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Equipment for Research of Parameters in Compression and Extrusion of Materials

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Abstract:*The paper deals with the development of experimental pressing equipment designed for complex experimental research of the influence of individual parameters on the quality of pressings and the energy demand of the compacting process, primary for particulate matter and high viscosity substances. Research and development of this design is based on the partial research results of particulate matter and powder densification. Designed construction equipped with rich accessories ensures research of the influence of all parameters on the overall process and the final production quality. Its modularity and sensor equipment allows to realize complex research whose output can be complex mathematical models of densification process allowing optimization of individual parameters. The presented case is demonstrated on biomass densification as a type of particulate matter.*

Keywords:*Extrusion, Compacting, Pressing chamber, Densification, Densification parameters.*

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I. INTRODUCTION

Optimization of the process of biomass densification into solid biofuels is currently a highly topical issue. Producers usually use the "trial-and-error" method to design the machine because there is no exact mathematical model for the biomass densification process [2,3,5]. A serious problem is not only the optimization of the design of existing compaction machines in order to eliminate failure rates, but also reducing the energy intensity of the compaction process, hence the need to modify existing structures or to develop new work principles compaction machines with higher efficiency. The issue of energy intensity of the process of biomass compacting into a solid high-grade biofuels must be seen as a priority [1,4,6,7]. It is the energy efficiency of the process that directly affects the price of biofuels and thus its competitiveness on the market compared to fossil fuels.

Importance of design parameters of pressing tools as well as the pressing chambers has to be seen on two levels. Design parameters directly affect the force ratios on the tool and in the chamber. This distribution of forces directly affects the resulting quality of the pressings. On the one hand, it is possible to control the quality of the pressings by knowing the force ratios in the pressing chamber and on the tool, on the other hand, it is possible to effectively optimize the design of these tools [7,8,10]. It is obvious that a detailed study of the influence of all design parameters on the process and the final quality of pressings is a very large task and requires a detailed mathematical-physical analysis of this issue [7, 9]. The most significant influence on the compacting process is the geometric parameters of the pressing chamber, i.e. shape and dimensions (diameter, length, conicity) [8, 11]. It should be noted, however, that in the vast majority of cases it is the pressing by extruding the material through an open chamber, the so-called extrusion. The geometry of the pressing chambers currently used for the production of solid biofuels by extrusion is very diverse. It consists of a cylindrical and in most cases also a conical part. Also, surveys and analyzes of compaction tools for the production of solid biofuels show that a combination of several cylindrical and conical parts of the pressing chamber is often used. The length of the cylindrical part provides the necessary pressing back pressure by means of frictional forces. It also provides the pressing with a high-quality smooth surface. The conical part of the chamber causes the spatial movement of the particles of compressed particulate matter, and thus a higher degree of compaction, which results in a higher quality of production. If the material is extruded through the conical part of the chamber, the pressings gain a higher density and strength. However, the friction and pressing conditions in the conical pressing chamber significantly increase the required pressing pressure, and thus, inter alia, the energy requirements for production [12]. The shape and dimensions of the pressing chamber have a direct influence on the achieved production quality and on the value of the required pressure [7-9, 13].

The design of the pressing stand as an experimental device designed for comprehensive experimental research of the influence of individual parameters on the quality of pressings and energy intensity of the pressing process (primary biomass, but not only that) is based on the results of partial research [7-10] carried out by the authors of this article. The designed pressing stand equipped with a wide range of accessories will ensure the research of the influence of the above mentioned parameters on the overall process and the resulting quality of production. With its modularity and sensor equipment, it will enable comprehensive research to be carried out. Its output will be complex mathematical models of the pressing process enabling the optimization of individual parameters. [7,10]

Due to its construction, this device enables the implementation of complex experiments in the field of compression and extrusion of particulate materials, powders, as well as materials with high viscosity. The aim was to design a modular construction of the device, which will allow to examine all technological and structural parameters of the compression and extrusion process and their subsequent optimization. It allows to research the influence of individual parameters as well as any interactions on the quality of the pressing, and the energy consumption of the compacting process. It also makes it possible to simulate compression in a closed pressing chamber as well as extrusion in an open chamber. The developed device allows to examine:

