PARTICULARITIES OF BIO-RAW MATERIAL PARTICLE AGGLOMERATION DURING SOLID FUEL PRESSING PROCESS

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Abstract. Processes of solid biofuel production by pressing with use of different pressing equipment (presses) differ much due to their energy requirements, the quality of the produced bio-briquettes and the combustion effectiveness in the burning chamber (which also depends on the burning chamber design). There is a task to determine an optimum composition of bio-raw materials which differs by rheologic properties during the deformation process. There were analyzed different sorts, sources and technologies of raw material preparation which exist in Moldova and a couple of models chosen of raw material preparation for bio-briquette production. In the course of material preparation the following properties were regarded: raw material structure and its main physical-mechanical and technologic parameters. Patterns of increase of the briquette density, derived tensions, forces of internal and external friction, lateral pressure, backpressure of previous briquette portions and the matrix cone, as well as stress relaxation at the exit from the matrix were analyzed; the analysis was carried out in the process of briquette monolith formation and its movement along the matrix. The pressing method efficiency and the bio-briquette quality were assessed as compared to the standards and also by means of macroscopic analysis. Special attention was given to the density, hardness, structure homogeneity, micro- and macro-defects and specific energy requirements. On the whole, the above tests allow optimization of compositions of raw material mixtures and raw material characteristics and selection of the pressing process regime.

Keywords: bio-briquettes, compaction mechanism, agglomeration, quality, defects of structure, pressing parameters

Introduction

The modern level of theoretical research on agglomeration processes of different types of materials is based on works of many researchers in the field of mechanics of continuous media. The composition of the crushed plant raw material differs by features of rheology during the deformation process in macroscopic basis. It is obvious that the macro-deformation of mechanical mixture can be described within the framework of mechanics of continuous media as a generalization of the theory of elasticity and plasticity the elements of which are separate clusters of the structure.

The formulated integration model of raw material compaction is fairly close and enables to help understand and analytically describe the pressing process of biobriquettes.

Materials and methods

The objective of analytical and experimental research has been analysis and identification of agglomeration rules during the pressing process of raw material mixtures: conditions and parameters of the particle interconnection process, which provides a high level of technological properties and quality of bio-briquettes as well as technological solutions for utilization of plant raw materials.

The main factors, which have significant influence on the agglomeration process of the biomass particles during the pressing process, are:

- characteristics of biomass particles as mechanical mixture (physical-mechanical properties, fractional composition, form and degree of roughness, cohesion, adhesion, density, moisture content and other technological properties);
- technological characteristics (porosity, nature, stress-strain state) and magnitude of the applied pressure;
- geometrical characteristics of the working bodies (piston, matrix, screw).

Results and discussion

Analysis of the agglomeration process (compaction) of composition of the chopped raw material components. In the compaction process of various materials there are three conventional phases of deformation: structural, elastic and plastic [1; 3; 4]. Under the strain influence the structural deformation is realized as intermingling of discrete elements of the surrounding environment to the new, denser, balanced formation.

At the same time, the efficiency of interaction and cohesion of raw material particles during the first phase of the pressing process is influenced by: structure and internal composition of material in the mixture; fractional composition, geometric shape, particle roughness, presence of fibres and parenchymal inclusions and presence of pores and air cavities. Then, in the second phase, particle relocation, partial destruction, interpenetration and deformation of the particles with the removal of the air take place under interaction of the working body on the material. In the final pressing phase, the plastic deformations and agglomeration of particles and their gluing together by lignin occur due to the significant increase of pressure and temperature.

The particles of the composite material are mechanically connected together (into aggregates) and deformed; less dense particles (e.g., parenchymatous from corn stalks) penetrate into the space between harder particles (e.g., woody chips and particles from crushed vine prunings, etc.), so cohesion occurs, monolith formation starts and the further air removal from the space between the particles takes place.

The classical theory of agglomeration [1] describes the processes of interconnections of agglomerated particles. In difference of solid materials the woody particles of vine pruning and parenchymatous particles of corn straw are well visible in the original composition mixture of biomass (see macroscopic photo – Fig. 1).

