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Experimental and analytical study on the assessment method of applicability of screw thickening systems for plant material briquetting

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Key words: briquette, plant material, screw briquetting press, working parameters briquetting machine

ABSTRACT

The article presents a method for a quick determination of the chosen screw-system applicability for the purpose of briquetting of the particulate plant material. The method is based on the results of the studies on densification systems: piston – closed chamber, piston – open chamber and on the results of screw densification system analysis presented in this article.

Badania eksperymentalne i analityczne nad metodą oceny przydatności ślimakowego układu zagęszczającego do brykietowania materiałów roślinnych

Słowa kluczowe: brykiet, materiał roślinny, prasa ślimakowa, parametry pracy brykieciarki

STRESZCZENIE

W artykule przedstawiono metodę szybkiego określania przydatności ślimakowego układu zagęszczającego do brykietowania rozdrobnionych materiałów pochodzenia roślinnego. W tym celu wykorzystano wyniki badań układów zagęszczających tłok – matryca zamknięta, tłok – matryca otwarta oraz przedstawione w niniejszej pracy wyniki badań ślimakowego układu zagęszczającego.

1. INTRODUCTION

Briquetting devices for fine-grained materials have been produced for many years now. The most common type of briquetting machines are the ones with a piston working system with hydraulic or mechanical (crank) drive and with screw working system. [1-3].

According to former research [4, 5] briquettes of the best quality are obtained in briquetting machines with the working system: screw – open compaction chamber.

Particles of the compressed material in briquettes obtained from a piston briquetting machine are arranged parallelly by bigger surfaces. By such arrangement empty spaces are created and filled with smaller particles. The consequence of such 'packaging' is diversification of the material density in briquette's microstructure and influences its quality [4]. The quality of a briquette is also affected by the "slice" effect, reduction of the crushing strength at edges of compressed material portions.

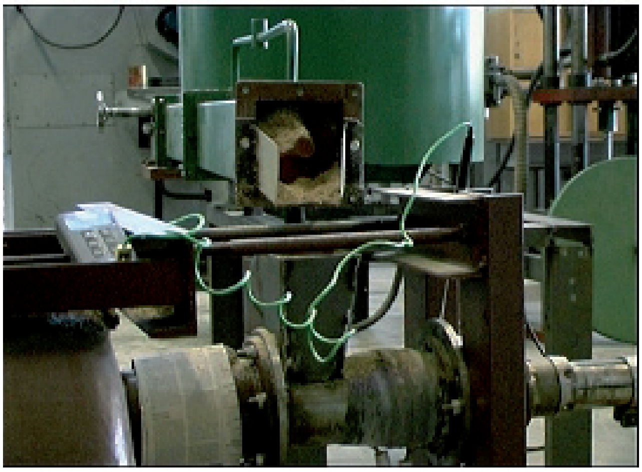
Thanks to the construction of the working system: screw – open compression chamber the material is additionally particulated and mixed. As a result of an extra grinding and mixing the air is pressed out and more plant material takes its place. This way particles of the compacted material 'overlap' improving quality of the briquette: density of the briquette is even in the throughout volume of the product, there is no "slicing" effect and the crushing strength on the side surface is few times higher when compared to the one of briquettes formed in a press with a piston working system [6].

2. TEST RIG FOR THE PURPOSE OF ANALYSIS OF THE FORCES IN THE WORKING SYSTEM OF THE SCREW BRIQUETTING MACHINE DURING THE DENSIFICATION PROCESS OF FINE-GRAINED MATERIALS

Pictures below (Fig. 1 a, b) present the test rig in which the analyses of the spruce sawdust densification process were conducted. The process was carried out in the working system: screw – compression chamber. The layout of the test rig with screw press is presented in Figure 2.

