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Influence of Temperature on the Quality of Briquettes in the Giant Miscanthus Densification Process

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A continuous increase in demand for biomass for energy purposes is the reason why people have begun growing plants known as energy crops, such as common osier, Jerusalem artichoke, giant miscanthus, etc. The power industry most often utilises biomass in the form of pellets and briquettes. One of the basic parameters of the biomass densification process is temperature. This article presents the results of the study about the influence of temperature in the giant miscanthus densification process on the quality of briquettes which are intended for combustion in combined heat and power plants and in stoker furnaces in individual households.

Key words: briquette quality, process temperature, giant miscanthus, piston briquetting machine, renewable energy.

1. Introduction

Carbon dioxide emission control programs that many countries are currently introducing aim to popularise the utilisation of renewable energy sources. The ever-growing energy demand together with tax policies of many countries results in increased focus on the means of obtaining energy from renewable energy sources. The sustainable energy sources that are particularly appealing are water and wind turbines, geothermal sources, solar collectors, biomass and biogas. The largest percentage of energy from renewable sources is obtained from biomass, which is often a waste product of agricultural industry, maintenance of forest resources, etc. Another types of biomass are cultivated energy crops, unfortunately not very popular in Poland despite the fact of availability of large wasteland areas. The regulations of the Minister of Economy from August 14th, 2008 aimed at changing this situation. These regulations were implemented to encourage Polish power industry to invest in the development of renewable energy crop cultivation.

The plants which are cultivated as energy crops should have large annual growth, high calorific value, good resistance to diseases and pests, and ability to grow even in poor quality soil. Their cultivation should last for a period of 15–20 years. The most commonly grown energy crops are the plants such as common osier, Pennsylvanian mallow, giant miscanthus, Jerusalem artichoke. The scientists who look for new and renewable sources of energy and raw materials for the industry have recently focused their attention on some of those plants. An example of the crop that is particularly interesting for these scientists is the giant miscanthus, also known as Chinese miscanthus, Chinese reed or elephant grass. The average productivity of the giant miscanthus after several years of harvesting is about 20 tons of biomass from 1 ha, with the moisture content of approx. 20%. The calorific value of such fuel ranges from 14 to 17 $\mathrm{MJ \cdot kg^{-1}}$ [6] and there are approx. 2% of ash produced from combustion [5] (with approx. 2% ash content).

The bulk density of the plant material is usually very low (from approx. 60–80 $\mathrm{kg \cdot m^{-3}}$ for buckwheat hulls to 280 $\mathrm{kg \cdot m^{-3}}$ for wood sawdust). It is also not easy to handle it in transport and the burn in automatic lines. From the economic and environmental point of view, the best solution for handling fine-grained materials is to briquette them without the use of binding substances and without additional pre-treatment such as crushing, drying, sieving, etc. [7, 8]. Given the large amount of raw material that is already being processed by briquetting, it is crucial to ensure the economic viability of such a processing. Therefore, it is necessary to conduct detailed studies on the densification process.

There are many compacting and briquetting machines available in the market and a number of mathematical models of the process have been developed. Despite all that, no coherent theory has yet been developed to describe these processes in a manner that would be useful for an engineer in the designing process of such machines [3, 4]. Among the difficulties in the theoretical description of the process are varying properties of the raw materials. These properties depend on many factors such as place of harvest, degree of grinding, processing manner, chemical composition, time of preparation, etc. An additional difficulty comes from the densification process parameters that also vary. One of the main parameters of briquetting process is temperature.

This article presents the results of a research on the influence of temperature on the quality of comminuted miscanthus briquettes obtained in the closed-chamber densification process.

2. Research method

The method of the analysis of giant miscanthus densification process in the operating system consisting of piston and closed chamber is presented in Fig. 1.