The structure presented in Figure 2 can be considered as a result of the pressing, especially of its third stage. The last (third) stage of compaction is characterized by the change of the compaction mechanism. It is due to the cohesion and full "fixation" of contacts and the deformation flow of the solid phase of the mixtures. When the selected pressing pressure exceeds the compression resistance of the particles the plastic deformation and agglomeration of particles begin and further interpenetration and interconnection of the composite particles with the air removal from pores continues. Due to the action of pressure and temperature the lignin (complex chemical compound most commonly derived from wood, and an integral part of the secondary cell walls of plants) available in the intercellular space starts melting, flowing and filling the space between the particles, eventually tying them in the monolith.

Fig. 1. **Original mixture of crushed vine pruning and corn straw**

Fig. 2. **Macrostructure at the center of the bio-briquette after the third stage of pressing (silvery inclusion – binding lignin)**

Special conditions of particle deformation occur in the zone of interaction of forming bio-briquettes and matrix. The friction forces have strong influence here; it is evident from Figure 3.

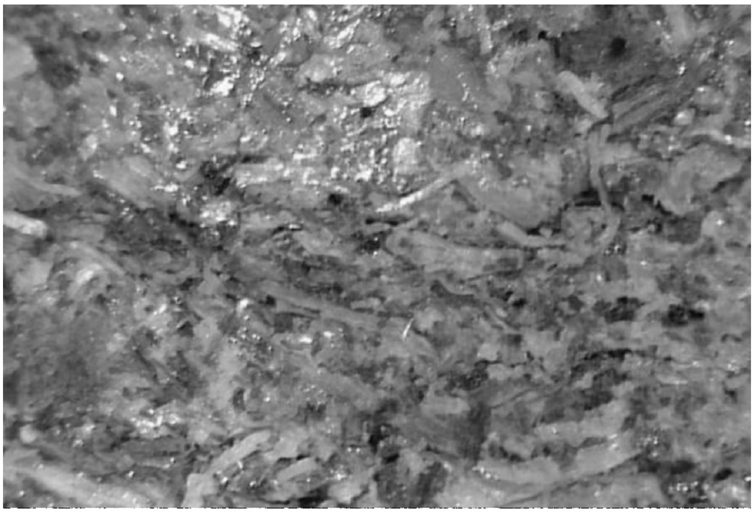

Fig. 3. **Typical macrostructure of lateral surface of the bio-briquette**

The photos received as a result of the macroscopic analysis (see Fig. 2 and Fig. 3) show the structural state of bio-briquettes produced by the hydraulic press.

By analogy with compaction of the powder materials [4] it is accepted that a criterion for the beginning of the third stage of the biomass compaction is achievement of a pressure p, which is greater than the pressure required for the material compaction. When establishing the rules of the pressing process of the composition made from chopped raw material components in a closed cylindrical matrix for each stage of deformation considering the technological properties of biomass and material density ρ, the stress distribution σ_3 along the pressing body (for the final stage of compression) can be estimated by the following formula:

$$\sigma_3 = -\sigma_s \cdot \left(\frac{2}{\sqrt{3}}\right) \cdot (\psi + \lambda) - \frac{\rho - \frac{d_k}{2}}{h}, \tag{1}$$

where d_k – diameter of the matrix;
σ_s – limit of the material fluidity;
ψ – function of modification of plasticity conditions due to the compressibility of the material mass;
λ – duplicity of the punch belt under the gap between the punch and the matrix, depending on the pressing height, mixture moisture content, quality of the working surfaces of production tooling and the thickness of the matrix walls;
h – pressing height.

Pressure on a punch. The total punch axial force F consists of the deformation force F_d and force overcoming friction F_f:

$$F = F_d + F_f. \tag{2}$$

In general, the pressure on a punch is derived from the formula 3:

$$p = \frac{2}{\sqrt{3}} \cdot \sigma_s \cdot \left(\psi + \lambda + \sqrt{f}\right), \tag{3}$$

where f – friction coefficient.

