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Agglomeration of natural fibrous materials in perpetual screw technique – a challenge for designer

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Abstract

The paper presents the characteristics of consolidation of natural fibrous materials for getting the renewable solid fuel. A special attention was focused on the perpetual screw technique. A detailed analysis of the consolidation process for this technique allowed to find its advantages and drawbacks. Economic reasons for this technique are also presented. Detailed characteristics of the process allowed to separate the stages when the designer can improve the construction and get the higher efficiency of the consolidation process of the material. Design algorithm for designers of such type of machines is presented.

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Keywords: compacting machine with perpetual screw; design; fragmented natural materials

1. Introduction

Energy strategy of the country is a symbol of its position in international area. Production of electrical and thermal energy has a decisive effect on the development of the industry, and the size and condition of the industry has a direct influence on the state of economy. Fossil fuels are widely applied for the production of the most of the energy. The main drawbacks of this solution are high emission of noxious chemical compounds and limitation of resources of this type of energy source. Therefore, the governments of many countries are looking for new, alternative and renewable energy sources. These types of energy sources are solar energy, wind energy, geothermal energy, wave power, water energy and renewable solid fuels.

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Renewable solid fuel is called as a biomass. The entire organic mass in the world can be called as biomass, but for the energy market the most important is wood and a wide group of natural fibrous materials such as straw, grass, special energetic plants etc. [1, 2].

Poland belongs to the group of the countries which uses mainly brown and hard coal for the production of the energy. It is estimated that over 70% of produced energy in Poland is obtained from coal burning and just about 10% is obtained from renewable sources of the energy. The rest i.e. 20% is obtained from gas burning. Energy politics of the European Union force the members to take the defined attitude. According to [3] the program 3x20 will be taken by all members of the European Union until 2020. This means that all members of the European Union will decrease the production of greenhouse gases about 20% until 2020. Besides, the energy consumption will be decreased about 20% and the application of renewable energy sources for energy production will be on the level of 20%. This value of 20% will be the average value for all member countries. The ambition of the Polish government is to get the level of 15% of renewable energy sources in the entire production of the energy.

To satisfy the requirements, it is necessary to find new renewable energy sources and apply the existing renewable energy sources in effective way. One of the most promising renewable energy sources is straw of cultivated corns in Poland. According to [1, 4, 5] the annual production of straw in Poland is on the level of 25 million tons where 40% of this value is the production surplus. These 10 million tons can be applied for energy production. The calorific value of the straw is in range 13 – 20 $MJ.kg^{-1}$ depending on the type and moisture of straw [6, 7]. The drawback of this material is a small concentration of energy and variable value of moisture which depends on weather conditions. Some special processes are needed to increase the energy concentration and provide the repeatable values of the moisture. To achieve these improvements, we need the machines which will satisfy the defined functions. We need the machines for agglomeration of such type of material, of course the preparation of straw demands also some machines for drying or breaking up. The straw consolidation is applied to increase the density of final product which is called briquette and its density is in range 300 – 450 $kg.m^{-3}$ [6, 8]. The straw with such form can be burnt in most of conventional furnaces, and the form of briquette allows for transportation and storage.

Consolidation techniques of fragmented natural fibrous materials such as straw have been known for many years. The most propagated technique is agglomeration in perpetual screw technique. Many types of machines have been designed for this technique [9, 10]. The development of these machines is running and it is caused by the increase of variety of materials which are applied for the energy production and pursuit of effectiveness improvement of consolidation process. It was found that the mechanism of the bonding process of fraction of loose material is still not recognized [11]. This process is complex and connected with variable thermo-mechanical properties of the condensed material. The aim of this work is the determination of the complexity of the design process of compacting machines for fragmented natural plant materials.

2. The characteristics of consolidation process

Fig. 1 presents the kinematic scheme of the compacting machine with perpetual screw. General idea of consolidation process with the application of this technique is based on supplying the fragmented material which will be agglomerated to container 4.

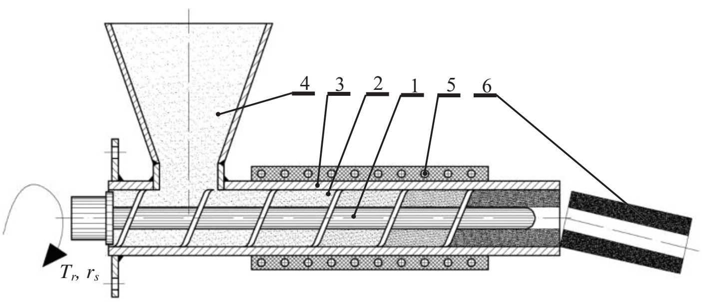

Fig. 1. Scheme of consolidation process of fragmented fibrous materials with the application of compacting machine with perpetual screw: 1 – perpetual screw, 2 – consolidated material in consolidating chamber, 3 – forming cylinder, 4 – container, 5 – heater, 6 – briquette.

