Modularity of Pressing Tools for Screw Press Producing Solid Biofuels

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Abstract

This paper focuses on the development of the newly-patented structure of a screw briquetting machine for compacting biomass into a solid biofuel. The design of the machine is based on the results of a comprehensive study of the complicated process of biomass compaction. The patented structure meets two main goals: the elimination of axial forces, leading to increased lifetime of the bearings, and the new modular design of a pressing chamber and tools with their geometry based on the application of a mathematical model.

Keywords: biomass, screw press, compaction process.

1 Introduction

Briquetting biomass by means of screw pressing is a progressive technology in the production of solid biofuels. Screw presses offer great advantages in producing pressings of high quality, and they represent the most current and promising technology in the compaction of biomass to produce briquettes. Research to develop this technology further is a logical step. Increasing the tool life will reduce operating costs, and will lead to lower prices for the final product, making it a more viable application for biomass use. Compacting biomass as a live material is very difficult process. It is necessary to control important construction parameters for different kinds of biomass. The newly-patented structure of a screw briquetting machine was designed in our department for this purpose.

2 New design of a screw press

Research results for parameters influencing the process of biomass compaction were applied in developing the design of a new screw press. The design that has been developed enables the technological and structural parameters of the compaction process to be controlled in order to achieve high quality output with various input factors. The requirements for the development of the structure were as follows:

- Eliminate the axial load of the bearings, and thus increase their life,
- optimize the tools in terms of shape and material properties to increase the efficiency of the compaction process and to increase their lifetime,
- achieve high modularity of the machine,
- enable all important parameters of the compaction process to be managed and controlled,
- ensure that the pressing screw and the pressing nozzle can be exchanged rapidly,
- produce pressings of various shapes and sizes.

The comprehensive design of the new screw press is shown in Figure 1. It is a double chamber two-sided design, allowing quality production of pressings from various organic materials, due to the control options for each significant parameter of the compaction process, e.g. compacting pressure, pressing temperature, pressing speed, cooling intensity of the pressings, rapid exchange of worn tools, and required changes of tool geometry. The structure is also equipped with sensors that provide feedback in the compaction process. This screw machine is a universal machine for producing solid high-grade biofuels from a variety of raw materials.

The machine consists of one common main drive, a special spindle bearing that captures the work axial load and defines the exact position of the pressing screw in the pressing chamber, two identical pressing chambers with tools, two filling systems, and two cooling channels.

Single screw extruders are characterized by the very short lifetime of the thrust bearings, or by their large dimensions. The main objective of the two-sided design of the press is to eliminate the axial workload resulting from pressing the material, and thus progressively increasing the lifetime of the bearings. The bearings are loaded only with the difference of the axial pressing forces caused by asymmetric filling of the material into the pressing chamber. The whole workload is transmitted in the axis of the machine through the outer flange system (tensile stress)
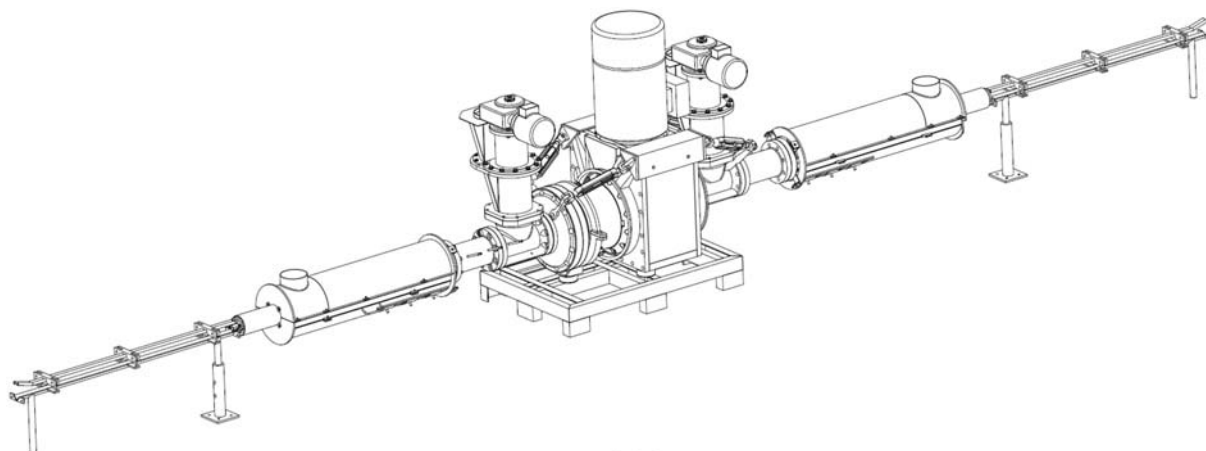
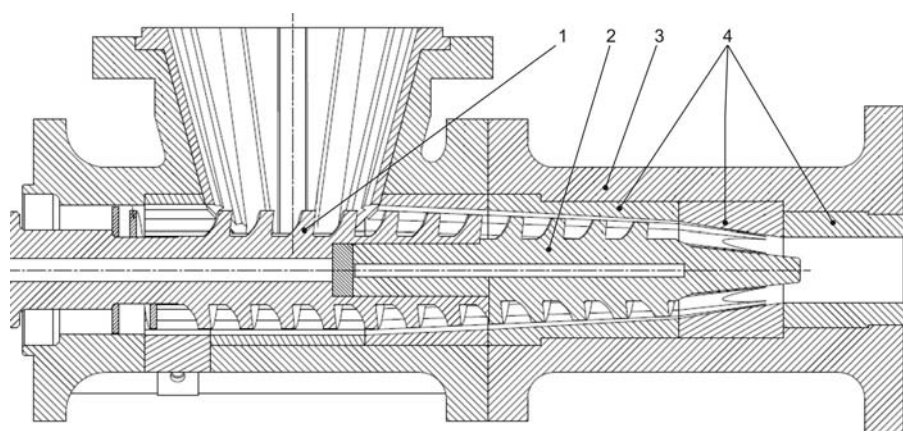Figure 1: Newly-patented design of a screw press

