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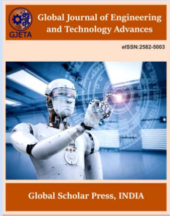

(Research Article)

Development of double screw press and method of controlling the parameters of the briquetting process

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Abstract

Paper is focused on development of new patented construction of screw briquetting machine for compacting biomass into the solid biofuel. Developed machine design is based on achieved results of comprehensive research of the complicated process of biomass densification. Patented construction provides two main goals: the elimination of axial forces, which causes increasing of bearings lifetime, and a new modular design of pressing chamber and tools with geometry based on application of the mathematical model. Research of the biomass densification pointed to the need for modular design of densification machine, where it is possible to control all significant parameters of the densification process. The goal of this paper is to present a new patented design of screw press, which satisfies all requirements for modularity and control of the parameters. It allows optimizing this process for different types of raw materials and achieving high quality production. Results of experimental research of densification process then allow the engineering design of the production machine tailor-made to the customer, while being able to minimize investment, energy and operating costs. The developed design of screw press is unique in its modularity and high reliability.

Keywords: Biomass; Screw press; Briquetting press; Densification; Briquette; Control of briquetting process

1. Introduction

The recent situation in the world associated with the disruption of energy supply in world markets, the gas crisis, as well as the global financial and economic crisis, highlights the challenges posed by energy markets and highlights energy security issues. The issue of energy security occupies an important place in the security of each state. It is particularly important because only a reliable supply of energy creates the conditions for the harmonious development of the modern economy and society as a whole.

The current geopolitical situation shows how important the diversification of energy sources is. It is the use of alternative energy sources that becomes the way out of this situation. At the time of the search for new energy sources in the world, the question of the possibilities and methods of efficient use of biomass as the most important renewable energy source arises. The use of biomass could be the answer to this question, but a more sophisticated solution is offered by the transformation of biomass waste into high-grade forms of solid biofuels with higher energy density, greater comfort of use, transport and handling. Biomass is the most promising renewable energy source with the most efficient storage options for this energy.

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Solid biofuels can only be competitive with fossil fuels if they are of high quality and produced at low operating costs. Existing technologies for densification biomass into solid biofuels enable high quality production, but reducing operating costs is much more difficult.

A number of scientific papers deal with research of the efficient densification of biomass into solid biofuels and the development of compacting machines. Study [1] deals in detail with the complex geometry of pressing channels in biomass densification, its impact on the quality of production and the function of individual parts of pressing channels. The work [2] is focused on Mathematical modeling of die pressure of a screw briquetting machine, where the authors examine in detail the effect of geometric parameters of the pressing chamber on the pressure and friction conditions in the chamber. This knowledge effectively influences the design of pressing tools. Design parameters of a pressing channel for solid biofuel production are essential for running optimal production in terms of energy consumption and quality of the biofuels [3]. In this study, the effects of the countersink angle and depth are investigated through experimental tests and Computational Fluid Dynamics (CFD) simulations. Experimental works [4, 5, 6, 7, 8] investigate the effect of important parameters of the briquetting process on the final quality of briquettes. The developed design of the compaction machine must guarantee the required optimal operating parameters. The authors of the scientific work [9, 10, 11, 12] present the results of extensive research into the construction of the pressing chamber of briquetting machine. Studies [13, 14] focus on Design Theory for Screw Geometry in a Briquette Press. Research outputs of scientific works [15, 16, 17, 18, 19, 20, 21] deal with research and development of efficient briquetting machine designs. They describe in detail the individual constructions of the machines, they are engaged in pressing experiments and the optimization of design parameters.

The presented contribution deals with the issue of biomass compaction and the development of the construction of a double-screw briquetting machine. The research is carried out comprehensively, from the study of elementary biomass particles to the design and production of a new construction of a briquetting machine and its tools.

The aim of the research was to design and verify a prototype of a new progressive design of a briquetting machine and to develop highly productive pressing tools while meeting the following framework requirements:

- ensuring the highest quality of production,
- reduction of operating costs compared to existing production machines,
- achieving high productivity,
- versatility for different types of input raw material,
- regulation of all parameters influencing the biomass pressing process,
- and others.