- effect of pressing pressure,
- effect of pressing temperature,
- effect of pressing speed,
- effect of the holding time of the material under pressure,
- effect of pressing size,
- influence of the geometry of the pressing chamber (influence of the diameter, length, angle of inclination of the walls of the pressing chamber, influence of the combination of shapes of the pressing chamber),
- coefficient of friction between the pressed material and the pressing chamber,
- horizontal compression ratio λ (main stress ratio: radial / axial),
- and other.

The basic requirement for the performance of this device is the possibility of producing various dimensions of pressings up to a size comparable to production briquetting machines while achieving real values of pressing pressures. The accuracy of the research requires the most faithful simulation of the production process. The most striking example is the process of densifying the same size fraction in a pressing chamber with different diameters (differences in pelleting and briquetting).

II. DESIGN OF PRESSING EQUIPMENT

The construction of the pressing equipment was designed with a view to maximizing functionality and economy. It is designed from commonly available semi-finished products of structural and tool steels. Conventional machining technologies can be used to produce individual parts. A 3D model of the designed construction of this press stand with a closed chamber is shown in Figure 1.

Example of the arrangement of the modular design of the pressing equipment is shown in Figure 2. The basis of the construction of the pressing stand is a rigid frame made as a weldment, which consists of a bottom plate 1, two trapezoidal supports 2, top plate 3 and press chamber body 4. Three delimiting sleeves 5 are inserted into the body of the pressing chamber 4. The exact relative position of the sleeves is established by one long tongue passing through the axial stabilizing grooves on the inner cylindrical surfaces of all three sleeves. The delimiting sleeves 5 are selected in the number of three due to the total length of the pressing chamber and the possibility of their production by conventional technologies (shaping). The inserts of the pressing chamber of the different combination 6 are successively placed one on top of the other in the delimiting sleeves 5 so that the opening formed by them - the pressing chamber reaches the desired geometry. The inserts 6 have a groove for the tongue on the outer cylindrical surface, which clearly defines their mutual position during insertion and cannot rotate relative to each other. The long tongue secures the relative position of the delimiting sleeves 5 and the inserts of the pressing chamber 6. The delimiting sleeves 5 have three longitudinal grooves adjoining one another on the inner cylindrical surface at a spacing of 120 °, which form channels for the sensor cabling. Three planar surfaces at a spacing of 120 ° are made on the outer cylindrical surfaces of the inserts 6, on which strain gauges for measuring radial forces during pressing will be placed and whose cabling will be routed through channels in delimiting sleeves 5 to the top of the pressing stand. By screwing the upper flange 7 to the body of the pressing chamber 4, the inserts 6 are pressed against and prevented from being pulled out during the backward movement of the punch in the event of a failure when the punch is jammed in the pressing chamber. Controllable heating device 12 surrounds the body of the pressing chamber 4. In the case of pressing in a closed chamber, the pressing chamber will be closed from below by a back-pressure plug 8 with a screwed-on guide rod 9. The pairs of support wedges 10 will be used to define the axial position of the plug 8. These will simultaneously transfer the axial load from the back pressure plug 8 to the lower plate of the frame 1 during pressing. In the case of using a short pressing chamber and the need to insert the back-pressure plug 8 deeper into the chamber, it will be possible to define its axial position together with the pair resp. pairs of support wedges 10 used one or more two support plug spacer rings 11. The height of the pair of wedges 10 corresponds to the height of one insert 6 and the height of the spacer ring of the back-pressure plug 11 is equal to the height of the three inserts 6. This ensures the modularity of the length of the pressing chamber. [10]

