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SCREW PRESSES STUDY FOR BRIQUETTES´ FROM DENSIFIED WOOD

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Abstract
Energy production from biomass is among the priorities of the energy strategy of Bulgaria and Europe for using renewable energy sources. One of the methods for converting woody biomass into fuel for powering industrial and municipal energy plants is the production of briquettes and pellets. This work was conducted to determine some basic parameters of the screw presses for production of briquettes from densified woody biomass. There are basic relations for determining the needed pressure in the screw presses for densifying comminutioned wood biomass. Analytical relationships are derived for the determination of certain structural and technological parameters of the machines.

Keywords: *screw press, woody biomass, briquettes*

1. INTRODUCTION

The woody biomass is an important source for the production of renewable energy in Bulgaria. For this purpose in 2011 a "Law on Renewable Energy" and a new "Forest Act" to provide the necessary incentives for energy production from biomass were adopted. The new legislation is in the context of the European energy policy – "Directive 2009/28/EC of the EP and the EU to promote the use of renewable energy". A "National Long-term program to promote use of biomass for the period 2008 - 2020" was developed in Bulgaria for this purpose. It provides that the proportion of the biomass to reach 36% of all RES (renewable sources) (Trichkov, 2011). In accordance with conventional logging technologies in our country, about 60% of its intended use standing pulp is generated. The rest of this mass (1,186,000 m3), in the form of branches, non-standard wood, stumps, bark and more are not used, while the softwood constitutes 38% of the total biomass, and the hardwood - 45%.This statistic shows that in Bulgaria there are large reserves of unused forest pulp. An additional source of bioenergy is the wood produced in thinning and forest health logging. Another prospective source is the forest rotation plantations, whose energy capacity in Bulgaria is about 500 MW. The sawdust and the wood waste in the wood industry constitute a large reserve of unused biomass.

The technology for briquetting includes fragmentation, drying and densifying of the biomass. The densifying of briquettes is done with piston and screw presses (extruders). The study on our and the international market indicates that the customers of this product prefer briquettes made with screw presses. Although this production is characterized by

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higher energy and operating costs, produced with screw presses briquettes have greater advantages over the briquettes produced by piston presses. First, it is the higher density of briquettes (ρ = 1200 ÷ 1400 kg/m^3), hence their higher calorific value (19 ÷ 25 *MJ/kg*). The resulting product has higher strength qualities, greater homogeneity, moisture resistance and durability. The presence of a central hole in the briquettes provides a more complete and stable combustion with minimal separation of flue gases and ash. The screw presses are characterized by more quiet operation and higher performance at lower mass, but they have higher energy (0,6 *kWh/kg*) and amortization costs compared to piston presses (0,5 *kWh/kg*) [2].

In Bulgaria, the production of screw presses for biomass briquettes began nearly 15 years ago. Lack of sufficient experience and qualification of the manufacturers led to some difficulties and poor performance of the manufactured presses. This caused some of the manufacturers to stop production or switch to the easier to produce and operate piston presses.

2. BACKGROUND

Briquettes produced with screw presses are characterized by higher quality performance and greater market demand. The development and testing of screw presses for production of biomass briquettes is still insufficiently studied in Bulgaria.

The aim of the study is to establish the influence of the pressure in the pressing chamber and the structural dimensions of the channel matrix on the density and quality of briquettes from plant biomass. The object of the study is the screw presses for production of briquettes from comminutioned woody biomass.