2. Design of briquetting press

During the development of a new compaction equipment - a new design of a screw press, the results of research into individual parameters influencing the biomass compaction process were applied. The developed construction enables the control of individual technological and design parameters of the compaction process so that it is possible to achieve a high quality of production at various input factors. The area of development is focused on screw presses due to achieving the highest quality of production by this principle. However, their wider application in practice is generally hindered mainly by the high operating costs associated with the low service life of the bearings and the working tool (pressing screw) caused by the high axial load. The established requirements for the development of the structure itself were as follows:

- Elimination of axial load of bearings, thus increasing their service life,
- Optimization of tools in terms of shape and material properties to increase the efficiency of the compaction process and increase their service life,
- High modularity of the machine,
- The ability to control and regulate all important parameters of the compaction process,
- Possibility of quick exchange of tools - screws and pressing nozzles,
- And other.

Figure 1 shows a schematic of the entire construction of a new screw press. It is a two-chamber double-sided construction enabling high-quality production of pressings from various raw materials, due to the possibility of controlling every important parameter of the pressing process. The construction is also equipped with sensors that provide feedback. The machine consists of one common main drive, a spindle bearing node that absorbs the workload and defines the exact position of the press screw in the press chamber, two identical press chambers with tools, two filling systems and two cooling channels.

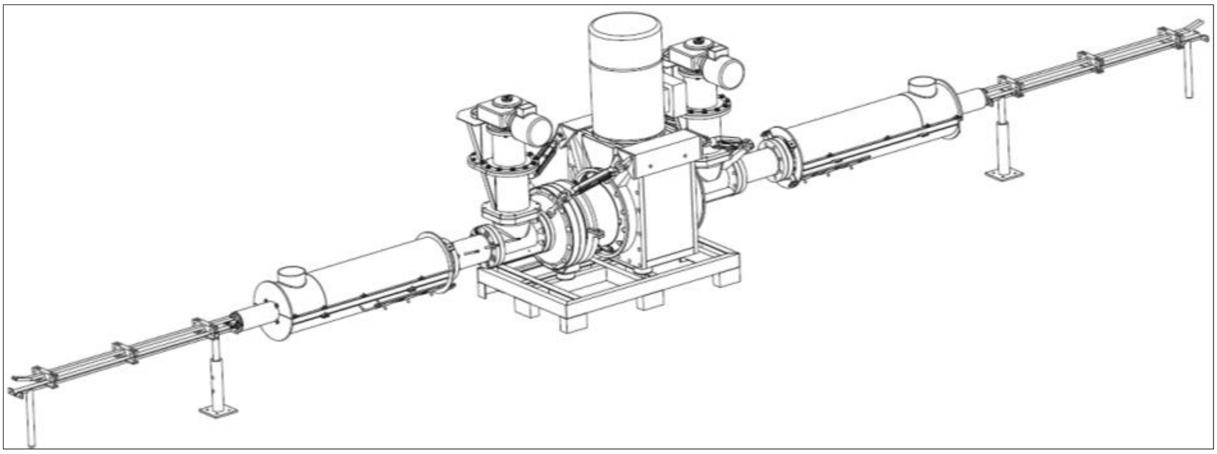

Figure 1 Design of developed screw press

The core of the machine without cooling channels is very compact (Fig. 2) and placed on the frame of the dimensions of the euro pallet for easy handling. The construction of the developed machine is not only exceptional in its compatibility, but also in its mobility, when the individual nodes can be dismantled very quickly to dimensions suitable for transport. Subsequent assembly is again very fast without the need for adjustment, setting up - e.g. due to more frequent transport of the machine to real customer production for longer-term operational tests and then back to the laboratories for evaluation. The machine does not need to be anchored during operation, the frame does not transmit any workload or vibrations.

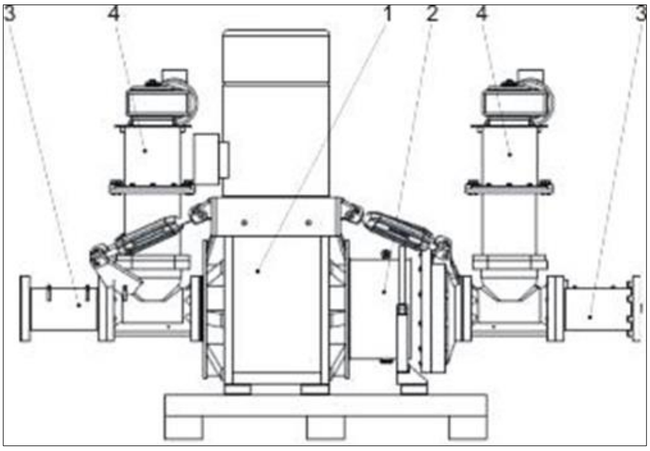

Figure 2 Basic parts of a screw press (1 - machine drive, 2 - spindle bearing unit, 3 - pressing chambers, 4 - filling systems)

The modularity of the designed machine makes it possible to create a single-chamber machine from double-chamber very simple and fast disassembly of one part of the press - the whole side from the press drive, without further modifications. Such a single-chamber design is used mainly in experiments and measurements, as it allows to measure the entire operating load.