Working system of the machine consists of perpetual screw 1 and forming cylinder 3. The perpetual screw is driven by a power transmission system which provides the following two parameters: rotational speed r_s and torque T_r. As a result of rotational motion of the perpetual screw its geometry is the reason of pulling the material from container 4 and its transportation along the forming cylinder 3. Friction forces between the external surface of the consolidated material and internal surface of forming cylinder 3 are the reason of the resistance to motion and consolidation of the material. In effect we get a final briquette with defined and assumed geometrical shape 6. Consolidation process of fragmented fibrous materials needs an additional source of heat 5. Higher temperature in range between 200 – 240 °C provides the improvement of consolidation process of the material.

3. Construction of compacting machine with perpetual screw

Fig. 2 presents a scheme of compacting machine with perpetual screw. The main working elements (presented in Fig. 1) and the general power transmission system are shown. Perpetual screw 2 is driven by electric motor with strand transmission 6 (chain or belt transmission). The characteristics of the perpetual screw work are directly connected with the defined type of loading of the driving shaft. The shaft is supported in radial bearings 3 and axial bearings 4. The construction of the perpetual screw 4 is directly connected with the geometric form of the briquette. The hole in the briquette is a characteristic feature (Fig. 1, element 6). The hole is an advantageous feature, because the consolidated material of the fragmented straw has the defined moisture. The consolidation process needs higher temperature, and the temperature is the reason of evaporation of the moisture surplus from the briquette. The hole in the briquette allows to make this process easy. The production of the briquettes without the hole can lead to the deformation of the briquettes due to the rapid expansion of the steam.

The highest requirements are for perpetual screw 8 which works in hard conditions i.e. the working area is heated to 200 – 240 °C and additionally high values of friction forces exist between the consolidated material and perpetual screw. This phenomenon can lead to further increase of process temperature and next accelerated wear of the working surfaces of the perpetual screw.

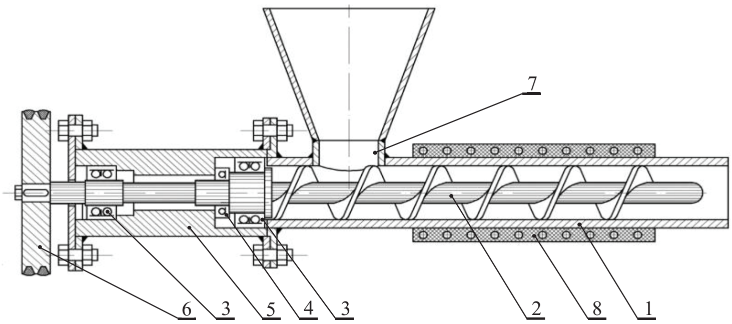

Fig. 2. Scheme of working system of compacting machine with perpetual screw: 1 – forming cylinder, 2 – perpetual screw, 3 – radial bearings, 4 – axial bearings, 5 – housing, 6 – driving belt pulley, 7 – delivery channel, 8 – heater.

4. Design challenges

4.1. Material properties

The difficulites connected with the design process of this type of machine result from the variable parameters of consolidated materials properties. First briquetting machines were designd for domestic materials such as rye straw, oat straw, rape straw, barley straw etc. Different types of straw have different types of thermomechanical properties. The increase of interest of production technique of renewable solid fuels was the reason of expansion of briquetting machines manufacturers to the other European countries and even the whole world. This fact forced the designers to adopt the existing machine constructions for consolidation of new materials.

Exotic materials such as rice straw, reed straw, bamboo chips, hazelnut shells have different properties of consolidation parameters and values of friction coefficient. Fig. 3 presents the scheme of complexity and thermomechanical properties of the analysed materials. All parameters are functions of temperature T and moisture m.

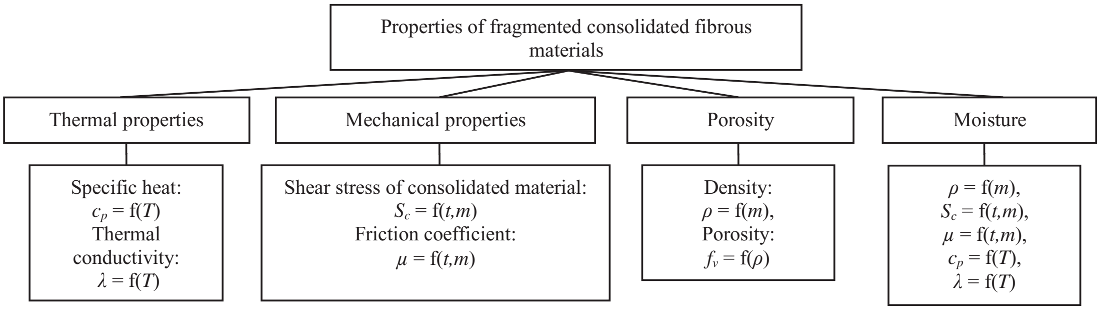

Fig. 3. Scheme of fragmented consolidated fibrous materials: T – temperature, m – moisture.