Figure 2: Pressing chamber with tools (1 – feeding screw, 2 – pressing screw, 3 – pressing chamber, 4 – nozzles)

and the continuous solid spindle with pressing screws on the ends (compressive stress). This system eliminates the need for a massive frame to transfer the load, or for anchoring the machine. The construction of the machine is designed for secure transmission of an axial load to 520 kN (pressing machine is able to draw 265 MPa for briquette diameter 50 mm).

The modularity of the double chamber machine enables a single chamber machine to be created very easily and quickly by removing a part of the press — the whole side from the drive of the press — without any other modifications. The single chamber design is used especially for optimization experiments and measurements, because it allows the full operating load to be measured.

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 (Figure 2). 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.

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 chosen 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 (Figure 3) 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.
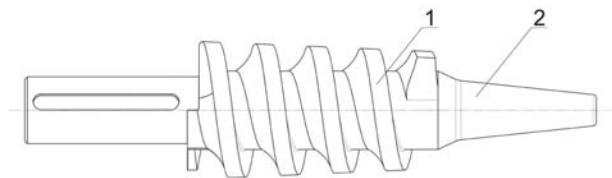
Figure 3: Monolithic pressing screw (1 – working thread part of the screw, 2 – tip)

We obtained a mathematical model (1) describing the dependence of the compacting pressure on the geometry of the screw by deriving the theory for the speed and power relations in the screw.

$$p = p_0 \cdot e^{A \cdot \frac{l}{D}} \tag{1}$$

This mathematical model is very important in designing the geometry of the pressing screw (p – working pressure, p_0 – initial pressure, A – constant of proportionality, l – active length of the screw, D – outer diameter of the screw). This relationship shows that the pressure in the screw profile is exponentially dependent on the length of the screw. The constant of proportionality (A) depends on the geometry of the screw profile and the friction between the material and the nozzle (fp), as well as the friction between the material and the screw (fz). The condition of a sharp pressure increase requires that the friction coefficient (fp) be as large as possible, while the coefficient (fz) is as small as possible. The coefficient (fz) can greatly affect the surface quality of the screw. The goal is to achieve minimum surface roughness. Coefficient (fp) can be increased by increasing the nozzle roughness or by machining grooves into the surface of the nozzles in the direction of the screw axis. Grooving not only increases the friction, but also prevents rotation of the material invoking so-called axial block flow.

