge from practice the effect of pressing chamber comicalness and effect of pressing chamber shape is calculated with using the volume-surface ratio. These calculations were applied on various shaped chambers and also original author´s design of pressing chambers were compared with usually used shapes of briquetting chambers.**

Keywords: **densification, pressing piston, screw, nozzle, tool geometry, solid biofuels, particle density**

I. INTRODUCTION

The production of solid biofuels is a suitable way how to recover biomass in an energy-efficient way. To ensure the production, sale and distribution of solid biofuels, technical standards [1, 2, 3, 4] have been developed, which define the quality of solid biofuels. In principle, solid biofuels are considered to be of good quality if they meet the values given by the technical standards. Technical standards define several parameters (indicators) on the basis of which the quality of solid biofuels is assessed. Biomass treatment, where densification belongs, has an impact on mechanical indicators in particular. According to the standard EN ISO 17225-2,3 [5, 6], the physical-mechanical quality indicators include the dimensions of solid biofuels, bulk and specific density, particle size, particle density and mechanical durability. When assessing and determining the influence of the structural parameters of the densification machine, it is necessary to evaluate all results from the physical-mechanical indicators of quality points of view. When choosing densification technology and individual construction types of machines, it is necessary to subject these technologies and machines to analyze in terms of the quality of the solid biofuels produced and the influence of the structural parameters of the pressing chamber. The meaning of this paper is to summarize the knowledge gained from practice, concerning the influence and differences of construction principles of densification machines and pressing tools of densification machines.

Despite the variety of constructions of densification machines, in principle there are only 2 basic ways of densification resp. pressing. We recognize densification in the so-called closed and in the open pressing chamber [7, 8]. The briquettes are, depending on the type of briquetting machine, produced as a cylindrical, square or n-angle shape. As is generally known, briquetting produces only one solid biofuel at a time (difference from pelleting). The pressing tool can be a pressing piston or a pressing screw (see Figures 1 and 2). We know mechanical briquetting presses (crank-shaft mechanism, knee-toggle mechanism, screw system) and hydraulic briquetting presses. Due to the small size of the pellets, it is unnecessary to analyze their internal failures depending on the type of pelletizing machine. In the case of briquetting technology, the situation is different. The briquettes are bigger, and thus their internal defects are more pronounced and significantly affect the quality, i.e. density and mechanical properties of briquettes. Since there are different constructions of briquetting presses, the question arises as to what is the difference between the resulting qualities of the briquettes. If we take a deeper look at the densification process on mechanical briquetting presses and compare them with hydraulic ones, we see the basic differences. In mechanical briquetting presses, the compacted material is under constant pressure in the so-called calibration chamber under the continuous cyclically repeating action of axial pressure, which results in compaction into a compact briquette and at the same time the displacement of the briquette along the pressing chamber. In the case of a hydraulic briquetting press, the material is pressed within a closed pressing chamber according to the set stroke of the hydraulic piston and the parameters of the hydraulic circuit. After releasing the axial pressure caused by the hydraulic piston, the pressing chamber opens and the briquette leaves the pressing space. The calibration phase is limited by the time during which is the hydraulic piston at maximum stroke. So we recognize the fundamental differences between the two design principles.

Fig. 1 Pressing piston as a tool of briquetting press

Fig. 2 Pressing screw as a tool of briquetting press

Based on practical knowledge, it can be stated that from the point of view of mechanical indicators of briquette quality (density and strength), it is clearly more advantageous to use a mechanical briquetting press, because briquetting takes place in the so-called "open" compression chamber, which has a positive effect on the creation of bindings between the material particles. From the point of view of requirements for dimensional and shape accuracy, it is more advantageous to use a hydraulic briquetting press, because briquetting takes place in the so-called "closed" pressing chamber, where the briquettes are produced one by one, gradually. Despite the lower final quality of the briquettes, all briquettes are the same length and have straight faces that do not crumble.