3. Design of the pressing chamber

The pressing chamber must be strong enough to withstand the internal pressure while pressing. It consists of the body of the pressing chamber, the feed screw, the pressing screw and the individual nozzles (Fig. 3). High material requirements and geometric requirements are placed on the tools inside the pressing chamber. The material requirements include high abrasion resistance, toughness and thermal stability. The geometrical requirements are complicated, and vary according to the type of raw material. The basic geometrical requirements are to ensure an increase in material pressure during compaction. In addition, the geometry of the tool must generate axial movement of the material to ensure continuity of the compacting process. [22]

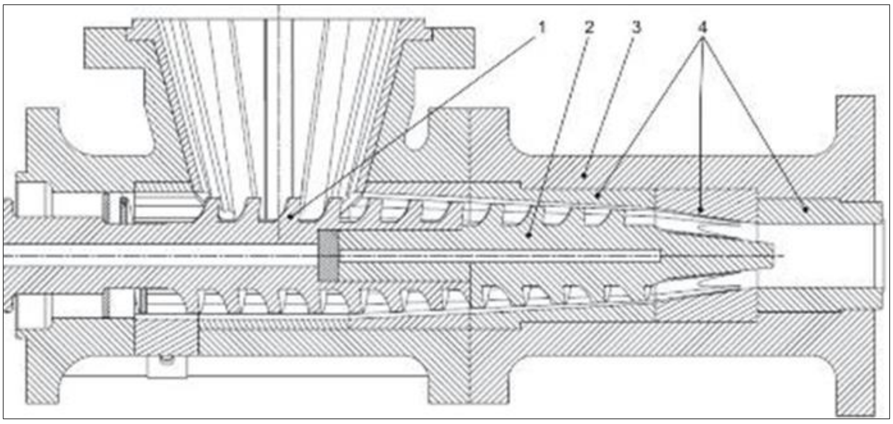

Figure 3 Tools of screw briquetting press (1 - feeding screw, 2 - pressing screw, 3 - pressing chamber, 4 - nozzles) [22]

The pressing chamber is coated by heating devices to control the pressing temperature, which is the most important parameter in the biomass compaction process. The design of the heating system provides direct measurement and control of the pressing temperature, up to 350°C.

During optimization of the compacting process, it is possible to change the shape and size of the pressing by simply and quickly changing the tool (screws and pressing nozzles), changing the inner diameter of the pressing chamber, the length of the pressing chamber, the combination of tool materials, the taper of the pressing chamber, etc. The structural parameters of pressing tools are optimized experimentally, e.g. the whole compaction process for different types of raw materials.

4. Design of the pressing screw

The geometry of the pressing screw (Fig. 4) ensures a high degree of material compaction in the pressing chamber and compression of the material through the nozzle, thus achieving a compact briquette of high density, strength and surface quality. The movement of the material, the compression, the rate of wear and the stress distribution depend primarily on the chosen geometry of the screw. It is therefore extremely important to pay close attention to the design of the screw geometry.

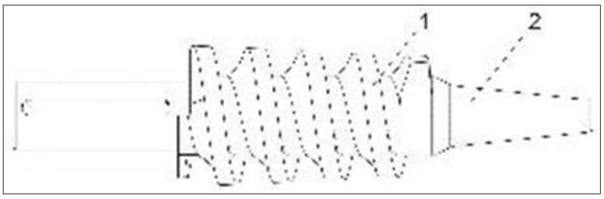

Figure 4 Monolithic pressing screw (1 - working thread part of the screw, 2 - tip)

The pressing screw is the most stressed component of the machine, with the highest level of wear. It is subject to high pressure, abrasion and heat. The critical part of the screw is the tip (Fig. 4) and the first 1.5 revolutions of the thread, which shows on the instruments workload distribution.

