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Theoretical modelling of the briquetting process with different pressing equipment

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Abstract. Recently, a large number of technologies for production of solid biofuels in the form of briquettes has been researched and put into practice. The main advantages and disadvantages of modern production methods are analysed in this study. The lack of information about the process of formation and agglomeration of briquettes of different types of processing equipment adversely affects the quality of bio-fuel, rapid and intensive wear and tear of the main working parts and higher energy compaction; this influences the cost of the final product. In order to solve the above problems, a theoretical modelling of the process of bio-briquettes' formation on the piston press is proposed in the present paper. The main task was not only an analysis of the optimal technologies for briquette production, but also a comparison and elaboration of mathematical multifactorial linear models of the pressing process. During the theoretical modelling the main factors influencing the mechanical quality of briquettes were analysed and calculated. For a more understandable description of the briquetting process in a piston press, the pressing chamber was divided into three pressing zones. Analysis of forces and pressure distribution during the passage of material through the pressing chamber was done. The study pretends to improve the design and operational parameters of the pressing equipment.

Key words: briquettes, piston press, theoretical modelling

INTRODUCTION

Today, briquettes are considered a superior fuel with positive environmental impacts (Pobedinschi et al 2009; Havrland et al 2011). Different biowastes with moisture content below 15% can be processed into briquettes; for example, wood shavings and sawdust, straw, crushed vine pruning, wood cuttings, processed energy crops, chopped wood, husks of rice seeds and sunflower, groundnut shells, etc. This technology is currently one of the most cost-effective processes insuring the use of various types of biomass.

Technological agglomeration equipment (presses) with high pressure and various cycles of developed force is used for the production of solid biofuels from biomass (Pietsch, 2002). The main types of equipment are as follow: percussion-mechanical piston press; hydraulic press; screw press-extruder; press with flat or circular matrixes and pressing rollers. These presses are used in stationary and modular mobile mini-factories for solid biofuel production.

MATERIALS AND METHODS

By analysing the first three groups of presses it could be concluded that bio-briquette production technologies using piston presses with mechanic and hydraulic drive have some *advantages* as compared with screw-type presses-extruders. By Eriksson & Prior (1990), Baskar et al (2012) they are as follows:

There is quite a reduced relative movement of biomass and therefore the wear and tear of the working bodies is significantly lower. The service life of working bodies of piston presses is 500–1,000 hours. For comparison – the service life of the working screw at presses-extruders does not surpass 100–300 hours. Fuel briquette is produced without adding any binders. The specific energy consumption of the bio-briquette pressing process at piston presses is 44–70 kWh t^{-1} which depends on the type of bio raw material. The pressing process of a screw press-extruder consumes about 83–132 and up to 180 kWh t^{-1} (energy consumption is up to about 10 kW higher than that of piston presses, which depends on the model);

The briquette exit from the press is portioned. The hydraulic press also works smoothly, which is similar to the screw press. There is no smoke development during the briquette pressing due to the absence of higher heating in the pressing zone up to 250–280 °C. The best briquettes are obtained at lower moisture content in raw materials (less than 12–14%).

There also exist some disadvantages with piston presses, which are: there is no carbonisation of the outer layer of the briquette – this is why the protection of the briquette from the surrounding atmospheric humidity is worse. There is a need for briquette packaging. The produced briquettes are somewhat fragile and they burn quickly. The improvement of the feeding mechanism is necessary in accordance with the technological characteristics of the raw material.

The aim of the research is verification of the model and analysis of the patterns of the pressing process of biomass compositions of piston presses with a hydraulic drive.

RESULTS AND DISCUSSION

Analytical modelling of the briquettes pressing process in the working chamber of the hydraulic press BrikStar. Osobov et al (1974), Mel'nikov (1978), Pietsch (2002), Reiavco & Kasperovich (2005), Plaskin et al (2007), Havrland et al (2011) and others have conducted studies on the pressing process of different materials and have learnt the relationship between power characteristics and density of monoliths. A large number of empirical expressions linking the pressing pressure with physical and mechanical properties of the material and with a density of produced monoliths was suggested.

Optimisation of parameters of the hydraulic briquetting press. The structural analysis of the hydraulic briquetting press BrikStar (Fig. 1) shows that the raw material that is fed by screw into the dozing chamber under the working operation of a piston is compacted and pushed by portions through the working chamber of the matrix. Here the briquette formation takes place. After every piston working stroke the briquette comes out from the matrix. The size and the other characteristics of briquettes are dependent on many parameters discussed below.

The main parameter that characterises the pressing process of materials is the final density ρ of produced briquettes. It depends on the magnitude of the pressure applied on the compressed material. The relationship between these values allows for determining the efforts in components and mechanisms of machines and the energy required for compaction.