Note: the highest pressure occurs in the central part of pressin.

According to the research results the Shore hardness (scale A) of bio-briquettes made of mixture of corn straw and vine pruning (1:1) with the density ρ = 959.097 kg·m^{-3} was: in the center at the break – 65.7 N; on the side surface – 72.7 N. For comparison, the density of the bio-briquettes made by screw press was ρ = 1200 kg·m^{-3} and the Shore hardness (scale A) was: in the center at the break – 89 N; on the side – 90 N.

Role of lateral pressure under axial load. There is a substantial irregularity of its distribution in the chopped material which is measured by the coefficient of lateral pressure ξ as the ratio of lateral pressure p_l (force created by the material per unit area of the side walls of matrix press-form) to the pressing pressure p:

$$\xi = p_l / p \leq 1. \tag{4}$$

The value of this coefficient depends on the material density. It is set as a parameter to assess the maximum and average values of pressure on the side walls in a hard matrix at static pressing. In general, the value ξ ($\xi \approx 0.3 - 0.6$) could qualitatively characterize the plasticity of the compressed material.

The numerous studies also show that it is advisable to use vibration for achieving the required (increased) density of the pressed material (powder, wooden chips, chopped straw). Thus, the necessary pressure with the use of vibrations can be reduced by many times as compared to the static pressing process, especially in the third stage.

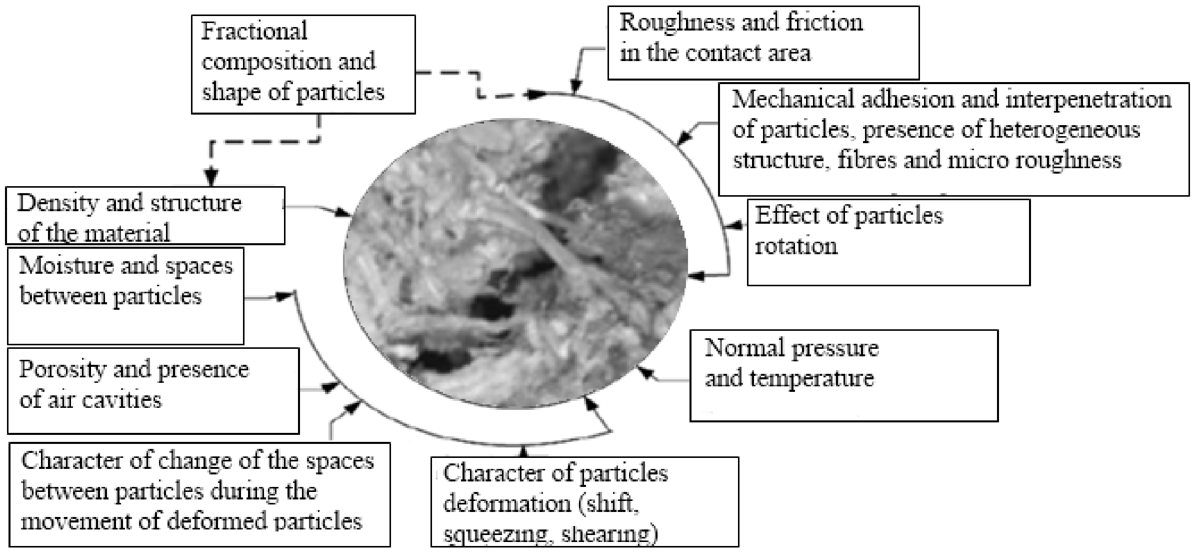

Fig. 4. **Factors influencing the pressing process of the biomass composition mixture**

If the technological regimes during the bio-briquette pressing process (from mechanical mixtures of raw materials) are non-respected some defects in the structure occur (see Fig. 4). In general, this disruption of the fractional composition, structure, physical-mechanical properties, presence of fibres and roughness as well as violation of the pressing regime may generate defects in the shape, structure and quality.

It is why there is a challenge of a correct selection of raw material composition which influences its rheological properties and the pressing regime to prevent the above defects.