The degree of the load and tool wear is also dependent on raw material. Further research and optimization is therefore under preparation for several sets of tools made from a variety of special steels, coating tools and tools with hard-grinding threads. Pressing screws are designed as monolithic (Fig. 4), as well as folded (Fig. 5, Fig. 6), which can have a rotating tip to reduce friction. A folded screw can have each part made of a different material, which reduces costs. The modularity of the tool enables optimization of the compaction efficiency of different types of raw materials at the lowest tool cost. [22]

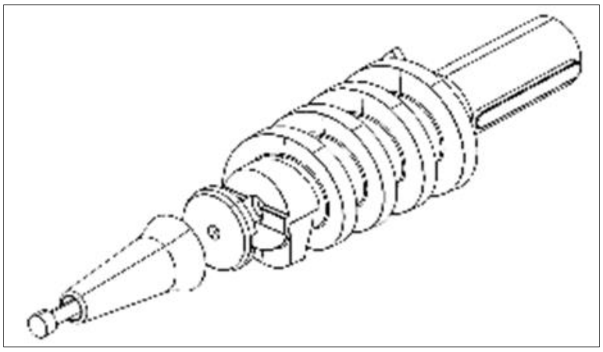

Figure 5 Folded pressing screw with a rotating tip

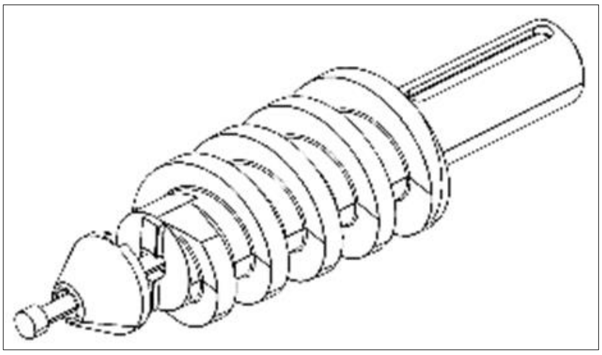

Figure 6 Folded pressing screw with a fixed tip

4.1. Method of controlling the parameters of the briquetting process

During the development of the machine, a very strong emphasis was placed on the possibility of controlling individual technological and construction parameters of the compaction process, which production machines do not currently allow. By controlling these parameters, it is possible to make accurate measurements and optimize the entire compaction process for any type of compacted material (organic), and thus to design an optimized machine construction tailored to each customer depending on his requirements. Optimization make it possible to set such process parameters so that the achieved quality of production meets the limits set by the standard at the lowest operating and investment costs.

The temperature and humidity of the incoming pressed material can be regulated by means of a controlled preheating located in the filling system. Research is currently underway into the possibility of applying microwave heating of the material before entering the filling system. If microwave heating proves to be a more effective way to control the temperature and humidity of a material, it will be necessary to address the continuity of such heating in further research.

The most important technological parameter influencing the quality of briquettes is the pressing pressure. It is derived on the pressed material with a tool (pressing screw). It is very important to know how to control the amount of pressure. The developed screw press allows several ways to control the pressing pressure. Primary pressure control is achieved by controlled performance characteristics of the drive, especially by controlling the amount of torque and frequency of pressing screw. However, in order for the pressing pressure to increase, it is necessary to effectively fill the space between the threads of the tool with the material. This requirement is realized by overfilling the pressing space due to the conical design of the filling system and the frequency control of its drive. Even these control methods may not always lead to an increase in pressing pressure to the desired level. The third method of regulation is a collet located behind the pressing chamber. The counterpressure in the pressing chamber can be controlled by changing the cross-sectional size of the collet through which the briquette exits the pressing chamber, and thus to achieve the desired value of the pressing pressure. The results of the research showed that the pressing pressure and the derived counterpressure are directly dependent. Therefore, the control of the pressing pressure is solved by the synergy of all three methods (Fig. 7). These methods of controlling the size of the pressing pressure, resp. necessary axial pressing force deriving this pressure, do not provide feedback in the form of measuring the size and course of the pressing pressure, resp. pressing force when changing individual factors. For this reason, a built-in system of direct measurement of pressing force is proposed. The system includes two piezo-crystalline force transducers located in the spindle housing and sensing the pressing axial force directly on the outer ring of the bearing. Both are located on one bearing at a 180 ° spacing. The sum of the measured and evaluated components of the axial force acting on the sensors corresponds to the resulting pressing force deriving the pressing pressure of the tool on the pressed material. The sensors are able to measure the dynamic course of the load, which allows to achieve more accurate and relevant measurement results.