However, the issue of process optimization and the resulting quality of briquettes is not always just a question of the design principle. Knowledge from practice confirms the influence of the type and principle of densification on the final quality of briquettes. However, as we already know, in briquetting we can divide the principle of pressing from the point of view of the used pressing tool into three groups, each principle having its own specific pressing tool and a different influence on the quality of briquettes. The Figures 1 and 2 show the basic pressing tools of briquetting presses. The pressing piston usually also includes an end crown (Figure 3), which during pressing helps to create a shape bindings and thus the cohesion of the material particles without the use of a binder. It is necessary to mention this fact, as in such a case there is the greatest wear of the end crown.

The purpose of this paper is to figure out the importance of the type of pressing tool used on the quality of briquettes, which we present through a simple theoretical analysis. It should be noted that these differences and analysis relate exclusively to briquetting tools, since in pelleting the principle of material densification, i.e. extrusion of material into the holes of the press die by rolling the pressing rollers, is the same for all design principles. This does not mean that with pelletizing machines it is not possible to influence the final quality of the pellets by adjusting the pressing tools. However, the external shape of the pressing rollers does not significantly affect the quality of the pellets. However, in the case of pelleting presses, the geometry of the holes of the pressing matrix is a significant influencing parameter, which can be compared with the influence of the geometry of the pressing chamber of the briquetting press. However, in briquetting presses, this influence and effect is further amplified and influenced by the shape of the moving pressing tool.

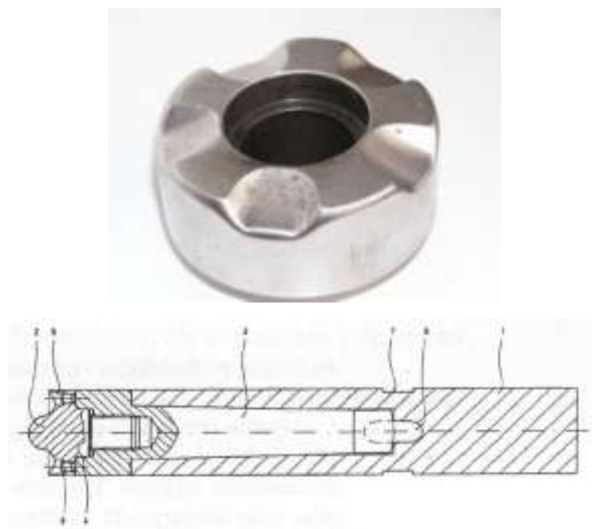

Fig. 3 Shaped crown (above) and its place on the pressing piston (beneath)

The shape of the pressing tool is closely related to the design principle of the densification machine and to the shape of the solid biofuels. In this part of the paper we deal with the analysis and optimization of the shape and size of the solid biofuels, so this parameter is not the subject of the solution. However, the aim of this part of the paper is to analyze the influence of the shape of the pressing tool with regard to the resulting quality of solid biofuels.

As mentioned above, the pressing piston or screw are the usually used pressing tools, but it should be noted that during pressing densification takes place in the pressing chamber, of which the pressing nozzle is also a part (see Figures 4 and 5). For the most part, the pressing nozzle is responsible for the final shape of the briquette, since the pressed material is pressed into a compact unit under the influence of a tool in the pressing nozzle. The pressing nozzle can be of a monolithic design, but it can also consist of several parts, which can differ from each other in internal shape. In this way, it is possible, e.g. by changing the shape of the pressing nozzle, increase the back pressure in the pressing chamber and thus achieve a higher final quality of briquettes. Higher back pressure can also mean more tool wear. Depending on the type and shape of the pressing tool and the construction principle, we recognize different quality of produced briquettes. Distribution of acting forces along the pressing chamber resp. the pressing holes is directly dependent on the shape. As there are differences, it is important to address this issue as well. Compared to pellets, briquettes are larger in size and therefore certain design shortcomings can affect the structure and internal failures of briquettes. Internal disturbances significantly affect the quality, i.e. density and mechanical properties of briquettes.