Factors influencing technological properties of deformable environment. If the optimal conditions of pressure p rise are not insured, the study of the material behavior can be conducted by using models of discrete bodies, where the contacting particles are treated as a set of elastic-plastic bodies of various shapes and sizes.

However, such a study is possible only at the initial stage of deformation. The presence of micro roughness, fibres, different densities and inclusions does not allow considering the original raw material as a loose substance. There is a need to take into account the connectedness, i.e., to consider the original mixture as a structurally bound body with flexible connections, which give this mixture the following property: the presence of limiting shear stress, the exceeding of which leads to destruction of the structural ordering, besides the exceeding of the limit shear stress in the material cannot appear. The factors influencing the nature of material particle interactions during the pressing process are combined by the group features and presented in Figure 4.

Moreover, the factors in one group are more or less closely interlinked. The fractional composition, material structure and surface properties of the particles (roughness, friction, adhesion) play an important role. On the other hand, friction, mechanical adhesion, cohesion, the possibility of deformation and interpenetration of the particles greatly depend on their state at different stages of the pressing process.

As to the part of the air (through porosity), its impact in different stages of the pressing process can be a very important factor, especially in the latter stages of deformation. The presence of moisture in the material over 14% causes its intense evaporation under conditions of high temperatures. This can lead to the formation of the so-called steam pockets and expansion of the material with following destruction of the briquette.

Results of testing biobriquettes. Based on our own research results the optimal bio-briquette composition is a mixture of crushed corn straw and shredded cuttings of vine pruning (1:1). By their quality the briquettes made of the above mixtures correspond to the EU new standards for solid biofuels such as EN 14961-3: 2011, EN 14961-1: 2010, EN14588 2010, EN: 14774-1: 2009, EN: 2009, 14775 EN 14918: 2009, EN-15149 1: 2010, EN-2 15210: 2010.

Conclusions

It has been shown that the quality of the mixture composition and technological characteristics of the raw material have a very important influence on the particle agglomeration during the pressing process. When the given pressing pressure exceeds the resistance (against compression) of the particles plastic deformation and particle agglomeration begin. This leads to further interpenetration and interconnection of composite particles and air removal from the pores. High pressure and temperature make lignin in the intercellular space to begin melting, flowing and filling the spaces between the particles and, eventually, tying them into a monolith. In the case of non-respecting technological regimes of bio-briquette pressing (from mechanical mixtures of raw materials) defects of the shape, structure and quality occur.

Currently, the briquettes are considered as superior solid fuels with positive environmental impacts. According to their main characteristics (calorific value, ash content, density) the briquettes produced by piston presses are similar to analogical briquettes produced by extruders.

There is a high potential of reducing energy for the pressing process through applying vibration. This enables to achieve higher density of the pressed briquettes produced from sawdust, wooden chips, chopped straw, etc.). Further research and material testing are necessary to reveal optimum vibration frequencies and design proper equipment which could be technologically proper and implementable in the briquette production.

References

1. Pietsch W. 2002. Agglomeration Processes: Phenomena, TechnoIogies, Equipment. Wiley-VCH, Weinheim, 1104 p.
2. Havrland B., Pobedinschi V., Vrancean V., Pecen J., Ivanova T., Muntean A., Kandakov A. 2011. Biomass processing to biofuel. Powerprint, Prague – Chisinau, 86 p.
3. Pobedinschi V., Havrland B., Muntean A., Vrancean V., Kandakov,A., Ivanova T. 2009. Manual for the Subject: Preparation and Processing of Agricultural Produce and Bio-wastes. Powerprint, Chisinau – Prague, 162 pp. (in Russian).
4. Kokorin V.N., Rudskoj A.I., Filimonov V.I., Bulizhev Je.M., Kondrat'ev S.Ju. Теория и практика процесса прессования гетерофазных увлажненных механических смесей на основе железа. Ульяновск, УлГТУ, 2012. 236 с.
5. Baskar C., Baskar S., Dhillon R.S. 2012. Biomass conversion: The interface of Biotechnology, Chemistry and Materials Science. Springer, Berlin, 465 p.