Pressing temperature is an irreplaceable technological parameter that must be controlled and regulated. The design of the press is supplemented by a heating device of the pressing chamber consisting of three independently controlled circuits (Fig. 7). It is an electric heating of the chamber regulated by a control unit and controlled by three temperature sensors embedded directly in the pressing chamber to a depth of 1 mm from the inner wall of the pressing nozzle, which allows very precise sensing of the pressing temperature directly inside the chamber.

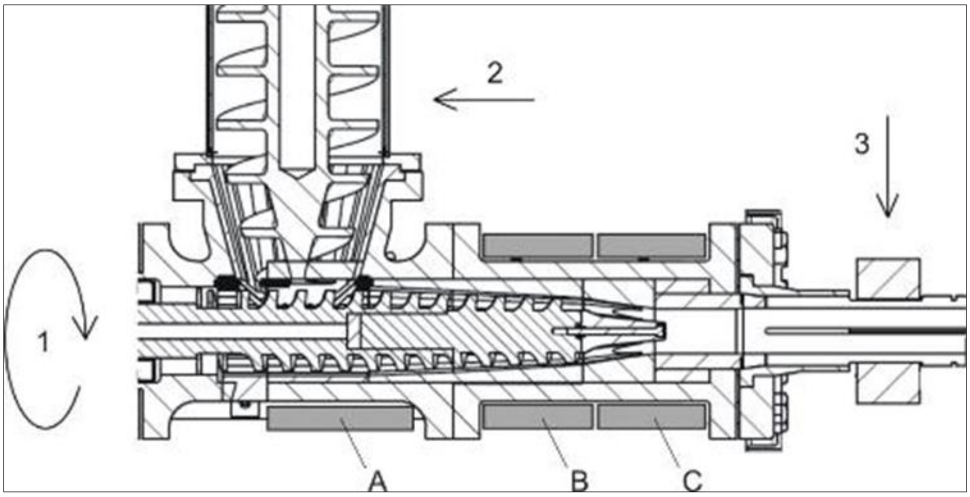

Figure 7 Pressing chamber section - methods of pressing pressure and pressing temperature control (1 - control of the torque and frequency of the tool, 2 - overfilling of the pressing space by controlling the speed of the filling system, 3 - control of the counter pressure by changing the cross section of the collet, A, B, C - controlled heating circuits of the pressing chamber)

The pressing speed is a very important parameter for optimizing the pressing process for different types of pressed raw material. Frequency programmable control of the machine drive is designed for its regulation.

From a technological point of view, a high cooling rate of the briquettes coming out of the press is highly desirable. Higher cooling rate of briquettes increases their mechanical quality parameters and can also increase productivity. This requirement has been integrated into the new design in the form of forced air cooling, the intensity of which is regulated by changing the air flow. The cooling system is located just behind the press chamber (Fig. 8) and surrounds the collet and part of the cooling channel. It creates a closed area through which the created briquette passes. The briquette is co-cooled by passing air through an industrial suction fan. The intensity of cooling is given by the air flow, which is controlled by a sliding lid covering the inlet openings into the body of the cooling system. Such a system also has a cumulative importance in the extraction of the generated vapors and gases after compression, or. dust particles. After exiting the controlled cooling system, the briquette proceeds further in the cooling channel, where further possible cooling in the air in the surrounding space takes place. The length of this cooling channel is also adjustable as required, as it consists of modular stages. The cooling channel is also important in the secondary generation of back pressure and in keeping the finished briquette under axial pressure during its cooling. In addition to the possibility of changing the length of the channel, it is also possible to control the radial pressure of the channel around the circumference of the briquette, which prevents its dilation during cooling. As the cooling channel is divided into several stages, the pressure (and thus the back pressure) can be controlled independently at each stage.