The application of this theory will be demonstrated on three geometric variants of pressing screws

(Figure 4, 5, 6). For simplicity in comparing the different variants, the input parameters are the same for each screw:
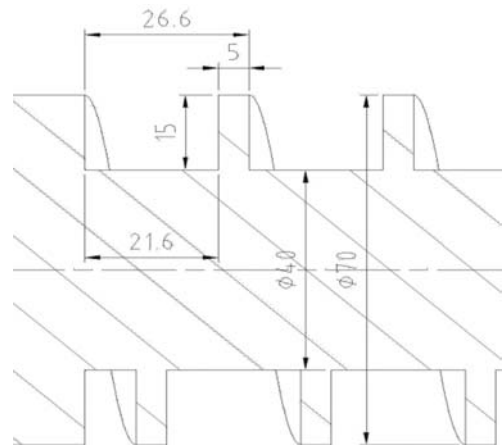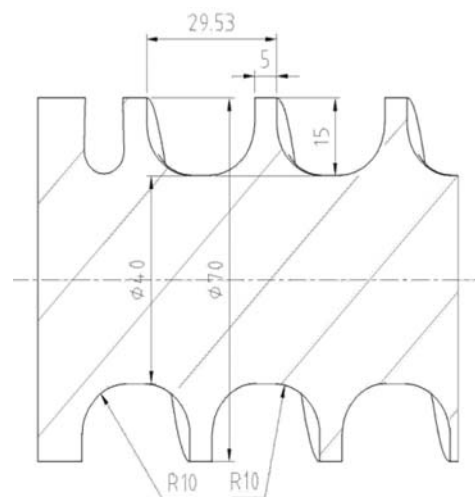
Figure 4: Screw section of variant A

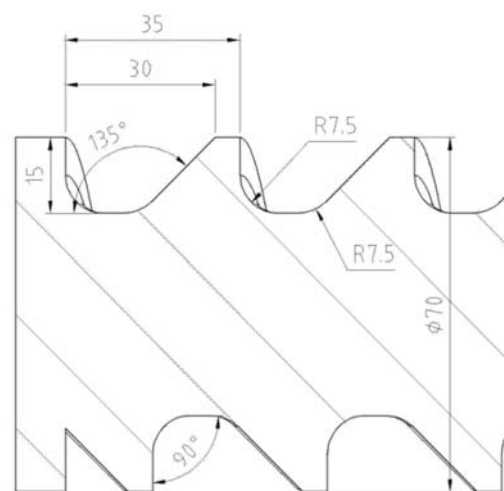Figure 5: Screw section of variant B
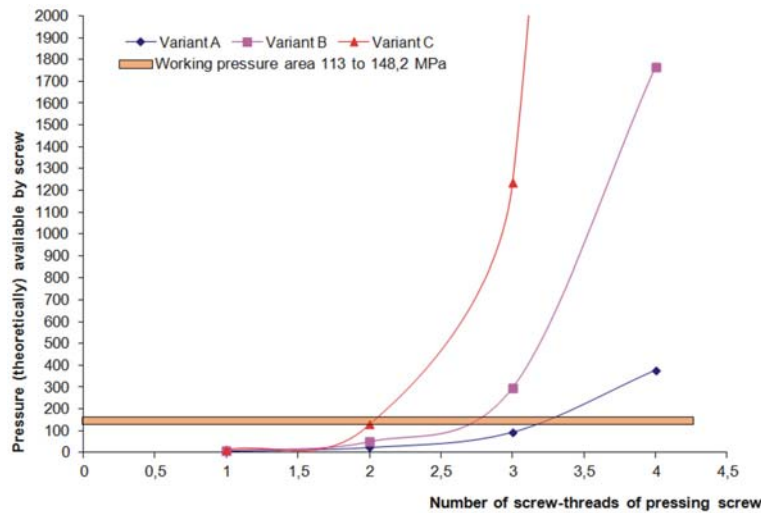
Figure 6: Screw section of variant C

Figure 7: Relationship between pressure and the number of screw threads at a constant initial pressure ($p_o = 1.05$ MPa)

- Outer diameter of screw ($D = 70$ mm)
- Inner diameter of screw ($d = 40$ mm)
- Cross-sectional area of thread ($S = 325$ mm^2)
- Width of screw guide surface ($e = 5$ mm)
- Number of threads ($z = 3$)

Figure 7 shows that the geometry of variant A has the smallest increase in working pressure. On the other hand, the geometry of variant C causes the working pressure to increase most (with respect to the number of threads). For each variant, the thread area is constant. Only the pitch of the screw changes in accordance with the screw profile. For the condition of a sharp increase in working pressure, the thread geometry of variant C is most suitable. However, it cannot be definitively held that the thread profile is optimal in all respects. Certainly it is necessary to verify the assumption made above also for other considerations — strength, technological factors, and cost.

The pressing screw is the most stressed component in 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 (Figure 3) and the first 1.5 revolutions of the thread, which shows on the instrument workload distribution.