Fig. 4 Basic parts of the pressing chamber

Fig. 5 Chamber nozzles with various shapes

II. SURFACE TO VOLUME RATIO

A very important parameter in the densification process is the ratio of surface to volume of biofuel and thus also the ratio of surface to volume of the pressing hole (chamber). Different shapes and dimensions have different surface to volume ratios. This ratio is significant in the burning process, but also in the wear of pressing tools. Significance in terms of solid biofuels burning is not the subject of this analysis.

Wear of the machine and its functional parts - pressing tools, is very important from an economic point of view. Therefore, it is important that wear is prevented during chamber design (size and shape) and other criteria. The greater the wear, the higher the repair costs and vice versa [10]. Also, the wear of the pressing tools affects the resulting quality of the solid biofuels. The lower the surface to volume ratio of the biofuel, the less wear. Thus, this means a lower wear ratio of the pressing chamber, the pelletizing die and the briquetting nozzle - i.e. the pressing tool. As an illustrative explanation, the following Figure 6 is a graphical comparison of the surface to volume ratio of different shapes of pressing holes in a briquetting nozzle (tool). The resulting shape of the briquettes is directly dependent on the pressing tools, but in the above cases it is the same - a cylindrical briquette ø 20 mm. Therefore, it is possible, through the shape of the pressing tool and its degree of wear expressed by the ratio of the surface to the volume of the pressing holes, to analyze and subsequently optimize the shape of the briquettes. Pressing nozzles marked as H140, H120, H100 and H70 represent nozzles with a cylindrical hole ø 20 mm, whose lengths are 70, 100, 120 and 140 mm. Pressing nozzles 7H140, 5H140, 3H140, 2H140 and 1H140 are nozzles with a conical hole, diameter at the inlet ø 20 mm and varying degrees of conicity 1 °, 3 °, 5 ° and 7 °. Based on the calculated value of the ratio of surface to volume of the pressing hole for each of the mentioned nozzles, we can state that from the point of view of the least tool wear - the pressing nozzle H70 is the most advantageous. In this way, it is possible to analyze the different shapes of the pressing tools, and thus to obtain an overview of the degree of wear of the pressing tool depending on the shape of the briquettes.

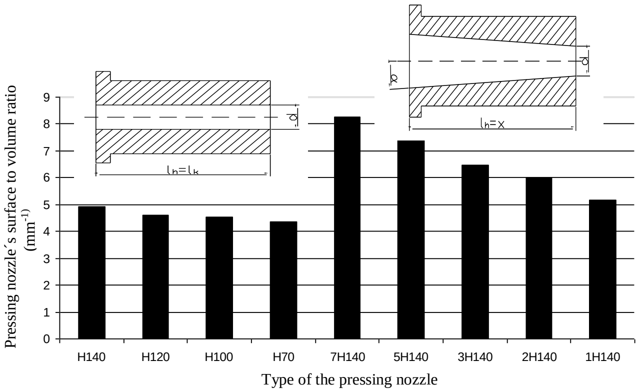

Fig. 6 Comparison of surface to volume ratios of various chamber nozzle configurations in a briquetting press [11]

Of course, the results analyzed in this way must be supplemented when designing the shape of the pressing tool with data that speak about the friction conditions between specific types of friction pairs (steel - wood, steel - straw, etc.). This means that if we know that when pressing wood sawdust, there is a higher wear of the tools than when pressing straw, we must also take this into account when designing the shape of the pressing tool. Based on the decomposition of the acting forces in the pressing chamber of the densification machine, we know that the friction force resp. the friction coefficient between the pressing tool and the pressed material are parameters that will significantly affect the failures and wear of the pressing tools. Also based on the results of experiments published by German scientists in [12, 13], we can say that the higher value of the friction coefficient also increases the axial pressure acting on the pressed plug (*Pm*). The force effects on the pressing tools also change significantly.