The test station is equipped with gear-motor with variable rotational speed in a range of 31-138 rpm. The torque measurement set *5* is attached to reducer shaft *3.* The measurement set consists of strain gauges, slip rings and brushes. The extrusion screw *1* is driven directly by the reducer shaft. The screw rotates inside the extrusion sleeve *4*.

a



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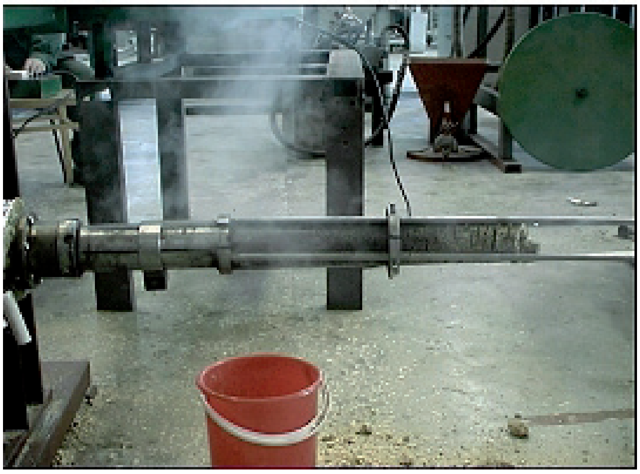

Figure 1 Test rig for the analysis of the densification process in a screw briquetting machine:
a) outlook of the test station, b) a briquette leaving the compression chamber

The section of the extrusion sleeve *4* between the end of the hopper and the exit has grooves on its inside surface. Grooves were integrated into the sleeve through milling process. The measurement matrix *2* is attached to a flange of the extrusion sleeve *4*. Holes in the matrix are adjusted for sliding measurement plungers *6* which are arranged lengthwise the matrix. Measurement plungers are slide-fit with matrix holes and blocked with resistance beam *8*.

The test station presented in Figure 2 enables measurement of the following forces inside the chamber of the screw briquetting device:

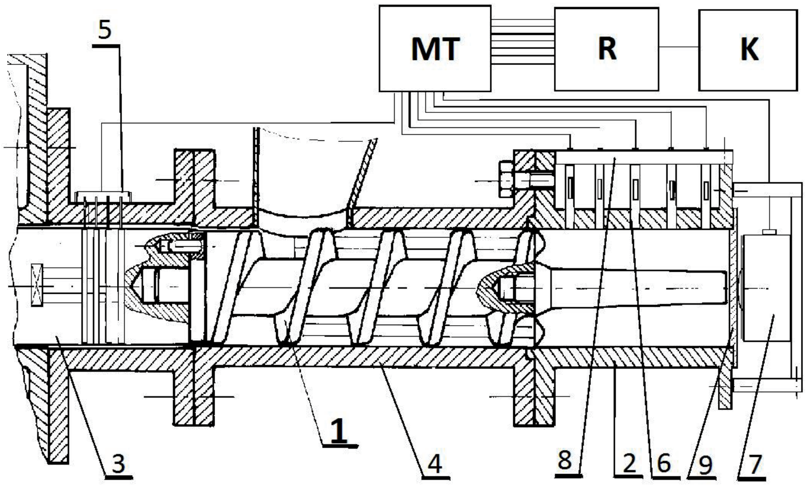

Figure 2 The layout of the test rig for measurements of radial forces, pressure on the die bed and the torque of the screw machine (according to author):
1 – extrusion screw,
2 – measurement matrix,
3 – gear-motor shaft,
4 – extrusion sleeve,
5 – torque measuring system,
6 – measurement plungers,
7 – a case with a force sensor,
8 – plungers resistance beam,
9 – matrix bed, MT – tensometric bridge type Hottinger KWS/6,
R – recorder, K – computer.

• lateral pressure on a given length of the compression die,
• compression pressure at a given distance from extrusion screw.

3. REALISATION OF MEASUREMENTS AND RESULTS OF THE EXPERIMENT

The measurements are taken in order to obtain initial results of the densification process realised in screw system. The initial results are used for the determination of technical and technological parameters such as densification pressure at the material exit from the screw etc. The parameters are obtained from laborious studies on plant material densification in different densification systems i.e. piston – closed chamber, piston – open chamber.
Initial assumptions are made in order to measure listed in point 2 parameters. The assumptions are as follows:
• compacted material – spruce sawdust of granulometric composition 0.5-5 mm,
• sawdust moisture content – 9, 12, 15, 20%,
• screw rotational speed – 50, 80 rpm,
• compression chamber dimensions: diameter – 68 mm, closed at length of 120 mm,
• measurement time – until the pressure stops rising (up to the time when the movement of the compressed material inside the sleeve stops, that is until shearing starts),
• temperature of the compression system – about 22˚C,
• shape of the working system – constant.