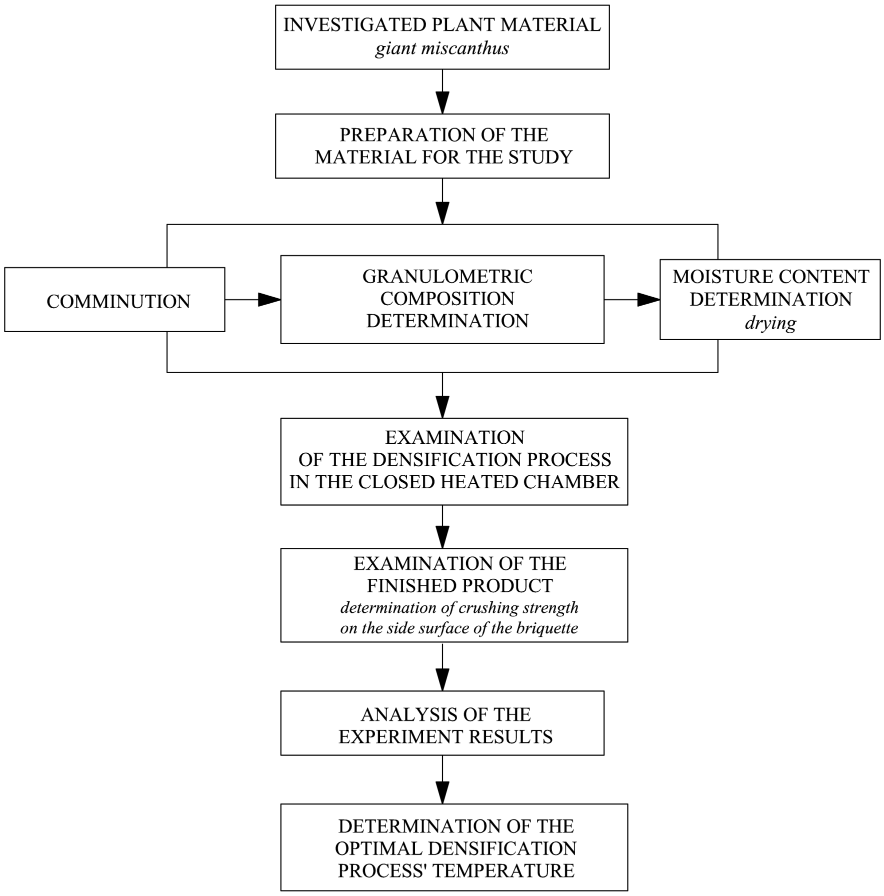

Fig. 1. The layout of the conducted research.

2.1. Description of the test rig

The experimental study of the briquetting (densification) process was performed using the test rig presented in Fig. 2. Such a set-up provides the possibility to investigate the following parameters, which have significant impact on the densification process:

- compressive pressure (axial),
- pressure exerted by the compressed material on the side walls of the die (lateral pressure),

- pressure exerted by the compressed material on the bottom of the die (closed chamber),
- densification rate (piston displacement),
- the height of the compressed material layer,
- axial pressure inside the briquette,
- pressure distribution on the compression piston radius.

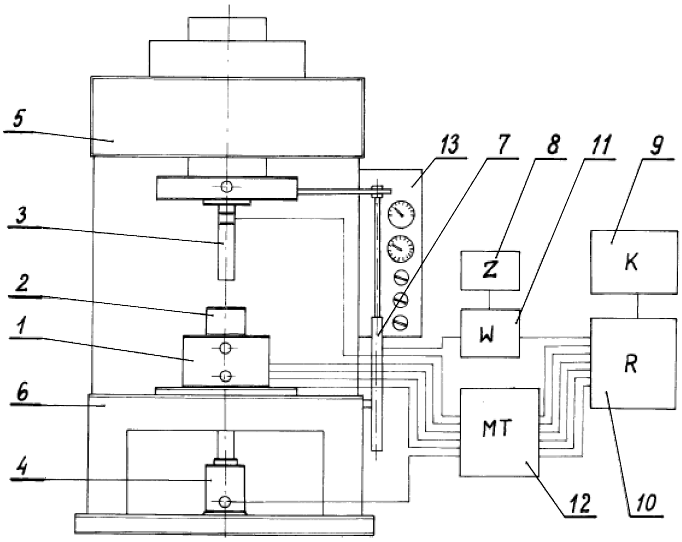

Fig. 2. The layout of the test rig for analysis of the forces occurring during briquette production process [1]: 1 – heated gauge head, 2 – top section, 3 – main compression piston, 4 – force sensor, 5 – hydraulic press PYE 63S1, 6 – press table, 7 – displacement sensor, 8 – power supply adaptor, 9 – computer, 10 – recorder, 11 – phase sensitive amplifier, 12 – full bridge strain gauge type Hottinger KWS/6-5, 13 – control panel of the press.