The parameter - the shape of the pressing tool, is more and more important nowadays. As manufacturers of densification machines try to adapt to new trends and requirements, which deals about the possibility of changing the shape of the solid biofuels, by a certain minor change of the densification machine or by replacing the minimum number of components of the densification machine. In the following Figures 7 and 8 we can see the briquetting nozzle of the crank-shaft briquetting press, which produces briquettes with a diameter of ø 50 mm as standard. By adding (inserting) the pelleting insert into the briquetting nozzle, it is possible to produce pellets with a diameter of ø 20 mm on the same briquetting press. The friction conditions of such a pressing tool when pressing the same material change, even though the pelleting insert is made of the same material as the briquetting nozzle. The surface to volume ratio of the chamber has increased, resulting in a change in the distribution of forces in the chamber associated with an increased wear rate of the pressing tool.

Fig. 7 Briquetting press nozzle (left), pelleting insert with four holes (right) [14]

Fig. 8 Pelleting insert installed within the briquette nozzle (left), comparison of extrusion – pellets/briquette (right) [14]

The change in the surface to volume ratio of such a multi-chamber briquetting nozzle is interesting to observe through parametric 3D modeling as a tool for the design and development of a pressing briquetting nozzle. The following figures 9-13 show ideologically designed pressing nozzles with the idea of reducing the pressing holes, but with an increasing number of pressing holes in one nozzle. It is clear from the figures that in some cases production would be very difficult, but they can be used for ideological comparison. All designed nozzles were compared in terms of surface to volume ratio. It is also possible to compare the total internal volumes that can be used as a basis for calculating the production of solid biofuels for such nozzles.

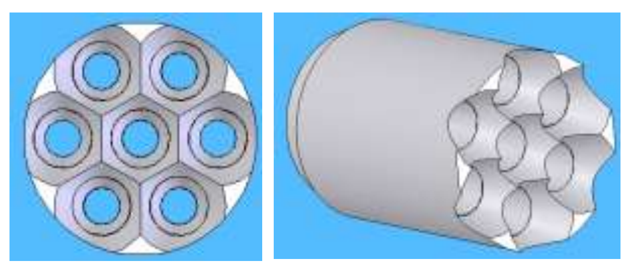

Fig. 9 Nozzle D10/7 (7x ø 10 mm holes) [15, 16]

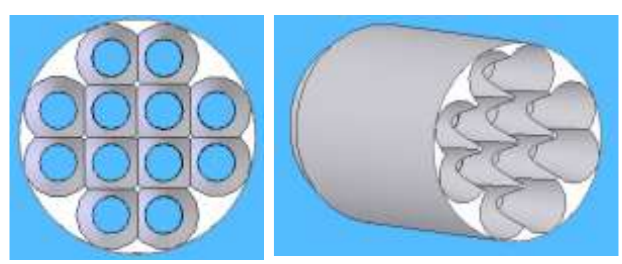

Fig. 10 Nozzle D10/12 (12x ø 10 mm holes) [15, 16]

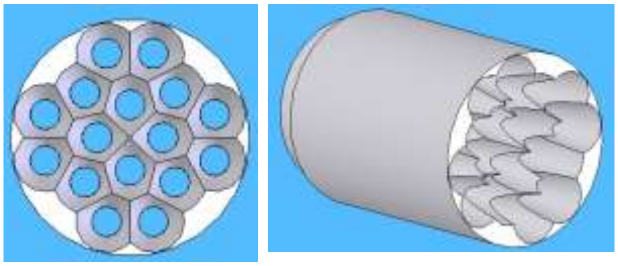

Fig. 11 Nozzle D8/16 (16x ø 8 mm holes) [15, 16]