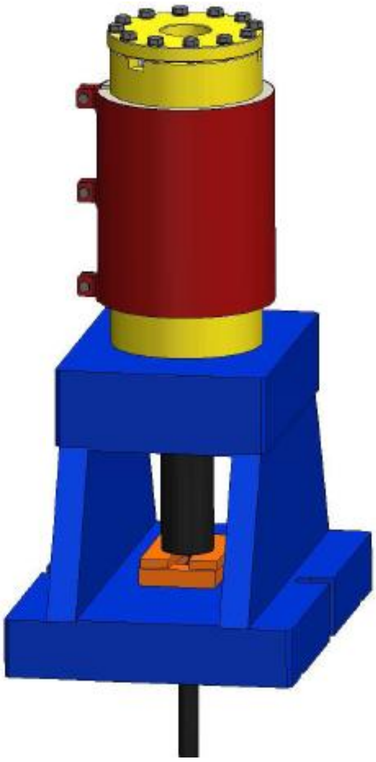

Figure 1 Model of the pressing equipment with a closed chamber

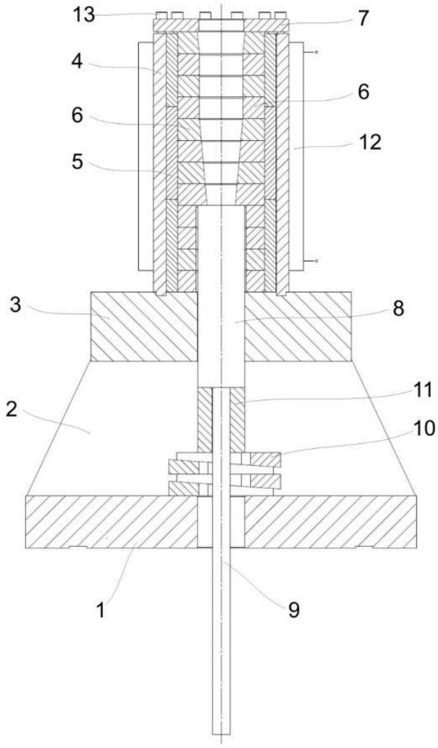

Figure 2 Example of the arrangement of the modular design of the pressing equipment

III. MODULARITY OF THE PRESSING CHAMBER

The aim of the research was to design a single device with maximum modularity of the pressing chamber. However, a change in the geometry and openness of the pressing chamber is also directly related to a change in the force load of the structure, which must be taken into account. The result of the design is a modular pressing chamber of a single device, which allows to simulate the pressing process both in the open chamber and in the closed chamber.

The geometry of the pressing chamber can be changed as required by simply replacing the inserts. The design took into account a punch diameter of 50 mm, what is an initial inlet diameter to the pressing chamber. The pressing chamber consists of first lead-in insert and subsequent eleven replaceable inserts in the pressing chamber. Each insert has a height of 25 mm, which sufficiently covers the modularity of the creation of different geometry of the chamber and at the same time suits a high workload. The geometry of the pressing chamber can be composed of four types of combinable inserts shown in Figure 3:

1. insert with cylindrical hole,
2. insert with conical hole,
3. insert with cylindrical continuation of the conical hole of the previous insert,
4. distance insert.

The versatility of the pressing equipment design in order to examine the pressing process of different types of particulates also requires a diverse range of different geometries (shape and size) of the pressing chambers formed by mentioned inserts. As part of the developed construction, a set of sixteen sets of individual combinable types of inserts in a total of 233 pieces was designed for the purpose of biomass pressing and extrusion research. A set of eleven cylindrical inserts is designed for the simplest shape of a cylindrical pressing chamber. The set of inserts for one apex angle consists of several successive conical inserts and two inserts with a cylindrical continuation of the conical hole for each conical insert in the set. For the realization of experiments to optimize the geometry of the pressing chamber with the most accurate results, it was proposed to graduate the apex angle of the conical hole by 2°, from 0° to 30°.

