Experimental research on biomass cutting process

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Abstract. This paper contains the results of the biomass cutting process in which wheat straw was used. Tests were made on the prototype test stand which made it possible to control the parameters of the cutting process and based on that define its energy consumption. During the research the following parameters were measured: rotational speed of electric motor, which drives the rotor with a set of cutting knives, electric current supply and torque on the shaft. Tests were made for the variable moisture content of the biomass and with knives with three different back-rake angles 5°, 15° and 30°. Using these measured parameters it was possible to calculate the power and the cutting force necessary to disintegrate biomass. The main goal was to find out if there is any influence of moisture content and the back-rake angle of the cutting knife on the dynamic parameters of the process - power and cutting force. The presented results can be very useful in a design process for a working assembly of biomass disintegrating machines which are directed to the energetic efficiency.

Keywords: biomass, biomass cutting process, humidity of biomass, energetic efficiency of cutting process

1 Introduction

Biomass is the third largest source of energy in the world, following coal and oil [1]. Undensified biomass is characterized by low density on the order of 0.1 ÷ 0.2 kg/l = 100 ÷ 200 kg/m^3 [1]. According to other sources, its density is in the 100 ÷ 200 kg/m^3 range for straw and grass, and 150 ÷ 200 kg/m^3 for wood biomass in the form of chips and sawdust [1-3]. This is a serious limitation for the use of this material as a source of energy due to storage and transport difficulties [1]. The densification process makes it possible to obtain the agglomerate of density equal to approximately 1.2 kg/l = 1200 kg/m^3, which affects the chemical structure of biomass that loses some of the water under pressure [4, 5]. The essence of this process has been broadly discussed in many works, including [6-10]. Densification promotes the hydrolysis of hemicelluloses and lignin to hydrocarbon compounds. This is needed in the production process of methane [1]. Factors affecting the strength and durability of the agglomerate are a type of material (materials) being densified, moisture content, particle size and distribution, process temperature, additional elements in the form of an adhesive or other additives, and densification process parameters (temperature, size of the press die, press die speed, etc.) [11, 12]. As was mentioned

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previously, particle size has an impact on the quality of the agglomerate. The process of biomass material fragmentation and its course are therefore very important for its densification [4, 13].
In this work research into the biomass cutting process as preceding biomass agglomeration into briquette form is presented. The straw material being fragmented was Triticale. A station for biomass cutting of our own proprietary design was used for research. The station design as well as research methodology and process are discussed. In following sections sample results of the experiment with conclusions is presented.

2 Research station and methodology

A research station consisting of two main systems was used in the experimental tests (Fig. 1). The first one is the system of cutters 2 used for cutting biomass material. Straw designated for cutting is transported to the cutter blades using the system of rollers 3 which are used to pull in and press biomass material. Actual cutting takes place in the cutter blades and counter cutter area. The cutter system 2 is driven by a three-phase electric motor 4 with power P = 2.2 kW and maximum speed n = 2850 RPM. Motor crank pin 4 is connected directly to the shaft of the cutting system 2 using the dog clutch. To control the motor 4, the inverter 9 Schneider Electric type MX pro 4V2.2 was used.

Fig. 1. Research station for the biomass material cutting process: 1 – shredded biomass material, 2 – system of cutters, 3 – electric motor driving rotational movement of the system of cutters, 4 – system of rollers, 5 – reduction drive of the rollers system, 6 – electric motor driving the rollers system, 7 – moisture analyzer, 8 – inverter of the electric motor of the rollers system, 9 – inverter of the electric motor of the cutters system, 10 – PC recording performance of the electric motor of the cutters system, 11 – PC recording performance of the electric motor of the rollers system

The system of rollers 3 is powered by the drive system in the form of a three-phase electric motor 6 with power P = 3 kW and maximum speed n = 1430 RPM, and a two-stage cylindrical gear reducer 5 with total gear ratio i_c = 14.5. Gearbox 5 is connected to the input shaft of the rollers system 3 using the dog clutch. The inverter Schneider Electric type 4V4.0 was used to control engine rotational speed 6. Registration of performance parameters of the engines 4 and 6 was made using Matrix software installed on the computers 10 and 11, where each was communicated with the inverter, respectively, 8 and 9. Matrix is a Schneider Electric software dedicated to support the company's inverters. This made it possible to register data on torque changes M [Nm] on the electric motor shafts 4 and 6, as well as amperage changes I [A] and voltage changes U [V] of these engines. The cutting module 2 has the ability to mount the blades with different back-rake angles of the cutting edge α (fig. 2), and the blade angle β (fig. 2). Angles α and β were successively α = 5°, α = 15° and α = 30° and β = 90°, 45° and 30°.