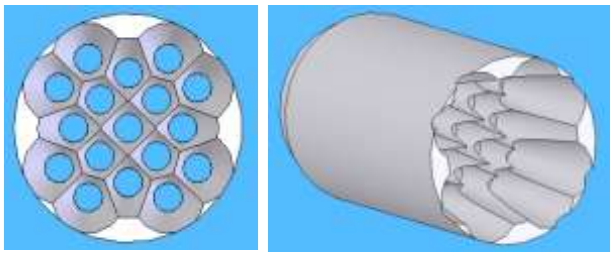

Fig. 12 Nozzle D8/17 (17x ø 8 mm holes) [15, 16]

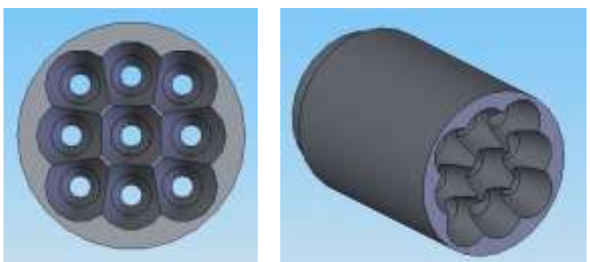

Fig. 13 Nozzle D6/9 (9x ø 6 mm holes) [15, 16]

Table I: Calculated Design Parameters of each nozzle Design [15, 16]

Nozzle type	Total volume – holes in nozzles	Surface to total volume ratio
Briquetting nozzle	279632.4	0.0682
Pelleting nozzle D20/4	134006.6	0.1662
Pelleting nozzle D10/12	111886.5	0.3082
Pelleting nozzle D10/7	81411.1	0.2749
Pelleting nozzle D8/17	97798.7	0.4002
Pelleting nozzle D8/16	102034.8	0.3621
Pelleting nozzle D6/9	47439.5	0.4022

Based on the calculated data of the volume of the holes and the ratio of the surface to the volume, the influence of the mentioned parameters on the production of biofuels and the wear of the pressing nozzle is obvious. The importance of these parameters in the design and development of the shape of pressing tools was confirmed.

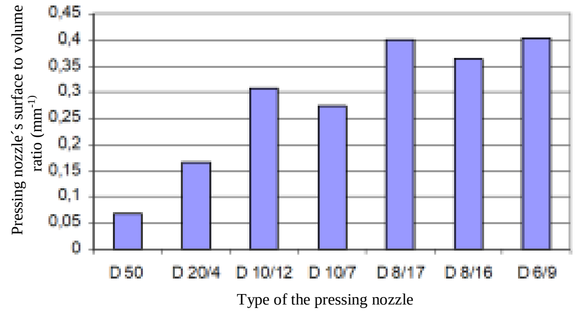

Fig. 14 The effects of the type of pressing nozzle on the surface to volume ratio [15, 16]

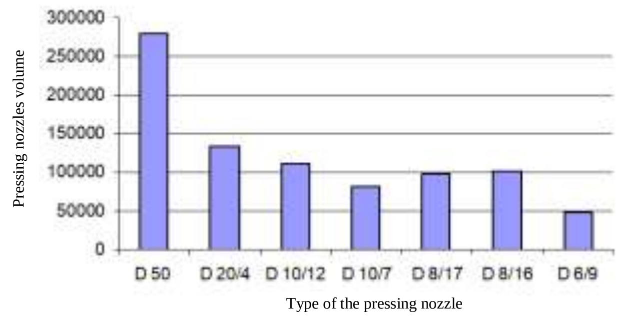

Fig. 15 The effects of the type of pressing nozzle on the volume of the nozzle [15, 16]