The densification machine used in the study was the hydraulic press PYE 63 type S1 (5) with a maximum pressure of 630 kN. Its operating characteristics ensure a uniform movement of the compression piston (3) during material densification in a set (range 0 to 250 MPa). The compression piston was equipped with a full bridge strain gauge in order to measure axial densification forces. The sensor was attached above the working section of the piston. The heated gauge head (1) with an extension (top section – 2) was fixed to the press table (6).

The pressure exerted by the densified material on the bottom of the matrix was measured with the strain gauge CL 18 (4). The measurement of piston (3) displacement inside the gauge head (1) was carried out with a displacement sensor, model CL 70-200 (7) connected to the phase sensitive amplifier CL 104 (11).

The movable bar of the sensor (7) was attached to the press holder to which the piston (3) was fixed as well. The second part of the displacement sensor was attached to the press table, on which the measuring head was placed. Limits of the maximum compression piston pressure values were controlled through the control panel (13).

The crushing strength test was conducted using an INSTRON-8502 servohydraulic frame with FastTrack 8800 controller.

The arrangement of elements for determination of briquette's crushing strength is presented in Fig. 4. A counter sample (1) with the diameter equal to the diameter of briquette (2) was placed in the hydraulic grip of the upper piston (4).

FIG. 3. Crushing strength measuring station with an INSTRON-8502 servohydraulic frame.

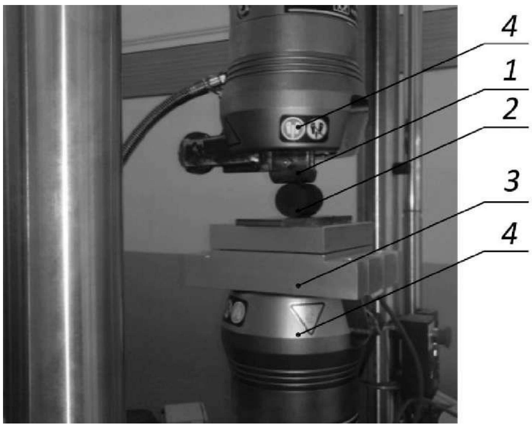

FIG. 4. Crushing strength measurement arrangement in the testing frame: 1 – counter sample, 2 – sample, 3 – additional pressure measurement device, 4 – pressing piston with hydraulic grip.

The additional pressure measurement device (3) was placed on the lower piston (4) in order to verify the accuracy of the test results. The tested briquette (2) was placed on the top of the additional pressure management device. The sample was placed perpendicular to the counter sample so that there was only one contact point. This is the arrangement in which briquettes are the least durable. The sampling frequency was set at 0.01 kHz, and the counter sample speed was set at 0.1 mm/s. The results of the measurements were recorded by the computer.

2.2. Test parameters of the process and of the studied material

Giant miscanthus was comminuted in a beater device, and the screening process was conducted next. The screening was performed on 10 screens with sieve openings ranging from 6.3 mm to 0.63 mm, to determine the particle size distribution (Table 1). The bulk density of the material was about 112 $\mathrm{kg \cdot m^{-3}}$.

Table 1. Particle size percentage content in the crushing strength test material.