In the core of the technology for producing briquettes from biomass is the unceasing pressing process in the molding channel of the matrix. The comminutioned biomass from the hopper (1), through the feeding screw (2) is fed to the pressure screw (5) (Fig. 1). From operational considerations, the screw often consists of two parts - transport (4) and pressure screw (5) and ends with a conical tip. The pressure screw wears out more quickly due to the higher pressure and friction. This requires its periodic replacement. The pressure chamber (7) has a conical shape and in there, along the screw, a pressure gradient on the material is created. At the end of the cone channel, the pressure can reach up to 150÷200 *MPa*, and the axial force on the screw - up to 800 *kN*, causing considerable friction. The pressure from the pressure screw seals and makes the mixture homogenic along its whole its whole section. In the result of the internal and external friction in this chamber and the rotation of the screw (600 to 800 min^{-1}), the biomass is heated to 200÷280 degrees. This leads to vaporization plastification of lignocellulose's and the other adhesive components in the biomass. The conic at the end of the pressure screw helps to increase the density of the briquettes. Due to loss of elasticity, the macropores space shrinks and the contact surfaces between the particles increase. Local bridges are being formed between the different particles and a process of mutual adhesion develops [2, 7, 8].

The heated biomass after the press chamber is subjected to pressure in the molding channel (6) of the matrix (8) where the pressure reaches its maximum value and an unceasing briquette is formed. The temperature in this section of the press reaches over 280 degrees. It is recommended to install a heating and cooling device (9) and (10) for limiting and maintaining optimal operating temperature in the press device. Due to the high temperature in the press channel, on the surface and the inner aperture of the briquette, a carbonized coat is formed. This hard shell increases the strength of the briquettes during storage and transport, has waterproof function and facilitates the passage of the briquette through the canal walls.

The shape and the dimensions of the briquettes are a direct function of the form and the section of the molding channel. The modern presses are equipped with mechanisms to regulate the dimensions of the section of the channel and thus the efforts to retrieve the pressed material. By changing the effort, the necessary specific pressure in pressing process is determined. The screw presses are constructively adapted for heating and cooling of the cylindrical part of the matrix channel. The outcome of experimental studies have shown that the optimum temperature of pressing lignocellulose biomass in the matrix channel matrix is about 280 ÷ 290 degrees [2, 8]. At this temperature the energy waste is lowest, and the wearing of the matrix is minimal. The lower temperature requires a higher pressure and hence higher energy consumption and lower performance. The higher temperature of the channel provides a higher level of carbonation and smoothness of the walls of the briquette,which leads to reducing of the friction, but poses the risk of spontaneous combustion. On the other hand, reducing the friction reduces the output resistance and decreases the pressure in the chamber, which lowers the density of the briquette. To produce briquettes with a density of 1200 ÷ 1300 kg/m3 and to reduce the risk of spontaneous combustion, the matrix's channel should not be overheated above 290 degrees.

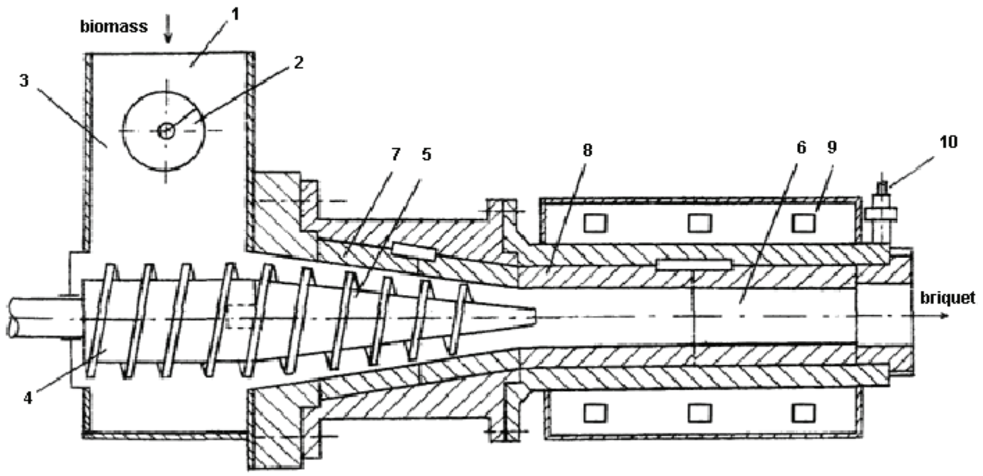

Fig 1. Scheme of the extruder’s working body:
1 – hopper; 2 – feeding screw; 3 – chamber; 4 – transport screw; 5 – pressure screw; 6 – molding channel; 7 – pressure chamber; 8 – matrix die; 9 – heating and cooling devices; 10 – sensor