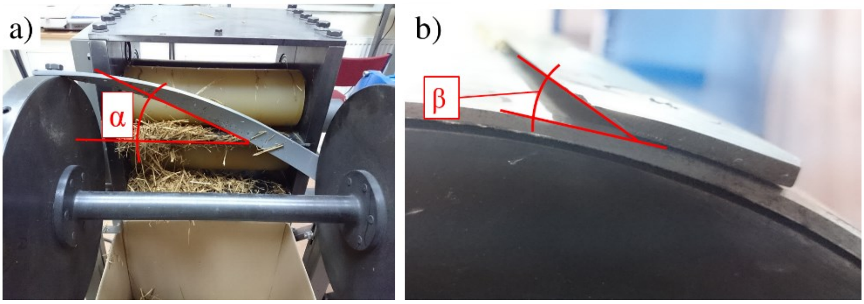

Fig. 2. View illustrating: a) back-rake angle α, the cutting edge of the knife, b) blade angle β

The conducted experimental studies made it possible to determine the change of the following performance parameters of the electric motors 4 and 6 depending on moisture of shredded straw, and the back-rake angle of the knife blade α and the angle of its blade β. Straw moisture content was determined using the moisture analyzer 7 (fig. 1 and 3).

Fig. 3. Moisture analyzer used for measuring straw moisture content before shredding

For testing purposes, a straw portion with initial average moisture 16.94% was weighed out (initial moisture is understood as straw with moisture content as delivered directly from the field), intended for shredding and for seasoning for the purpose of studying the cutting process of straw with increased water content. The weight of the portion was 36.5 g ± 1 g (weight tolerance is due to losses during specimen transfer from and to the seasoning container). The prepared portions were stored in special containers so that the straw with initial moisture content did not dry up and so that some specimens were moisturised.

In order to moisturise it, the straw was seasoned for 648 hours (fig. 4) in containers with increased humidity content in the air. This made it possible for the straw to achieve average moisture content equal to 28.75%.

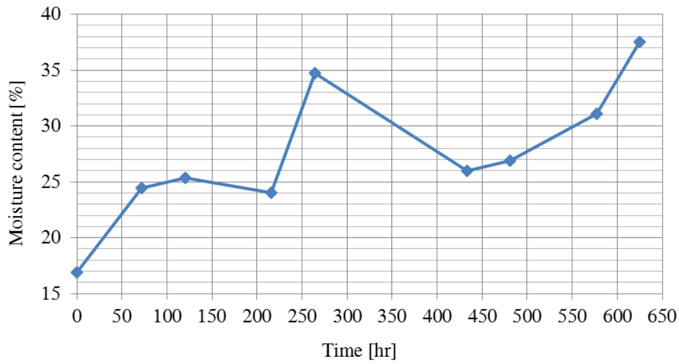

Fig. 4. Change of straw moisture content during seasoning

Straw specimens prepared in such a way were fed (fig. 5) into the system of rollers, where they were pulled, pressed and passed on to the system of cutters. For each specified angle value α and blade angle β, both during shredding the straw with moisture 16.94% and 28.75%, twenty specimens were shredded. In total, 180 specimens were shredded. The system of cutters has the ability to set the distance between the cutting edge of the knives and the edge of the counter cutter. In the current research, this distance was 0.2 mm and the feeler gauge was used for this purpose.

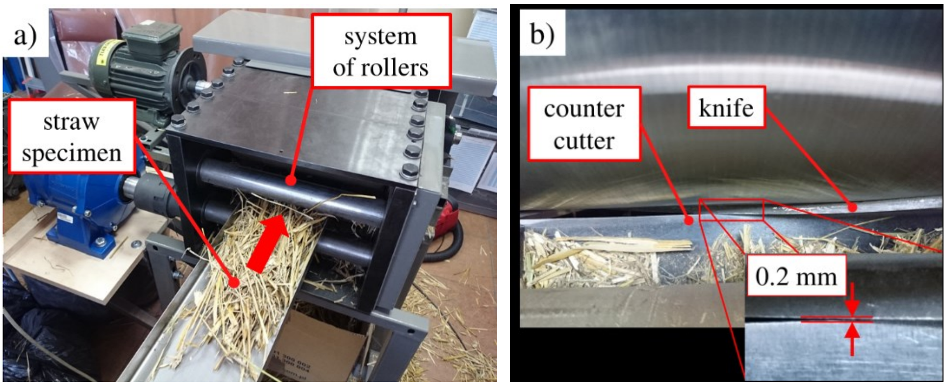

Fig. 5. General view: a) prepared straw specimen which is passed on to the system of rollers, b) cutting knives and counter cutter and the gap between them

On Figure 6 shredded straw is presented.