III. EFFECT OF THE PRESSING CHAMBER WALL´S CONICITY

As already mentioned above, the geometry of the pressing chamber is very important in the densification of biomass. Based on practical experience during briquetting of wood biomass, we know that when changing the briquetting nozzle, i.e. replacing the cylindrical nozzle with a nozzle with a certain conicity, positive effects on the resulting quality of briquettes were recorded. This fact provides a clear assumption that there is a relationship between the size of the taper of the walls, the pressing pressure and the resulting quality of the briquettes. Therefore, it is important to determine the effect of the change in the pressing chamber walls conicity on the resulting quality of the briquettes. With this dependence, it is also possible to obtain knowledge about the required holding time of the briquette in the pressing chamber after pressing, during which the briquette is subjected to calibration and axial and radial pressures are rearranged. As mentioned above, due to the higher residual radial pressures when the briquettes are pushed out of the chamber, the briquettes are crushed and disintegrate. With the correct shape of the pressing chamber, we can prevent this.

Since the change in the conicity of the pressing chamber influences the distribution of the applied forces and thus also affects the wear of the pressing chamber, it is also very easy to express the effect on the ratio of surface to unit volume of the pressing chamber. For comparison, it is possible to mention 2 types of pressing chamber - conical pressing chamber (Figure

16) and combined pressing chamber (Figure 17), i.e. conical pressing part with cylindrical calibration part.

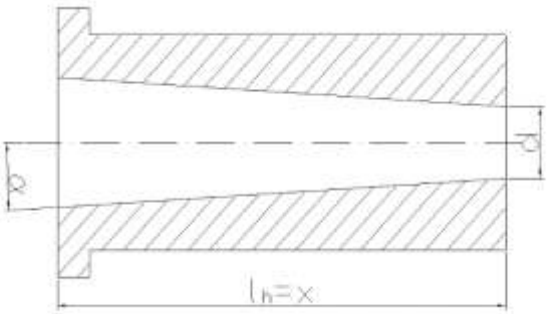

Fig. 16 Conical pressing chamber - "α *H* l_h"

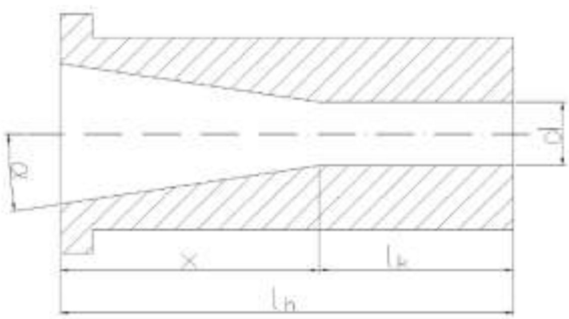

Fig. 17 Combined pressing chamber - "α *H* l_h / l_k"

The output diameters are the same d = 20 mm for both types of chambers. The total lengths of both pressing chambers are also the same l_h = 140 mm. The length of the cylindrical part of the combined pressing chamber will be constant l_k = 60 mm, i.e. the tapper of the chamber (1, 4, 6, 9 and 11 °) will change over the remaining length (x = 80 mm). In the case of a conical pressing chamber, the angle α (1, 2, 3, 5 and 7 °) will vary, but this angle will be l_h = 140 mm along the entire length of the pressing chamber.

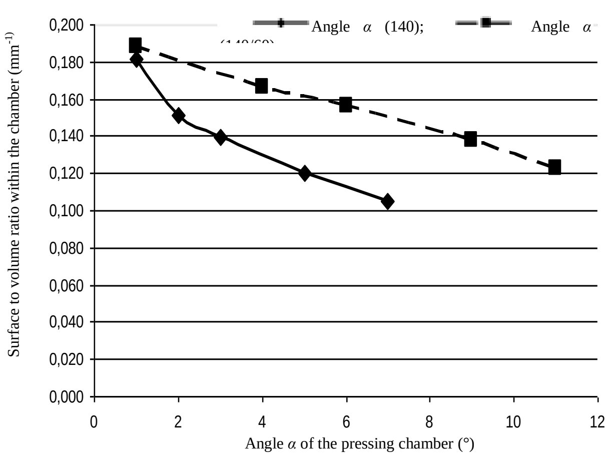

Fig. 18 Dependence of the surface to volume ration on the pressing chamber taper angle