3. MATERIALS AND METHODS

The process of pressing of bulk materials with screw presses can be expressed by the density of the produced briquettes. One of the most popular methods for determining the density of fodders of plant origin is based on the statement that the density of the material in the extrusion process increases continuously, the normal pressure in the press chamber is evenly distributed and the change of the pressing forces do not depend on the deformation rate [4, 6]. If we assume that the physical and mechanical properties of plant feed and the wood lignocellulosic pulp are similar, we can assume that the abovementioned statements will be fulfilled in the processes of extrusion with screw mechanisms. From this assumption it follows that the derivative of the pressure to the density of the pressed material is a continuous function of the applied pressure f (p) and can be expressed by the equation

$$f(p) = \frac{d(p)}{d(\rho)}, \tag{1}$$

where p is a current pressure;
ρ – the density of the pressed material.

From the studies on the process of extrusion was found that the function f (p) can be considered linear. After the integration of equation (1) and performing the necessary transformations, the following equation comes

$$p = C.\left[e^{a(\rho-\rho_0)} - 1\right], \tag{2}$$

where C and a are constant parameters of the equation;
ρ_0 – initial material density.

Equation (2) ;can be regarded as a fundamental equation of the pressing in the screw presses for briquetting of woody biomass. With its help, the pressure required to obtain briquettes with a specific density, can be determined. The values of the parameters C and a in formula (2) depend on the type and fraction composition of the pressed material. Experimental results for comminutioned wood. [Modin and Eroshkin, 1971 and Osobov, 1976] are used in the present study in order to determine these parameters.

The pressure in the screw presses along the screw is changing by an exponential law (Fig. 2). In the initial zone of transferring of the material from point A to point B, the pressure does not increase and $p_1 = 0$. From point B to point C is the area of transportation and pre-compaction, where the pressure increases slowly from 0 to p_2. The compression zone starts in the front of thepressurecone chamber from point C with a pressure value p_2 and increases rapidly by exponent to its maximum value p_3 in point D. The extrusion zone located in the matrix channel is characterized by constant pressure and is described by the segment DE, and the pressure is $p_3 = p_4 = p_{\max} = const.$

Maintaining cerrtain pressure in the press chamber requires appropriate response by the exit opening. In the process of extrusion of the briquette, this can be done by creating the necessary friction powers in the walls of the matrix channel. Thus, the extruded briquette is the support that would provide the necessary counteraction. In accordance with the principles of equilibrium it is required that the following condition is met:

$$\vec{F}_D + \vec{F}_{TP} = 0, \tag{3}$$

where F_D is a screw axle force at the end of the press chamber and the beginning of the matrix channel in point D^1 (fig.2);
F_{TP} is strength of the friction in matrix's channel.

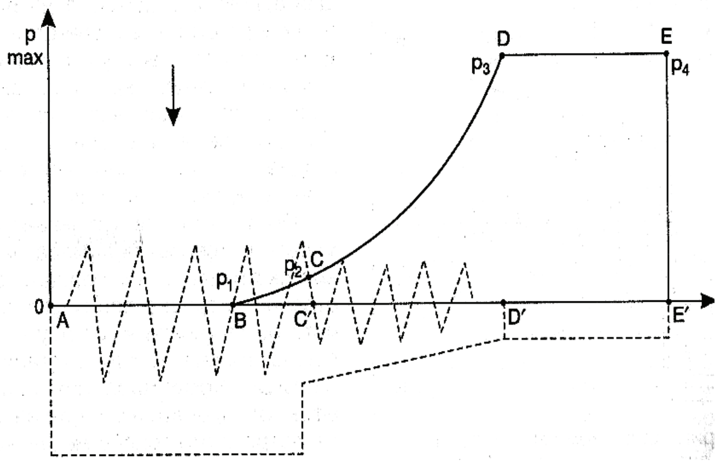

Fig. 2. Diagram of pressure variation in extrusion screw press

The F_D strength depends on the size of the axial pressure p in point D and on the intersection of the matrix channel, which is equal to the intersection of the briquette. The size of the strength F_D is determined by the expression

$$F_D = p \,.\, S, \tag{4}$$

where p is the maximum pressure along the axis of the screw at the end of the pressure chamber in point D, $p = p_D = p_3 = p_{max}$, Pa (fig. 2);
S – cross section of the matrix's channel, m^2.