3.1 Measurement of the pressure on the die bed

Points marked on diagrams are mean values of five pressure measurements taken for each of the chosen initial parameter. Test results are shown in Figure 3.
Test results show that rotational speed of the screw influence increase rate of pressure on the bottom of the screw device closed chamber.
Pressure on the die bed reaches different values depending on moisture content of a compacted material. The differences between pressure values, e.g. at screw rotational speed of 80 RPM and sawdust moisture content of 9% (Fig. 3, curve 5) and at 15% moisture content and the same rotational speed (Fig. 3, curve 7 and 8), are about 4 MPa. Differences between pressure values for different moisture contents at 50 RPM are similar to the ones at 80 RPM.

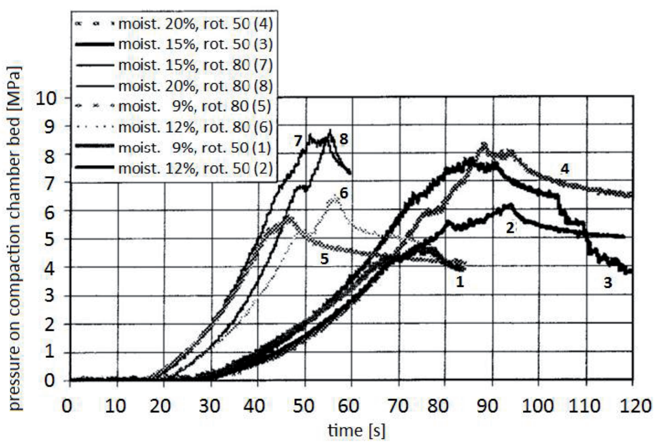

Figure 3 Average pressure exerted on bottom of the closed compaction chamber in screw briquetting machine

3.2 Lateral pressure measurement

Results of lateral (radial) pressure measurements inside the closed chamber of the screw briquetting device are presented in Figure 4.

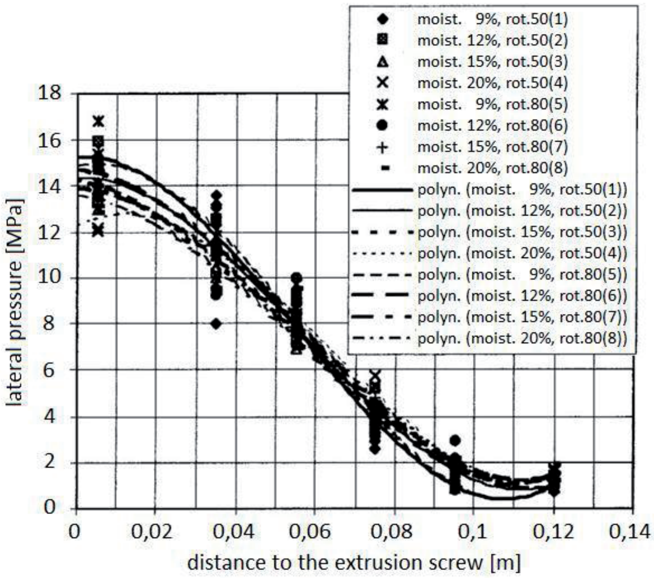

Figure 4 Radial pressure distribution in closed chamber of screw briquetting machine

Test results show that the highest values of lateral pressure can be found at the place where compacted material leaves the screw. The pressure decreases with increasing distance from extrusion sleeve, until it reaches a certain value. After the pressure reaches the lowest value it stabilises and becomes constant in the further part of the compression chamber (on average: from 12-16 MPa – at the head of the screw, up to 1-3 MPa – at a distance of 1 m to the screw).

Moisture content of the feed material has a significant influence on the lateral pressure values, what is illustrated by regression curves in Figure 4. Difference in pressure values reach 4 MPa at a close distance to the screw while at a bed of the chamber it is about 1 MPa. Change in rotational speed of the screw does not cause significant changes in lateral pressure values.

Polynomial equations for distribution of lateral pressure values lengthwise the closed compression chamber of the screw briquetting machine are obtained by the method of multiple regression applied for the points of measured values.