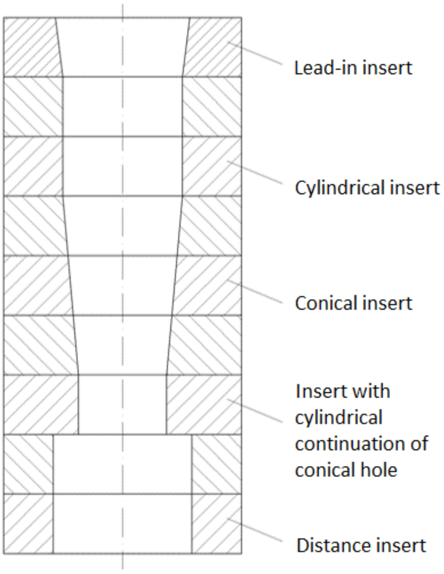

Figure 3 Types of pressing chamber inserts

Theoretically, it is possible to achieve up to 1513 different basic geometries (shapes and dimensions) of the pressing chamber by combining the arrangement of the inserts of the individual sets (combination of conical inserts set with a cylindrical inserts set) to ensure a smooth transition of the pressing chamber shape. Examples of the modular arrangement of the inserts creating the geometry of the pressing chamber are shown in Figure 4. The modularity of the pressing chamber by arranging the inserts also allows other types of geometries beyond the basic number of 1513. It is a continuation of two inserts from different sets with different apex angles, for example, geometry of the type "cone - cylinder - cone", "cone - cone - cone", "cone - cylinder - cone - cone" and others. The possibilities of application of these types of press chamber geometry depend on the smooth transition of the hole from one insert to another. However, based on the design of very fine gradation of the apex angle of the conical hole of the inserts, there is no problem in applying such combinations of geometry.

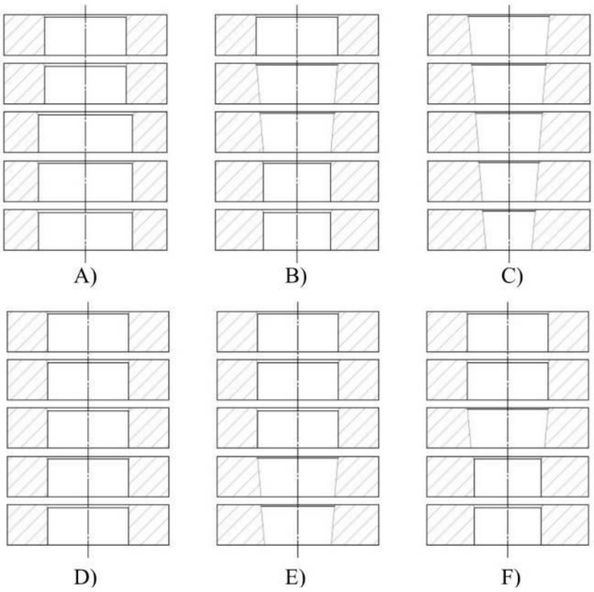

Figure 4 Examples of modular arrangement of pressing chamber inserts

The modular definition of the position of the back-pressure plug is also directly related to the modularity of the closed pressing chamber. This position definition is realized by means of a pair resp. pairs of support wedges. In the case of using a short pressing chamber and the need to insert the back-pressure plug deeper into the chamber, it will be possible to define its axial position by using the pair resp. pairs of support wedges possibly by using one or two support plug spacer rings. Modularity is based on the replaceable dimensions of the components. The height of the pair of wedges corresponds to the height of one insert and the height of the spacer ring of the back-plug is equal to the height of the three inserts. This ensures the modularity of the length of the closed pressing chamber.

IV. EXPERIMENTAL VARIABILITY OF THE PRESSING EQUIPMENT AND ITS EXPERIMENTAL POSSIBILITIES

The design and variability of the pressing equipment enables the regulation, measurement and examination of all technological and construction parameters of the compaction or extrusion process of particulate matter and high viscosity substances. The developed design allows to examine the entire process on a single device, and directly and also easily regulate individual parameters. The pressing equipment enables the realization of:

Investigation of the influence of pressing temperature

The body of the pressing chamber is equipped with a heating device. The research of the influence of the change of the pressing temperature in the pressing chamber can be realized by continuous regulation of the heating power and by direct measurement of the temperature of the body of the pressing chamber. The problem with heating is usually the time hysteresis of the rise and fall of temperature with larger volumes of materials (structural and pressed). Therefore, the heating power must be large enough.