The strength of the friction F_{TP} depends on the stretching force, caused by lateral pressure in the briquette, which acts in the transverse direction of the motion, the friction coefficient and the surface of the inner surface of the channel. In order to determine the stretching forces and the coefficients of friction of the comminutioned wood mass in terms of pressing under high pressure and temperature there may be used the experimental data from Modin and Eroshkin [6], Yosifov [2] and Melnikov [5]. The relationships between the normal and the lateral stretching pressure, temperature and friction have been established in these studies. In order to calculate the friction coefficients in the matrix channel the following formula can be used:

$$F_{TP} = f.p.\varepsilon.P.L, \tag{5}$$

where f is the friction coefficient between press material and matrix's walls;
ε – coefficient of proportional, which expresses relationship between normal pressure at the material's transversal expansion in the channel and size of the axial pressure [4, 5];
P – matrix's channel perimeter, m;
L – length of the matrix's channel, m.

After equations (5) and (4) are substituted in equation (2), the length of the matrix channel L can be determined by the formula:

$$L = \frac{S}{P} . \frac{1}{\varepsilon . f}, \quad (6)$$

Equation (6) allows to determine the minimum length of the matrix channel in order to provide the necessary pressure in the press chamber. The produced briquettes are mostly round, square or hexagonal cross section (tip of "Pini & Kai"). The necessary minimum length of the matrix channel L for the different cross sections can be determined by the formulas:

- for briquettes with round cross section – $L = \frac{d}{4.\varepsilon.f}$, where *d* is the outer diameter of the briquette;
- briquettes with square cross section – $L = \frac{a}{4.\varepsilon.f}$, where *a* is the side of the briquette;
- for hexagonal cross-section briquettes – $L = \frac{\sqrt{3}.a}{4.\varepsilon.f}$, where *a* is the side of the briquette.

The above equations are used to construct graphical dependences for determining the length of the matrix channel for production of briquettes with a certain density.

4. RESULTS AND DISCUSSIONS

The pressure in the press chamber for pressing of woody biomass with initial density between 125 and 250 kg/m^3 is determined according to the methodology described in point 2. Based on this graphical relationships are built (fig.3). These relationships enable us to easily determine the required pressure in the press chamber p depending on the initial density of the raw material ρ_0 and the density of the produced briquette - ρ.

The graphs in Fig. 3 show that for the production of briquettes with a certain density, the woody material with a smaller initial density requires a higher pressure. The obtained dependences show that by increasing pressure above 100 ÷ 120 *MP*a, the density of the briquettes increases slightly. This fact is more obvious in using feedstock of lesser density. Higher pressure in the screw presses is associated with higher energy costs and faster wearing of the working bodies. According to the surveys conducted by Yosifov [2], the qualitative indicators of briquettes from woody biomass improve more significantly in the range of 50 to 125 *MPa*, and afterwards they change slightly. This means that working with screw presses at a pressure above 120 *MPa* is inefficient in terms of cost and quality of the briquettes.

The obtained dependences show that for the production of briquettes with high density and reducing energy costs and wearing of the screw presses, it is necessary to use material with a higher bulk density. This can be achieved by comminutioned of the woody biomass in smaller fractions.