Exemplary equation of lateral pressure distribution (measurement at sawdust moisture content of 9% and rotational speed of 80 RPM – Fig. 4, curve 5, and at 9% moisture and rotational speed of 50 RPM – Fig. 4, curve 1) are presented below:

$$y_5=27291x^3-4851x^2+64.014x+16.158 \quad (1)$$

$$y_1=29629x^3-5054.4x^2+67.447x+14.486 \quad (2)$$

where: x – distance from extrusion screw [m], y – radial pressure [MPa].

4. UTILISATION OF TEST RESULTS FOR ESTIMATION OF SCREW BRIQUETTING MACHINE COMPACTION SYSTEM

A simple method was developed in order to determine applicability of the given working system of screw compaction device for densification of particulate plant materials.

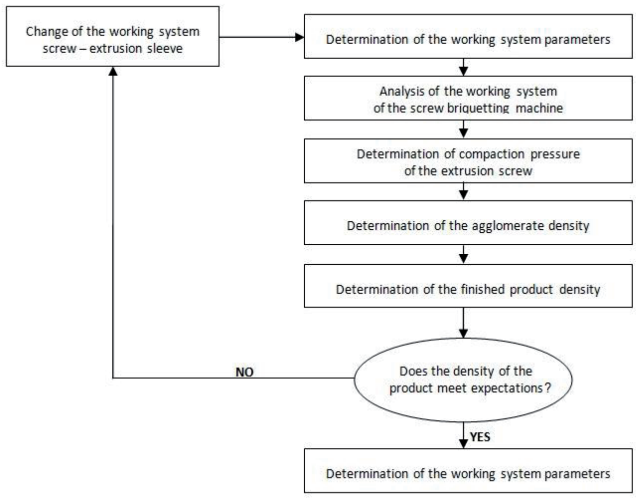

Figure 5 Block diagram of determination method of screw working system applicability for sawdust compaction

The method described by Figure 5 is based on author's research on spruce sawdust densification in the working systems: piston – closed chamber, piston – open chamber, screw – extrusion sleeve of screw briquetting machine [4].

In the (shortened) test it is necessary to close the open chamber of the screw device with a lid with a force sensor in a distance of about 0.04-0.12 m to the screw (Fig. 2 element 9).

Determination of the initial parameters:

x_z – length of the closed chamber in screw densification system,

w – moisture content of the material dedicated for compaction,

n – rotational speed of the extrusion screw,

ρ_{ocz} – expected (demanded) density of the fuel log (briquette, finished product) obtained from analysed compaction system.

The parameters for the research are set as follows: x_z=0.12 m, w=12%, n=50-80 RPM.

Results of the research on compaction system of screw briquetting device

As the result of the test the maximum pressure value can be obtained. Maximum pressure P_d on die bed (see Fig. 6) is determined by continuing the densification process until the pressure stops rising (shearing of the material between the screw and the sleeve).

Determination of densification pressure of the extrusion screw

The value of compaction pressure in the area around the screw $P_{śl}$ is determined on the basis of the measurement results of axial pressure distribution inside a briquette, at its full length, in the working system: piston – open chamber [4] (according to pressure P_d on chamber bed measurement in screw compaction device). The pressure $P_{śl}$ value is taken directly from the diagram (Fig. 6) according to the given scheme. Pressure values can also be calculated from empirical formula for pressure distribution (3):

$$P_{śl} = -2659.8x^3 + 1926x^2 - 602.56x + 76.431$$

where: $x = x_1 - x_z$.

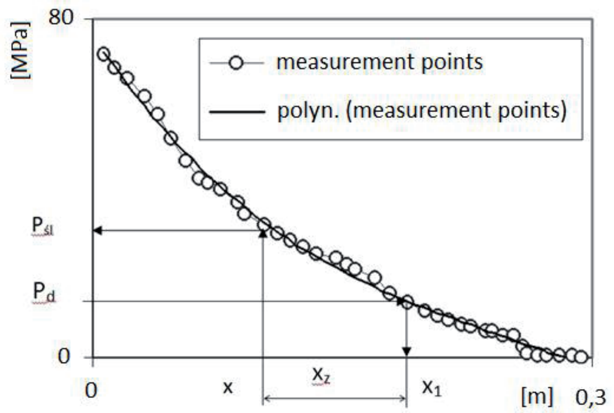

Figure 6 Determination method for densification pressure of the extrusion screw

Determination of the agglomerate density

Agglomerate density ρ_a at maximum compaction pressure generated by a extrusion screw $P_{śl}$, was determined on the basis of the characteristic of spruce sawdust densification process in a closed chamber according to the diagram – Figure 7 [4].