Sieve No	1	2	3	4	5	6	7	8	9	10
Sieve opening [mm]	6.30	4.00	3.15	2.50	2.0	1.5	1.25	0.80	0.63	<0.63
Fraction content [%]	1.13	3.62	5.27	4.16	10.2	18.5	5.11	13.27	16.25	22.5

A portion of comminuted material was separated and its moisture content was stabilised at a 12% level 48 hours before the experiment. Twenty four hours prior to the experiment the material was checked and corrected by drying or adding water (Fig. 1). Moisture content was determined using WS-30 RADWAG moisture analyser with accuracy of ±0.1%. The prepared material was used to form samples. The mass of a single sample prepared for compaction was set to 50 g. Each sample was weighed on a laboratory scale with an accuracy of ±0.01 g just before it was put into the compaction chamber. The densification process was conducted in a compacting set with a closed die. The diameter of the compression chamber was 0.048 m (Fig. 2). The compressive pressure was set to 160 MPa.

The analysis of the densification process was conducted at compression chamber temperatures of 15, 30, 45, 60, 75, 90, 105, 120, 135, 150, 165, 180°C respectively. Both the temperatures of the sample and the chamber needed to be equal. This condition was accomplished in 90 s after placing a portion of the material into the compression chamber. The densification of the material was continued until the pressure had reached the set point and the piston was stopped. Three measurements were carried out for each of the twelve temperatures.

2.3. Measurement of the crushing strength on the side surface of the briquette

Briquettes are the weakest when a force is applied to their side surface. Such an orientation of the force occurs in reality during pouring into bags, shovelling, heaping and during transport. In this sort of situations, it is highly possible that briquettes will get arranged in such a manner that their side surfaces are perpendicular to each other. This is the least desirable position as it creates a single point contact. In order to create crushing conditions in the experiment (Fig. 4) to be analogous/comparable to the real-life situation a counter sample's (1) diameter was equal to the diameter of the tested briquettes. The counter sample was clamped to the upper piston of the test frame and the sample (2) was placed on top of the lower grip perpendicularly to the counter sample. Crushing strength was measured in the test frame described and saved to the computer memory.

3. The results of the of giant miscanthus densification process investigation

The process of giant miscanthus briquetting was performed at temperatures ranging from 15 to 180°C (in 15°C increments), at a constant compressive pressure of 160 MPa, 50 g sample weight and 12% moisture content. The characteristics of samples' densification are presented in Fig. 5. The biggest differences in the density, during giant miscanthus compaction at different temperatures, can

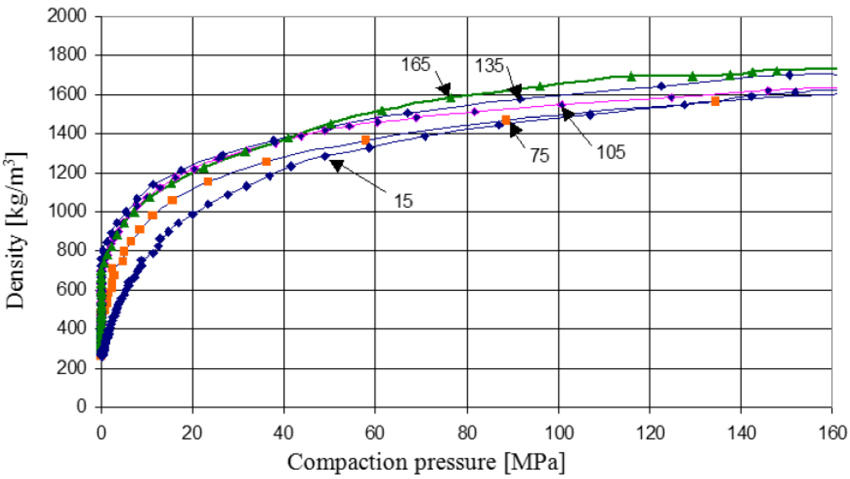

Fig. 5. Characteristics of giant miscanthus densification process at various temperatures (12% moisture content of material, 50 g sample weight, 160 MPa densification pressure).

be noticed at relatively low pressures. When the compressive pressure reached 10 MPa, the density difference between the samples that compacted at 15°C and 165°C was about 400 $\mathrm{kg \cdot m^{-3}}$.