The degree of load and tool wear is also dependent on the raw material. Further research and optimization is therefore under preparation for several sets of tools to be made from a variety of special steels, coating tools and tools with hard-grinding threads. Pressing screws are designed as monolithic (Figure 3), as well as folded (Figure 8, Figure 9), 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. A worn pressing screw can be replaced or the raw material can be changed very rapidly thanks to the use of a supermagnet. It is only necessary to insert the screw.
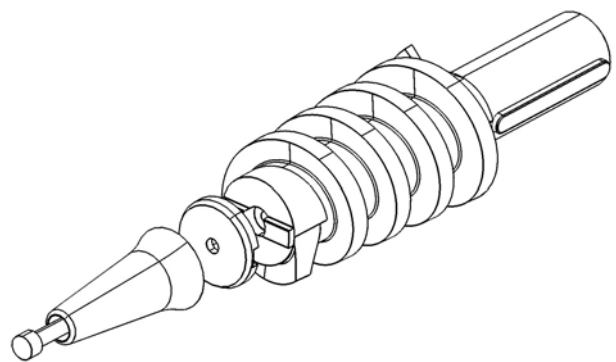

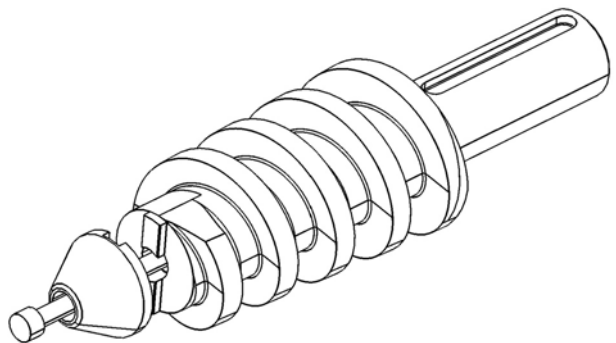Figure 8: Folded pressing screw with a rotating tip

Figure 9: Folded pressing screw with a fixed tip

Figure 10: Pelleting nozzle

Figure 11: Pressings made by a single machine

5 Pressing nozzle

The individual nozzles within the pressing chamber must copy the shape of the thread of the screws and prevent rotation of the material, while simultaneously allowing it to move axially. The nozzle geom-etry is determined in such a way that it copies the thread, from the pressing chamber to its tip, while gradually transforming the material into the desired product shape, i.e. a briquette. The nozzles are highly stressed by the compressive pressure, the heat and, most importantly, by abrasion. The surface of the material must therefore be very hard and resistant to abrasion, while internally the material must be relatively ductile.

Several pressing nozzle geometries were developed within the research project, with different lengths, diameters and tapers. These nozzles are, as well as screws, made of different materials for purpose of using them for different types of raw materials They can be exchanged very quickly and easily, thanks to the cassette system. The pressing nozzles determine the size and shape of the resulting pressings by their shape and design. The pressing nozzle in the chamber can be exchanged to produce several pressings at the same time (Figure 10, 11). In this way, the same machine can produce briquettes or pellets by simply changing the pressing chamber. By making a simple change, it is possible to produce pressings of various shapes: cylindrical, elliptical, polygons, etc.

6 Modularity of tools in the pressing chamber

Modularity of the pressing chamber (Table 1) of the screw press enables the compaction process for different types of raw materials to be optimized easily and quickly by exchanging the tools. The optimization criteria are: quality of production, process efficiency, energy costs, tool costs, and tool lifetime. A major advantage is that pressings of various shapes and sizes can be made using a single machine.

Table 1: Scheme of the pressing chamber modularity of the screw press

Modularity	Material	Geometry	Construction	Technologies
Pressing screw	Steel Coating Hard-grinding	Length of screw Diameter of screw Taper of screw Profile of thread	Monolithic Folded a) fixed tip b) rotating tip	
Pressing nozzles	Steel Coating Hard-grinding	Length of nozzle Diameter of nozzle Taper of nozzle Different section of pressings (circle, ring, ellipse, polygon, etc.) Shape of pressings Number of pressings	Monolithic Folded Briquetting nozzle (one pressing) Pelleting nozzle (more than one pressing)	Briquetting Pelleting

7 Conclusion

Research on biomass compaction indicated a need for a compacting machine with a modular design, where all significant parameters of the compaction process can be controlled. The aim of this paper has been to present a newly-patented screw press design that satisfies all requirements for modularity and control of the parameters. It enables this process to be optimized for different types of raw materials, and high quality production to be achieved. The results of an experimental study of the compacting process led to the engineering design of a production machine, tailor-made to the customer's requirements, that is able to minimize the costs for investment, energy and operation. The design of the screw press is unique in its modularity and high reliability. Six patents and utility models protecting the intellectual property rights of the authors have been taken out for this screw press.

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