Fig. 6. General view of shredded straw

3 Research results and their analysis

On Figure 7 sample characterizations illustrating the changes of torque, current and voltage of the electric motor driving the system of cutters are presented.

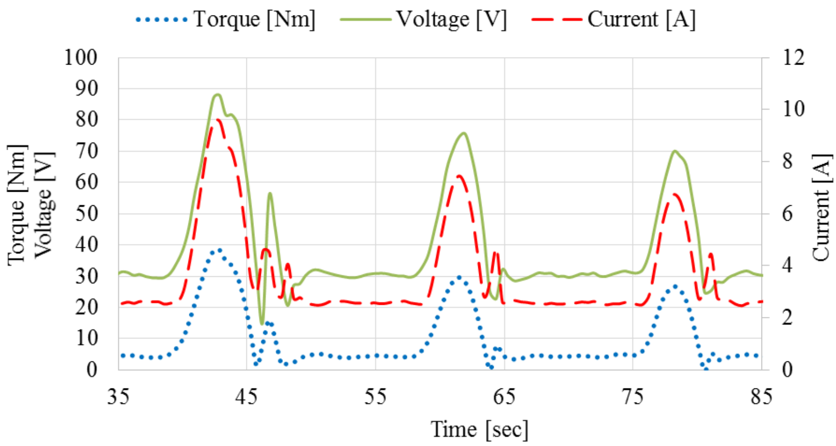

Fig. 7. Sample change characterizations of torque, voltage and current of the motor driving the system of cutters, for the process of shredding the straw with moisture content 16.94%, back-rake angle $\alpha = 15^{\circ}$ and blade angle $\beta = 90^{\circ}$

On Figure 8 sample characterizations illustrating the changes of torque, current and voltage of the electric motor driving the system of rollers are presented.

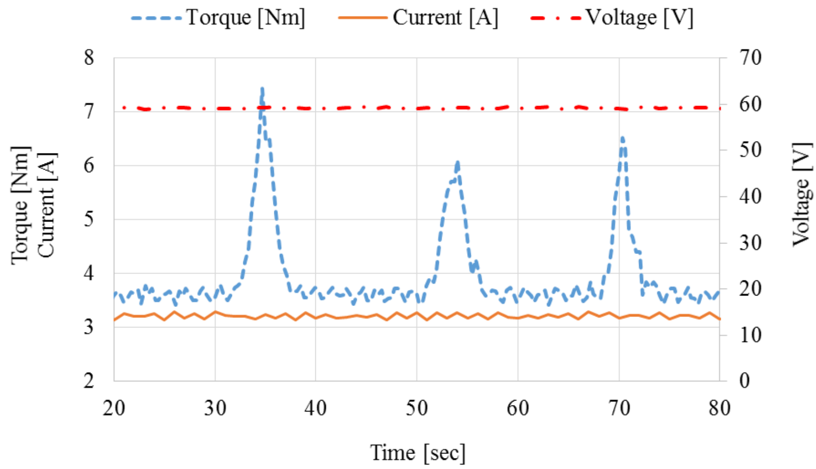

Fig. 8. Sample change characterizations of engine torque, voltage and current of the motor driving the system of rollers, for the process of shredding the straw with moisture content 16.94%, back-rake angle $\alpha = 15^{\circ}$ and blade angle $\beta = 90^{\circ}$

By dividing the recorded values of the torque on the motor shaft of the cutting system by the value of the radius of the cylindrical surface to which the knives were attached, the values of the cutting force needed to shred a given straw specimen were obtained. In this way, the characterizations shown in the following figures were obtained.

On Figure 9 the changes of the cutting force depending on the value of the back-rake angle of the cutting knives α and blade angle β, for shredding straw with medium moisture content 16.94% are presented.