IV. EFFECT OF THE PRESSING TOOL SHAPE

As mentioned above, densification machine manufacturers have a wide portfolio of types of pressing tools depending on the type and kind of densification machine. In the case of briquetting presses, we also distinguish between a co-related and working pair of pressing tools, a pressing tool - a pressing nozzle. As mentioned above, the pressing tool can be a piston or a screw. The pressing nozzle is in principle always cylindrical in shape, but gradually the manufacturer is developing various modifications of the pressing nozzles, where they use a combination of cylindrical surfaces and conical surfaces. When producing briquettes on briquetting presses, mainly using the principle of an open pressing chamber, it is necessary to ensure a sufficient back pressure "p_G" (Figure 19) during a defined time unit. This is also due to the pressing method itself, which is unstable from the point of view of ensuring a constant pressing pressure. In principle, the back pressure in the pressing chamber can be provided [17, 18]:

→ controlled "throttling" of the pressing chamber;

→ By managing the so-called "upper dead center";

→ By shaping the pressing chamber.

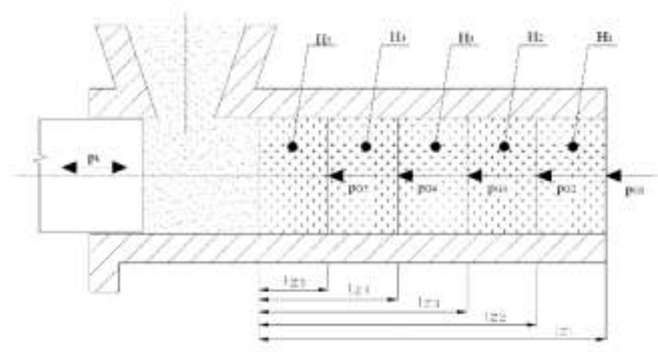

Fig. 19 Behaviour of backpressure during continual pressing

In any case, there is a higher degree of wear compared to standardly produced cylindrical pressing chambers, therefore it is necessary to deal with the question of the appropriate choice of material and heat treatment when designing the shape of the pressing chambers. A parameter which makes it possible to define in advance at least an approximate degree of wear of the pressing chambers is the ratio of the surface of the pressing chamber to the unit volume of the pressing chamber. The lower this ratio, the lower the assumption that the pressing chamber will wear. And since wear is also related to the distribution and action of pressures in the pressing chamber, it can be assumed that the shape of the pressing chamber also affects the resulting quality of the briquettes. The aim of the following theoretical analysis was to show the influence of the shape of the pressing chamber in the pressing process through the ratio of the surface of the pressing chamber to the unit volume of the pressing chamber.

When comparing the nozzles in terms of the calculated surface and the calculated volume, it is clear that when using different types of nozzles, we achieve different hourly production of the machine with the same supplied input energy. The following Figure 20 shows a comparison of the nozzles in terms of surface to volume ratio. The *7H140* nozzle appears to be the most suitable nozzle in terms of surface to volume ratio. There is the least wear of the nozzle, which is the most economically advantageous. This analysis shows that it is suitable to use the conicity of the wall of the pressing chamber along the entire length of the pressing chamber, because in the second and third place there are nozzles of this type. As the nozzle wears the least, frequent nozzle changes are not necessary, and thus the productivity may be higher than with other types of nozzles. It can be noted that nozzles with a cylindrical pressing chamber along the entire length of the pressing chamber appear to be the most unsuitable types of pressing nozzles. From the point of view of the final quality of the briquettes, nozzles with a certain conicity are also more suitable, due to the action and distribution of pressures in the pressing chamber.