4.2. Geometrical parameters of working elements

Geometrical parameters of working elements of compacting machine have an essential influence on the geometrical featrues of the final product. The diameter of forming cylinder is very important, because the briquette diameter depends on this diameter. The perpetual screw is also very important in consolidation process. The geometrical features of the perpetual screw are presented in Fig. 4.

During the design of working system one should use the geometrical indicators which are connected with defined geometrical features. In case of the perpetual screw we can formulate three basic geometrical indicators:
- diameter indicator:

$$I_D = \frac{D}{d} \tag{1}$$

- pitch indicator:

$$I_P = \frac{P}{D} \tag{2}$$

- indicator of perpetual screw core diameter:

$$I_d = \frac{d}{w} \tag{3}$$

where P – perpetual screw pitch, D – outer diameter of perpetual screw, d – core diameter of perpetual screw, w – thickness.

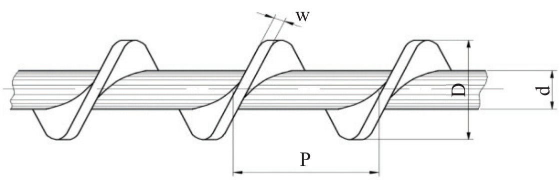

Fig. 4. Geometrical parameters of perpetual screw: P – pitch, D – outer diameter, d – core diameter, w – thickness.

The application of geometrical indicators is very useful during the design of the series of types of compacting machines.

4.3. Prototype investigations

After determination of parameters of material properties and geometrical parameters, one should conduct the investigations of the prototype. This machine should be equipped with measuring apparatus. During the investigations the most important is monitoring of the basic work parameters i.e. perpetual screw torque during the machine work and axial force. Fig. 5 presents the scheme of agglomerating machine with the measuring system of torque and axial force. Fig. 6 presents an exemplary construction of torque meter for compacting machine with perpetual screw [12].

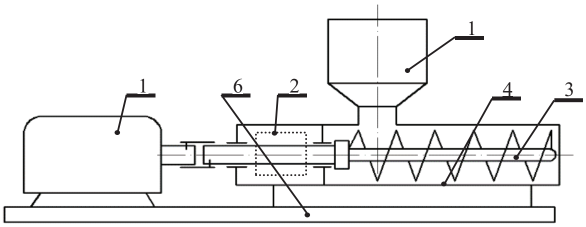

Fig. 5. Simplified scheme of agglomerating machine with perpetual screw: 1 – driving motor, 2 – possible place of installation of torque meter/dynamometer, 3 – perpetual screw, 4 – housing, 5 – charging hopper, 6 – foundation.

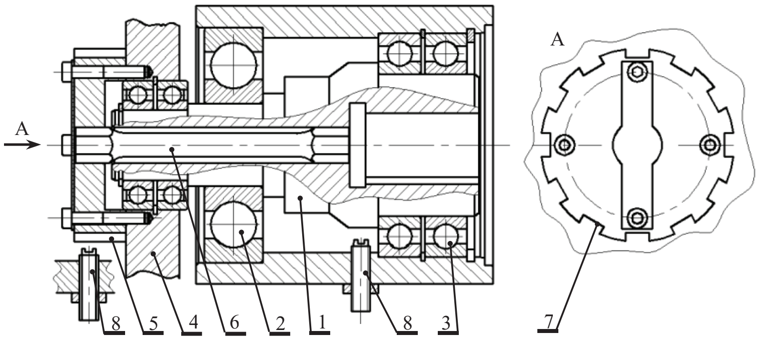

Fig. 6. Constructional scheme of torque meter [12]: 1 – driving shaft, 2,3 – radial contact ball bearing, 4 – chain wheel, 5 – measuring disc, 6 – torsional shaft, 7 – inductive sensor, 8 – rows.

Torque meter (Fig. 6) consists of main shaft 1 which is supported on three radial contact ball bearings 2 and 3. Torque is transferred from chain wheel 4 to the shaft journal 1 by measuring disc 5. Measuring disc 5 is supported on one end of torsional shaft 6. The other end of torsional shaft 6 is connected with main shaft 1. As a result of this connection the torque is transferred by torsional shaft 6 from chain wheel 4 to main shaft 1. Measuring disc 5 and main shaft 1 have some rows 7 which allow to generate the impulses by sensors 8 during the shaft rotation. Twisting of shaft 6 causes a phase displacement of electrical impulses generated in sensors 8. As a result of loading of torsional shaft 6 the electronic system defines its torsional angle φ (Fig. 7). The knowledge of the value of torsional angle of torsional shaft 6 (for known geometrical parameters and mechanical properties of its material) allows to estimate torque moment which is transferred by power transmission system.