The modelling of the biomass pressing process in the pressing chamber of a matrix (Fig. 1), which is used in the hydraulic press (open conical channel), was designed on the basis of research results of Pietsch (2002), Reiavco & Kasperovich (2005), Judin (2007), Plaskin et al (2007), Pobedinschi et al (2009), Fraczek et al (2010), Baskar et al (2012). In accordance with the mechanism of material particle agglomeration and patterns of increase of the briquette density during the pressing, Fig. 1 shows the dozing chamber (zone 0) whose length is equal to the length of the piston stroke L. The pressing chamber of the matrix, whose length is L_d, includes a cylindrical part – zone I and a conical compacting part – zone II. Under the action of axial pressure P_a created by the hydraulic cylinder with a working pressure of P_h, the portion of raw material with parameters V_0, ρ_0 passes by screw into the dozing chamber (zone 0). Then it is compressed by piston to pressure $P_{x.0}$. Thus, the more or less regularly distributed pressure p acts on the contact surface between the piston and front-end of the compressed briquette. Then the briquette is squeezed into a working zone I of the matrix where it is compressed with reduction of its volume to V_I and increase of density ρ_I. The pressure in the monolith rises up to $P_{x.I} = P_{x.max}$. As a result, the residual pressure $P_{re.I}$ ($P_{re} = \psi(P_x)$) remains in the material of the emerging briquettes; and the briquette generates a side pressure $P_{s.I}$ ($P_s = f(P_x)$) on the walls of the matrix. During pressing the positions $l_{x1}, l_{x2} .... l_{x6}$ of briquettes being formed in the working chamber of the matrix can be distinguished. There is a distance x from the front-end of the piston to the briquette element $l_{x3} – l_{x4}$ with the length d_x. The pressure $P_x + dP_x$ acts on this briquette.

The increase of briquette density ρ is visible on the horizontal axis. The change of pressure P_x is shown on the vertical axis. Based on the research results it is possible to design a diagram AA′B′C′D′E′F′G′ that characterises the interdependence of pressing pressure and briquette density $P_x = \varphi(\rho)$ during the pressing process with six strokes of the piston. Here, the curves BB'; CC'...GG′ are typical for patterns of density rise with variable decrease and increase of pressure for each new portion of briquette (raw material).

However, the resistance to the material passing through the channel is ensured by friction forces F of the briquette monolith on side surfaces of the channel; they are dependent on lateral/side pressure P_s of the material on the walls of the matrix as well as the pressure P_r of several briquettes wedging in the conical part of the matrix and their compression pressure P_{co}. In addition the residual pressures P_{re} are created due to tension in the body of the briquette.

As it is evident from Fig. 1, each new portion of the material is pushed out from the working zone I of the matrix to the conical zone II during the subsequent course of the piston; it is because the matrix is provided with a slit that allows compressing its end with a clamping device working with P_c. In this zone the volume of briquette V_{II} consistently reduces and the pressure $P_{x.II}$ decreases according to the diagram B′C′D′E′F′G′. The final formation of briquette with the agglomeration of particles and their binding into the monolith by lignin excretion takes place. The density of briquette reaches ρ_{max}.

At the briquette exit from the matrix (zone III) the pressure P_x drops to zero and the briquettes pass through the device where the cooling, stabilising of density to ρ_r and stress relaxation occur. Thereat, the volume of the briquette slightly increases to V_r, and the length to $l_{x.r}$.

The explanation of rules of briquette pressing process in the matrix with the open channel can be done by an example of the elementary briquette $l_{x3} - l_{x4}$ with the length d_x (Fig. 1). The pressure P_x is represented at the area C′D′ of the diagram AA′C′D′E′F′G′. The area is characterised by a stable regime of briquette compaction and formation.