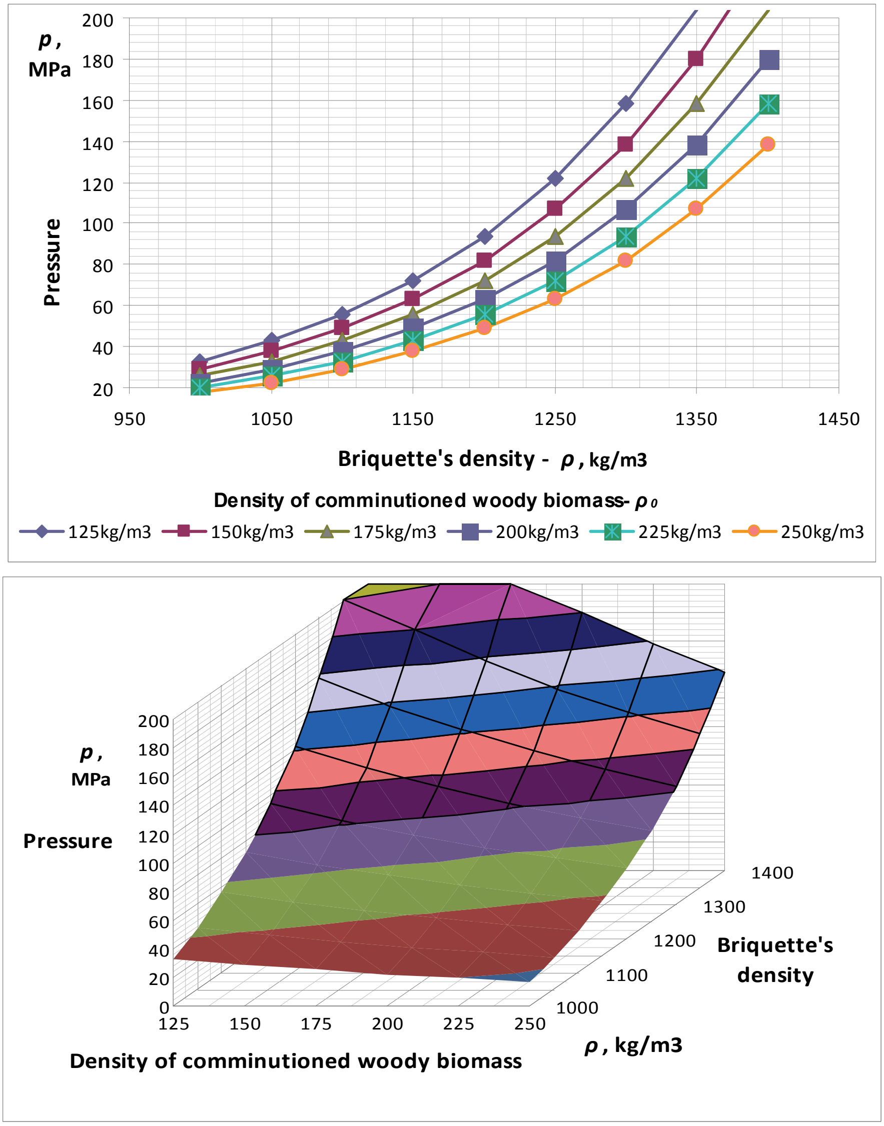

Fig.3. Variation of the normal pressure, depending on the density of compressed woody biomass

The length of the matrix channel is determined by the cross section of the briquette and the pressing conditions. For this purpose, on Fig. 4 and 5 are built graphical relationships that express the relationship between the size of the briquette and the necessary length of the channel. To determine the length of the matrix channel L and the coefficients f and ε of the pressed material in formulas (5) and (6), it has been used experimental data for comminutioned softwood and hardwood.