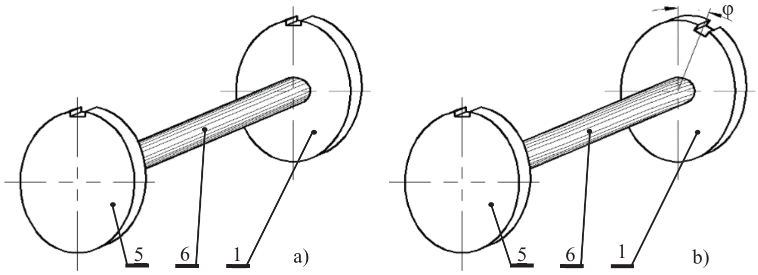

Fig. 7. Scheme of the measurement of torsional angle (denotations are the same as in Fig. 6): 1 – driving shaft, 5 – measuring disc, 6 – torsional shaft, a) unloaded shaft, b) torque loaded shaft.

The author of work [13] has presented an idea of the measurement of forces which occur in forming cylinder during the consolidation process of wheat straw. Such types of elaborations allow to recognize the complex process of consolidation of fragmented plant materials.

5. Design algorithm of compacting machine with perpetual screw

Fig. 8 presents the design algorithm of compacting machine with perpetual screw.

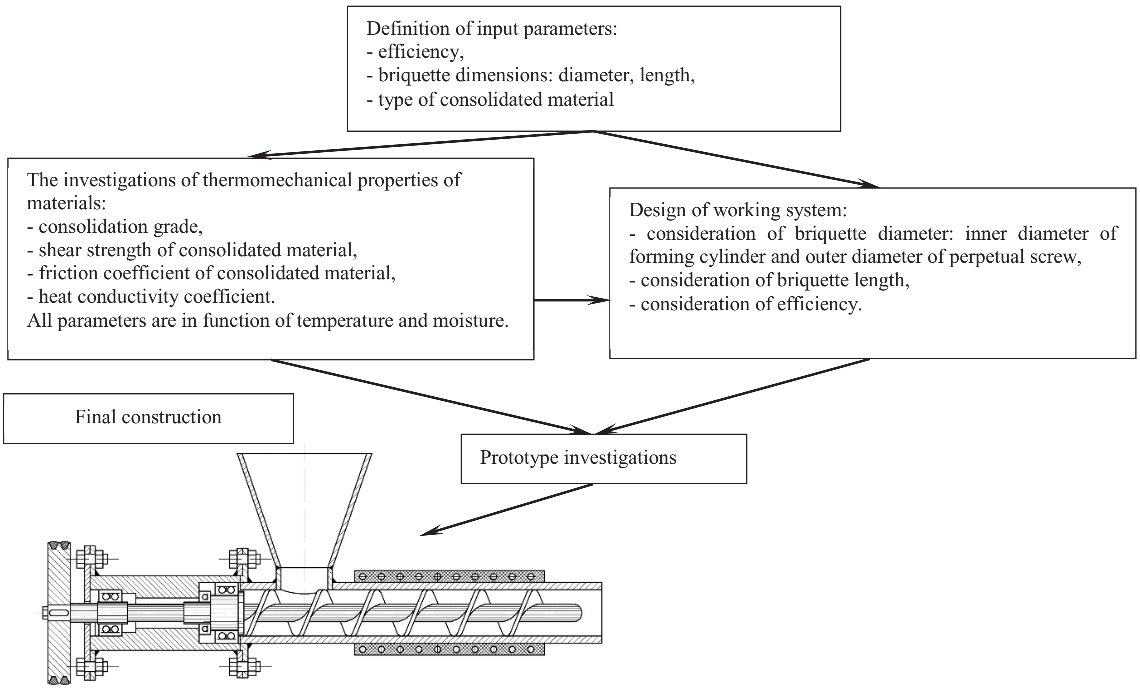

Fig. 8. Design algorithm of compacting machine with perpetual screw.

6. Summary

Design of compacting machines with perpetual screws is hard due to complex properties of processed materials. Additionally, all material properties are in function of moisture and temperature. Even the place of plant growth has an impact on straw properties. All these matters complicate the design process and force the designers to use their own experience especially during the first stage of designing. Unfortunately, detailed information on consolidated materials and mechanics of consolidation process is still poor in literature.

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