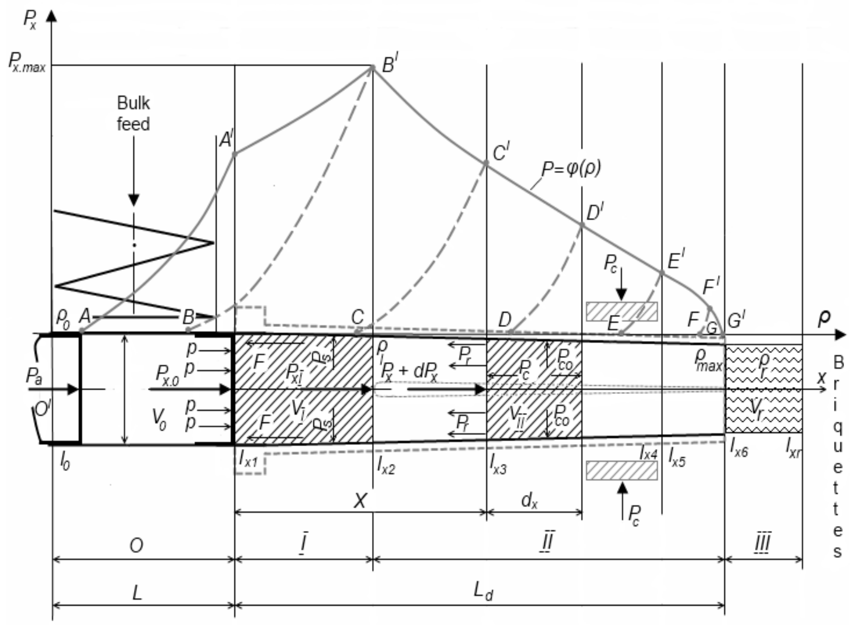

Figure 1. Model of the pressing process of bio-briquettes in the working chamber of the piston hydraulic press.

However, for theoretical justification of the dependence of the pressing pressure of material P_x on material density ρ in the pressing chamber as in the open channel several assumptions are made:

- the initial material density is the same everywhere in the volume of the compaction channel;
- the rules of the density changes in the material of briquette is linear;
- normal tensions at each point of any cross section of the pressing channel are the same;
- the density of the material during the compression process increases continuously;
- the cone of the matrix does not have a significant effect on the pressing process;
- pressing efforts do not depend on the deformation speed.

These prerequisites allow for thinking that the derivative of pressure with respect to density is a continuous function of applied pressure, i.e. $\frac{dP}{d\rho} = f(P)$.

The conducted studies on the pressing process done by Osobov et al (1974), Mel'nikov (1978) and Pobedinschi et al (2009) have shown that the function *f*(*P*) can be considered as linear, i.e.

$$\frac{dP}{d\rho} = aP + b \quad (1)$$

According to Skljar (2006), Pobedinschi et al (2009) by separation of the variables and integration of the right and left sides of the equation in the interval from ρ_o to ρ and from *0* to ρ the main pressing equation can be written as follows:

$$P = c\,[e^{a(\rho - \rho_o)} - 1],\ \text{Pa} \quad (2)$$

where c – constant parameter for the given kind of material that depends on its structural and mechanical properties: *density*, *strength*, *moisture content*, *size*, *shape*, *adhesion*, *cohesion and surface roughness of particle*. It shows the resistance of the material to compression; $c = в/a$, where a and $в$ are coefficients of the linear equation of the pressing process; $e = 2.718$ – the base of the natural logarithm (Euler number); ρ and ρ_0 – final and initial material density, kg m^{-3}.

The pressure P_s and resulting friction force F act in the cross section of the element on the lateral/side of the perimeter. This force is directed along the channel of the pressing chamber of the matrix and is oriented in the opposite direction to the axial pressure. The value of the force F is defined by the expression:

$$F = \mu\, P_s\, \Pi_c\, dx,\ \text{N} \quad (3)$$

where μ – static coefficient of the material friction on the walls of pressing chamber, $\mu \approx 0.2$–0.25; Π_c – perimeter of the cross-section of the pressing chamber, m.

The regularity of the pressure change along the length of the pressing chamber of the matrix, without counting the impact of the conical part of the compressed end of the matrix with the cut is expressed as (Skljar (2006), Pobedinschi et al (2009)):

$$P_x = \left(P + \frac{P_{co}}{\xi}\right) e^{-\frac{\mu\xi\Pi_c x}{S}} - \frac{P_{co}}{\xi},\ \text{Pa} \quad (4)$$

where S – area of the side surface of the pressing chamber, m^2; ξ – coefficient of the lateral pressure [$\xi = \frac{\nu}{1-\nu}$ = *const*; ν – Poisson’s ratio ($\nu \approx 0.29$-0.31)]; P_{co} –briquettes' compression pressure, Pa.

The length of the cylindrical pressing chamber is:

$$L_d \approx \frac{d}{4\mu\xi},\ \text{m} \quad (5)$$

where d – diameter of the channel of the pressing chamber, m.

CONCLUSIONS

In the course of studies number of advantages and disadvantages of modern methods of the solid biofuels production in the form of briquettes was identified and analysed. Production of fuel briquettes by hydraulic piston presses is more attractive for economic reasons and has a number of advantages as compared with press-extruders. These advantages are such as lower specific energy consumption and less wear and tear of the main pressing organs of the piston briquetting press.

The modelling of the bio-briquette formation process in the working chamber of the matrix at the hydraulic briquetting press contributes to selection of alternatives how to reduce energy consumption and improve quality and efficiency of the pressing process. It was shown that the quality and technological characteristics of the raw material have an important influence on the process of agglomeration of the particles during the pressing.

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