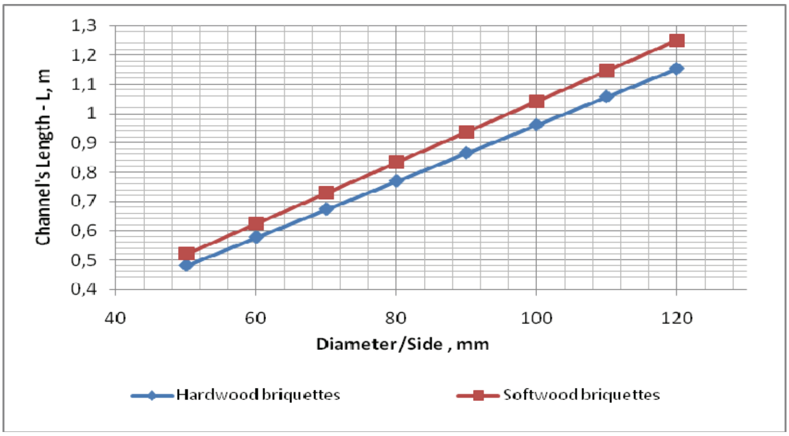

Fig. 4. Variation of the channel’s length, depending on the diameter or side for round or square cross section press form

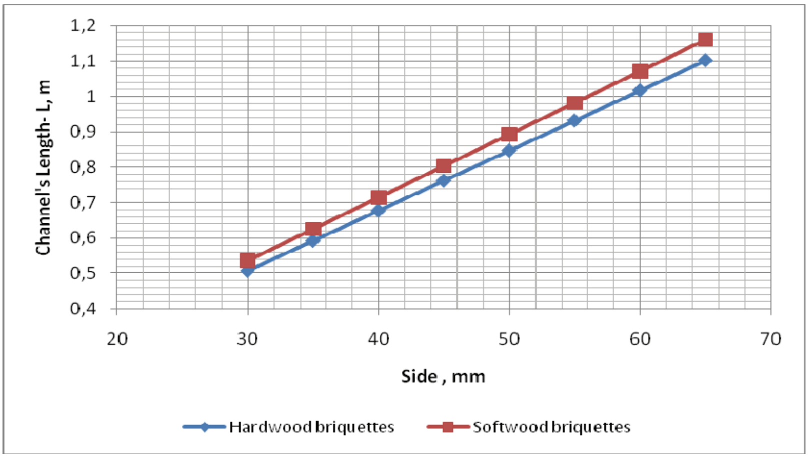

Fig. 5. Variation of the channel’s length, depending on the side for hexagonal cross section press form „Pini&Kai”

The obtained dependences show that the increase of the cross-section of the matrix channel and the cross-section of the briquettes leads to the increase of the length of the channel *L*. By reducing the cross-section of the channel, at a certain length of the matrix, the normal lateral pressure and frictional forces increases. This leads to an increase of the normal pressure in the pressure chamber and thus to increase of the density of briquettes.

5. CONCLUSIONS

The increase of the amount of woody biomass for energy production is important in implementing the overall strategy to increase the relative share of renewables. The forest industry sector in our country has the potential to make greater use of waste wood resource.

The production of briquettes from waste wood is one way to provide renewable energy. The screw presses for briquetting are characterized by relatively high productivity and product quality, but have higher energy and operating costs. To reduce these costs, it is needed that the constructive and technological parameters of the working bodies of these machines to be scientifically grounded. This study was though conducted for this purpose.

Based on the results obtained, the following important conclusions can be made:

- The necessary pressure in the screw presses for densifying the comminutioned woody biomass to obtain briquettes with a certain density has been justified;
- It has been found that, for materials with a lower bulk density, it is necessary to realize a higher pressure in the pressure chamber in order to obtain briquettes with a certain density;
- To reduce energy and amortization costs while working with screw presses, it is recommended that the maximum pressure may not exceed 120 *MPa*. It is recommended that the working pressure in the pressure chamber to be within 70 ÷ 120 *MPa*.
- It is recommended that the feedstock should have a smaller fractional composition (0,5 ÷ 2,5 *mm*), in order to increase its mass density. This will result in lower energy and amortization costs of the production.

Reducing the operating and energy costs and improving the screw presses, can be achieved on the basis of extensive theoretical and experimental research. These studies will help develop a strategy for using woody biomass as a renewable energy source

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