Determination of the finished product density

In order to determine density of the finished product the ω_g [4] coefficient needs to be assessed according to Figure 8, or calculated using formula (4). Density of the finished product formed in a given working system is as follows: $\omega_g \cdot \rho_a = \rho_b$, (where ρ_a – is determined according to Figure 7, ω_g – density coefficient of reverse expansion).

$$\omega_g = 3 \times 10^{-6} \rho_{śl}^2 - 0{,}0014 P_{śl} + 0{,}8794 \qquad (4)$$

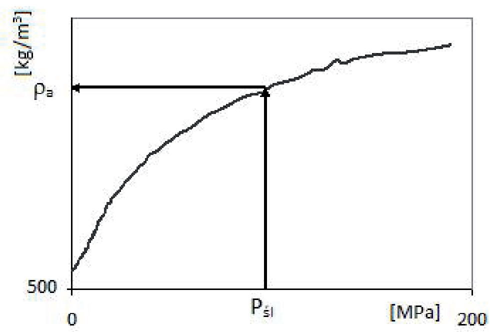

Figure 7 Determination of agglomerate density inside compaction chamber of the screw briquetting machine

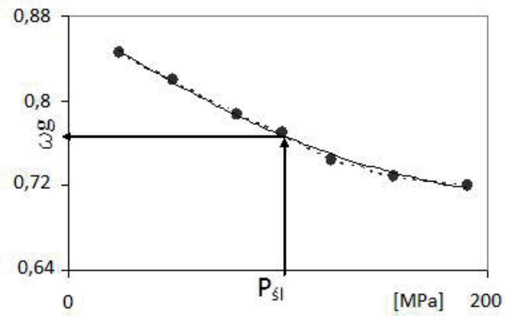

Figure 8 Determination of the value of ω_g coefficient at given compaction pressures

Assessment of the working system: screw –sleeve

The above mentioned methods allow to determine a (maximum) density of the finished product (briquette) which is possible to obtain from the analysed screw press working system. If a determined product density ρ_b is higher or equals to the expected (assumed) ρ_{ocz}, the given working system can be considered as suitable for the given feed material. Then, it is also possible to determine a length of the open chamber. If a determined product density is lower than expected it is necessary to change the screw parameters or a shape of the internal surface of the extrusion sleeve. After the parameters are changed the analysis needs to be repeated.

Determination of the length of the open compression chamber

Length of the open chamber l_m in screw press (for the calculated briquette density ρ_b) is determined on the basis of the author's former research [4], where influence of length of a chamber on briquette density was considered. The length is determined according to the diagram presented in Figure 9.

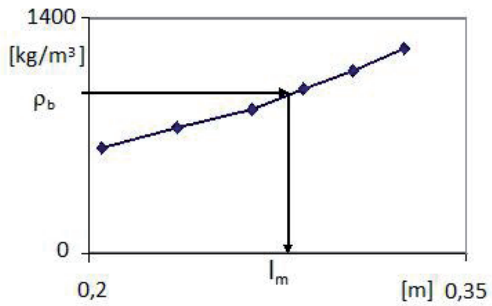

Figure 9 Determination of the compression chamber length

5. CONCLUSIONS

The research has proven that the chosen method is suitable for screw press parameters determination. Differences between fuel logs density values obtained experimentally and determined according to presented method are no bigger than 3-5%. Presented method is suitable for determination of screw presses applicability for the purpose of various particulate plant materials. The method requires preparation in a form of measurements of compaction characteristics, pressure distribution in the briquette and reverse expansion determination.

As, in many cases, briquette density for different feed materials does not always correspond directly with its quality, it may be necessary to perform a measurement of the crushing strength of the obtained product. Crushing strength is an essential parameter in fuel logs utility assessment.

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