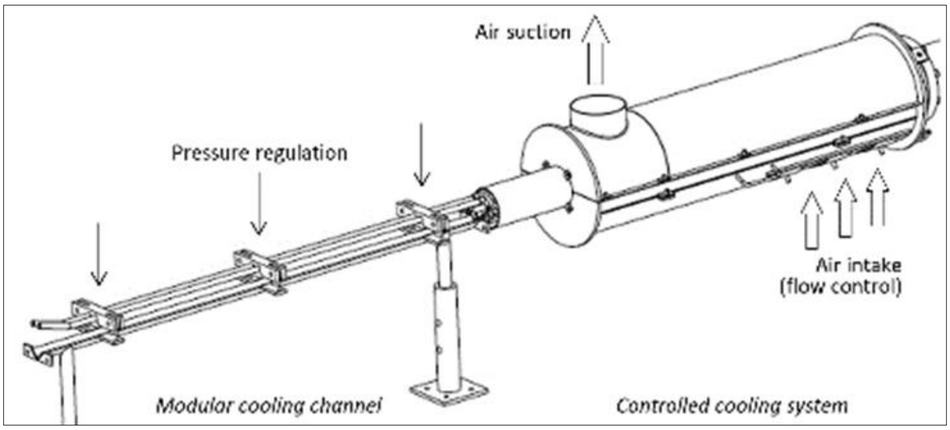

Figure 8 Controlled cooling system

In order to be able to optimize and regulate the design parameters, several sets of press tools (pressing screws, pressing nozzles) with different shapes and sizes have been designed and manufactured. By simply and quickly replacing these tools in the pressing optimization process, it is possible to change the shape and size of the briquette, the inner diameter of the pressing chamber, the length of the pressing chamber, the combination of pressing tools materials, the conicity of the pressing chamber walls, etc. Changing these parameters involves quick replacement of the pressing screw and individual pressing nozzles. The design parameters of the pressing tools, as well as the whole process of pressing various raw materials, can be optimized on the basis of experiments that this machine allows.

Biomass densification is a relatively complex process. Therefore, the design of the correct pressing tool geometry is a basic condition for the success of the technology. During the development, considerable attention was paid to the research of the geometry of the pressing tool, in this case the pressing screw. The development considered different tool geometries, especially different thread profiles, in the mathematical analysis. Mathematical theory of pressing screw geometry design was used to design a suitable screw geometry as a pressing tool. Each screw geometry has its advantages and disadvantages and it is necessary to analyze it from different points of view. However, after performing a mathematical analysis, it cannot be definitively stated that the thread profile is optimal in all respects, which moves the research to the next phase of optimization, where real pressing tests are necessary. For this reason, several sets of pressing screws have been designed and manufactured for experiments on the developed press. They differ not only in the geometry of the threads, but also in the geometry and construction of the tips (different shape of the tips, monolithic screw with tip (Fig. 4), without tip, replaceable screw with folded tip (Fig. 5, Fig. 6), etc.).

Figure 9 Developed two-chamber screw press located in the technological briquetting line

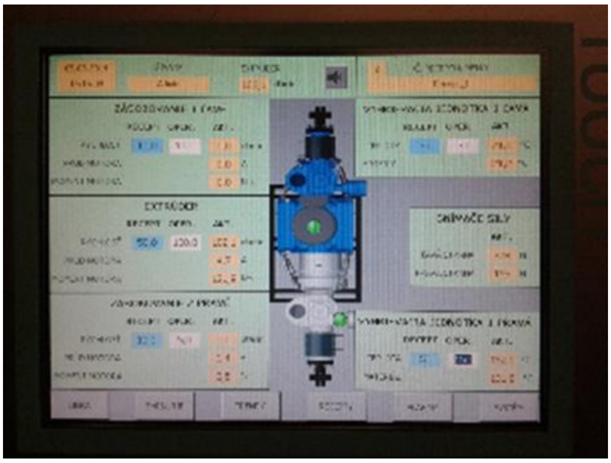

Figure 10 Developed control system for the machine

Figure 11 Results of experimental tests

Figures 9 and figure 10 show the manufactured developed design of a two-chamber briquetting press located in a technological line. A number of tests and optimization experiments were performed on the press (Fig. 12) and the achieved research results are excellent.

5. Conclusion

The aim of the paper is to point out the results of research of biomass compaction into the form of solid biofuels and their evaluation in the design of a new patented screw press design (Fig. 10). The design allows to control all the important parameters of the pressing process, and thus optimize this process for different types of compacted materials. The variability of the control of these parameters allows to densify and optimize the pressing process for a wide range of materials, not only from biomass. The results of the experimental research subsequently enable the optimization of the design of the production machine tailored to the customer, while it is possible to minimize investment, energy and operating costs.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

There is no conflict of interest.

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