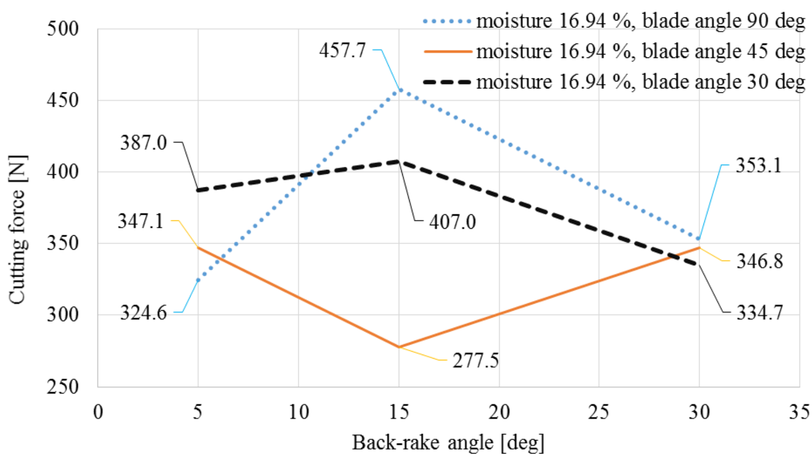

Fig. 9. Characterizations of the cutting force depending on the back-rake angle α and blade angle β, for the shredding process of straw with medium moisture 16.94%

According to Figure 9, no clear trend in the change of the cutting force was observed. The smallest dispersion of the force is visible for the back-rake angle α = 30º and all three blade angles β. The largest dispersion is visible for the back-rake angle 15º.
The smallest force value was recorded for the angle α = 15º and the blade angle β = 45º. This is also confirmed in the case of shedding the straw with average moisture content 28.75% (fig. 10). On Figure 10 change characterizations for the values of the cutting force, for shredding the straw with average moisture content 28.75%, depending on the changes in the value of the back-rake angle α and blade angle β are presented.

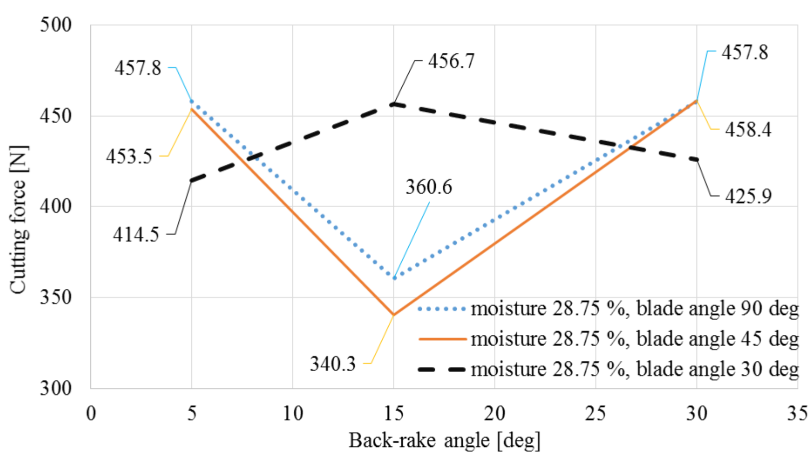

Fig. 10. Change characterizations of the cutting force value depending on the back-rake angle α and blade angle β for the shredding process of straw with medium moisture 28.75 %

According to the characterizations in Figure 10, it can be observed that the value of the cutting force increased with the increase in straw moisture content. For the back-rake angle

$\alpha = 15^o$ and the blade angle $\beta = 45^o$ and 90^o, the cutting force is the smallest. It can be said that this is a kind of confirmation of the trend of declining force for $\alpha = 15^o$ and the blade angle $\beta = 45^o$, which is visible when shredding straw with moisture content 16.94% (fig. 9).

Conclusions

Based on the obtained research results, the following conclusions can be reached:

– as straw moisture content increases, there is an increase in the force needed to shred the straw,
– the lowest values of the cutting force was registered for the back-rake angle $\alpha = 15^o$ and the blade angle $\beta = 45^o$ in both straw moisture cases; the humidity of straw; for confirmation, more research needs to be performed by shredding more specimens for each specified angle α and angle β,
– to increase measurement accuracy, additional torque sensors encased in the pins of the motors driving individual systems should be used,
– the smallest dispersion of the cutting force was registered for the angle $\alpha = 15^o$ and the blade angle $\beta = 30^o$,
– in further research, the impact of the gap between the knife blade and the edge of the counter cutter should be taken into account,
– further studies should be performed for the straw with average moisture content of approximately 17% and lower, since shredding the straw with higher moisture content requires greater cutting force, which negatively affects the increase in energy intensity of this process.

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