As the compressive pressure increased differences in the sample density decreased until the pressure reached 140–160 MPa. At that pressure level the density stabilised at the constant level of 1700 kg/m^3 at 165°C and about 1580 kg/m^3 at 15°C. These values relate to the density of the samples under the pressure of compaction piston. The approximate density of finished briquettes can be calculated using the so-called density turning expansion coefficient ω_g [1].

The effect of temperature of the giant miscanthus densification process on the briquettes quality, for the process conducted at the pressure of 160 MPa, is presented in Fig. 6. The differences in density are relatively small for the temperatures of 15–105°C and are in the range of 20–25 kg/m^3.

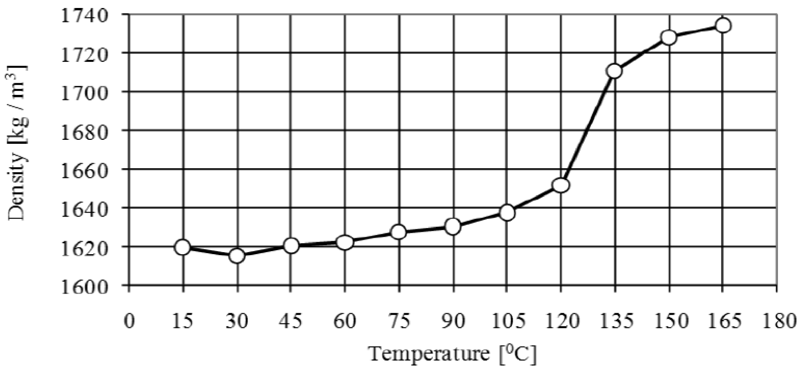

FIG. 6. The relationship between briquettes' density and temperature of the densification process under the pressure of 160 MPa (about 12% moisture content of the raw material).

A rapid increase in the density of compacted samples occurred when the temperature of the process reached 105°C, where the density was about 1640 kg/m^3, up to 1730 kg/m^3 for 165°C. The measurement at the temperature of 185°C was not performed as the sample started to burn inside the die.

On the basis of spruce sawdust compaction analysis [1], it was found out that if the value of crushing strength on the lateral surface of the briquette is higher than 300 N, thus the product is considered to be of satisfactory quality.

The results of the crushing strength measurement for the giant miscanthus briquettes, formed in closed-die under the compacting pressure of 160 MPa, show that the best quality product is obtained at the process temperatures of 15–30°C and above 135°C. The biggest difference in the crushing strength is between briquettes formed at the temperatures of 90°C and 165°C respectively. The difference in that case is about 250 N.

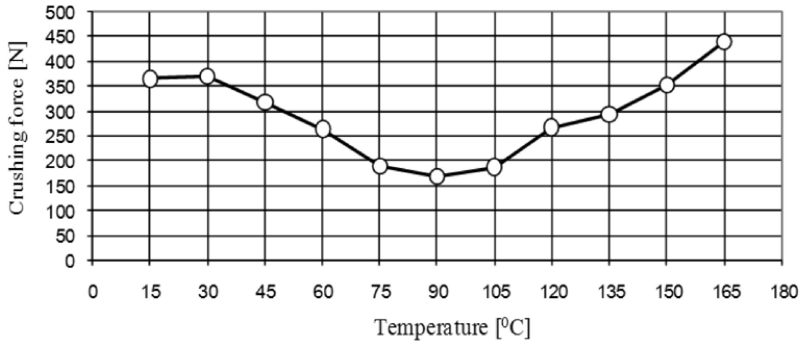

Fig. 7. The relationship between briquettes' crushing strength and temperature of the giant miscanthus densification process under the pressure of 160 MPa (about 12% moisture content of the raw material).

4. Conclusions

1. Giant miscanthus is a plant material having good properties for briquetting.
2. Good quality briquettes made of giant miscanthus can be obtained without additional heating in the processing system.
3. The recommended moisture content of the material used for briquetting is 12%.
4. Giant miscanthus can be compacted in piston and screw worm briquetting machines.
5. The parameters of both the raw material and the process of densification should be set by the briquettes' manufacturer depending on whether the pellets are designated for home furnaces and fireplaces, or large combined heat and power systems.

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