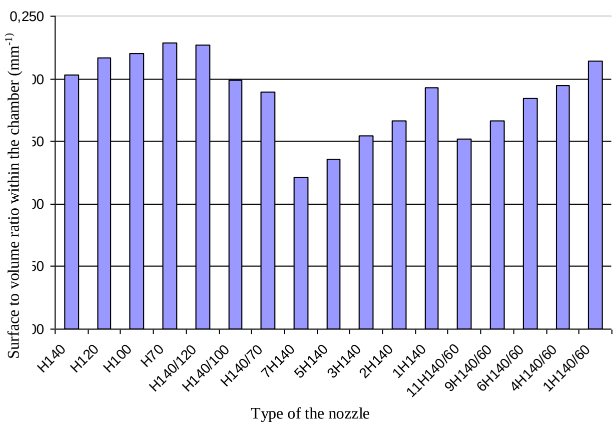

Fig. 20 Comparison of different nozzle types in terms of their surface to volume ration [11, 16]

The data in the previous Figure 20 are obtained by calculation and consider rather the dimensions of the pressing chambers, which could be applied in an experimental pressing stand at our workplace. Of interest, however, is a similar comparison made for produced pressing chambers. This is shown in the following Figure 21. Here you can see a comparison of the pressing channels of pellet plate dies with a diameter of 6, 8 and 10 mm, with briquetting nozzles with a diameter of 50 and 90 mm. This comparison is complemented by a briquetting nozzle, which was developed at our workplace (see Figure 8), with which it is possible to produce on a briquetting press at one time 4 briquettes with a diameter of 20 mm, hence the designation *20/4*.

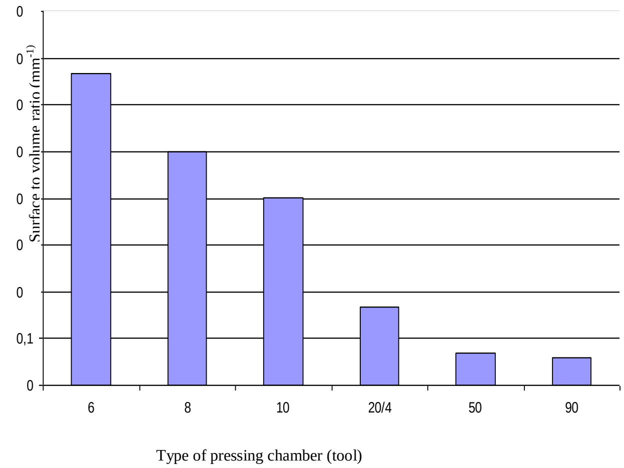

Fig. 21 Comparison of different commercially available pressing chambers (tools) [11, 16]

V. CONCLUSIONS

The performed analyzes show that the analyzed structural parameters significantly affect the pressures in the pressing chamber and thus also affect the resulting quality of the briquettes. However, based on practical experience, it is important to deal with the experimental verification of the influence of all structural parameters of the machine and pressing tool. However, the benefit of the analysis and study of the influence of structural parameters is the acquired knowledge, which can be "reflected" in the future in the production of a new experimental pressing stand, which would provide the opportunity to experimentally verify all the structural parameters. Therefore, one of the benefits of the knowledge in this paper is the information obtained for the design of a new experimental stand, which will monitor the effects of pressing chamber diameter, pressing chamber type and geometry, pressing tool material, friction forces, radial forces and counter pressures, and calibration (cooling) channel length. The analyzed information in this paper is applicable in all densification pressing tool cases, briquetting and also pelleting. Briquetting nozzle forms the final briquette on the base of the nozzle geometry. In the case of pelleting, pelleting matrix consist of many pressing holes, where also the diameter, length and geometry of pressing hole are influencing parameters. Because the direction of initial axial pressure (or force) is similar in both technologies (briquetting and pelleting) the structural parameters of pressing tools effects the distribution and value of acting pressures (or forces) in the pressing chamber during densification. That's way these findings can be applied to both technologies.

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