Investigation of the influence of pressing pressure

The size of the pressing pressure plays the most important role in compaction and extrusion. Therefore, a hydraulic press with a range of pressing force up to 1 MN is recommended for the implemented research. The press makes it possible to directly regulate this force by changing the pressure in the hydraulic circuit. Accurate measurement of the compression force is realized by means of sensors placed directly on the punch.

Investigation of the influence of pressing speed

The speed of pressing plays an important role in the production of pressings and significantly affects the quality of production. It will be possible to control the pressing speed directly by controlling the flow in the hydraulic circuit of the press.

Investigation of the influence of the holding time of the pressing under pressure

When researching the effect of the holding time on the pressed material under pressure, it is possible to control and accurately measure the pressing pressure (pressing force) acting on the pressed material as well as the time during which the desired pressure of a constant value will act on this pressed material.

Investigation of the influence of the geometry of the pressing chamber

As already mentioned in detail, the modularity of the design makes it possible to press in the open chamber by extrusion and also in the closed chamber. By simply exchanging and arranging the designed inserts, it is possible to examine the pressing process in more than 1513 basic variants of the geometry of the pressing chamber.

Investigation of the coefficient of friction

Coefficient of friction is directly related to the pressure conditions in the pressing chamber through the friction forces, and therefore affects the quality of production. Its examination is possible by measuring the pressing force and the force exerted by the pressed material on the stopper when the cylindrical chamber is closed. It depends on the pair of materials - the material of the pressing chamber and the pressed material, further on the type, chemical composition, fraction size and water content of the pressed material, on the surface roughness of the chamber.

Investigation of the horizontal compression ratio λ

The horizontal compression ratio, i.e. the ratio of the radial stress to the axial stress in the compressed particulate matter, is specific to each type of compressed particulate matter and its structural properties. Its definition and knowledge of specific values is a basic prerequisite for the accuracy of applied mathematical-physical models of pressing. Its investigation consists in measuring radial pressures by strain gauges on the inserts of the pressing chamber when loading the pressed material with axial pressure. The cabling of the sensors will be routed through channels in the delimiting housings to the surface of the pressing stand. In this way, it is possible to measure and evaluate not only the value of the radial pressures acting on a individual insert, but also the distribution of the radial pressures in the pressing direction depending on the different geometry of the pressing chamber.

In Figure 5 and Figure 6 is a view of a real construction of the pressing equipment of the verification experiments of the compression and extrusion. Figure 7 shows a view of the assembled pressing chamber with the cabling for strain gauges on the inserts. Calibration of these strain gauges for measuring the radial compressive load was performed by a controlled hydraulic pressure acting on the inner wall of the calibrated insert clamped in a specific jig (Figure 8).

Figure 5 Pressing equipment in a hydraulic press

Figure 6 Design of pressing equipment

Figure 7 View into the assembled pressing chamber with the cabling for strain gauges

Figure 8 Pressure jig for sensor calibration

V. CONCLUSION

Based on the results of the market research and patent search in the implemented area, no suitable equipment was found that would meet all the requirements for the complexity of the implemented and planned research. The developed construction of the pressing equipment with accessories is based on specific requirements for the study of the complex process of compression and extrusion, i.e. investigation of the effects of all process parameters on the quality of production and energy intensity of this process. The design is significant especially for the modularity of the geometry of the pressing chamber. The versatility of the design and the complexity of quantification of individual parameters of the compression and extrusion process predetermine its use in process research for a wide range of particulate matter, powders and substances with high viscosity. As a result of the design of this construction "Laboratory facilities to assess the impact on compression parameters of particulates" patent number SK288498B6 was granted on October 3, 2017.

Conflict of interest

There is no conflict to disclose.

ACKNOWLEDGEMENT

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