

EFFECT OF CHANGES IN THE ANGLE OF ORIENTATION OF ROLLERS FOR COMPACTING STRAW BY ROLLING ON PARAMETERS OF OBTAINED BRIQUETTES

Summary

Nowadays, many methods for compacting straw for energy purposes are known. Compaction of unchopped straw by rolling it with an operating unit consisting of five conical rollers is a new method not used for this purpose so far. Various compaction of briquettes formed by this method takes place by changing the skew angle of the axes of briquetting rollers β relative to the axis of a briquetting chamber. The work presents the study results of the effect of changes in the twist angle of the axes of briquetting rollers on capacity, specific density and mechanical strength of briquettes. The study was conducted for the following twist angles of roller axes: $\beta = 5^\circ$ and $\beta = 7^\circ$. The study results show that there are significant differences between the values of the obtained degree of compaction of briquettes for both studied angles.

Keywords: briquetting by rolling, briquette, briquetting roller, twist angle of axis, specific density, capacity, mechanical strength

WPLYW ZMIAN KĄTA USTAWIENIA WAŁKÓW ZAGĘSZCZAJĄCYCH SŁOMĘ METODĄ ZWIJANIA NA PARAMETRY UZYSKIWANYCH BRYKIETÓW

Streszczenie

Obecnie znanych jest wiele sposobów zagęszczania słomy z przeznaczeniem na cele energetyczne. Nowym, do tej pory do tego celu nie wykorzystywanym sposobem jest zagęszczanie niepościętej słomy metodą zwijania przez zespół roboczy, składający się z pięciu stożkowych wałków. Różne zagęszczenie brykietów tworzonych tą metodą następuje przez zmianę kąta zwichrowania osi wałków brykietujących β względem osi komory brykietowania. W pracy przedstawiono wyniki badań wpływu zmian kąta skręcenia osi wałków brykietujących na przepustowość, gęstość właściwą i wytrzymałość mechaniczną brykietów. Badania przeprowadzono dla kątów skręcenia osi wałków $\beta = 5^\circ$ i $\beta = 7^\circ$. Wyniki badań pokazują występowanie istotnych różnic pomiędzy wartościami uzyskanego stopnia zagęszczenia brykietów dla obydwu badanych kątów.

Słowa kluczowe: brykietownie metodą zwijania, brykiet, wałek brykietujący, kąt skręcenia osi, gęstość właściwa, przepustowość, wytrzymałość mechaniczna

1. Introduction

Rational use of cereal straw as a Renewable Energy Source (RES), solid biomass combusted in order to obtain thermal energy (transferred in a thermal manner) entails the necessity of its earlier intensive compaction. This necessity results from the spatio-tubular construction of the straw stalk which makes it a volumetric material having its structure characterised by excess air. As a result, the straw in a loose form has a low volume weight and lower energy density [8, 12, 13]. One method of increasing energy density of straw consists in briquetting thereof. At present, this process is conducted for the straw having been previously milled or chopped into chaff of various length. There is also a method of briquetting the straw in the form of whole stalks left over after threshing grain with a harvester, the method using roller (rolling) briquetting presses [2, 3, 4, 5, 12]. This method, in contrast to the briquetting of chopped straw, can be used both in stationary machines and in machines hooked to the tractor working directly in the field.

Compaction of unchopped materials by rolling consists in twisting them with several (in the analysed case - five) cylindrical rollers or rollers in a conical shape, oriented at a slight angle to the axis of the briquetting chamber and rotating in one direction. Twisting of the axes of the briquetting rollers causes that the briquette formed in the briquetting chamber is simultaneously ejected outwardly therefrom as a

result of axial components of force. Having left the briquetting chamber, the briquette must be divided into sections by means of a cutting mechanism.

The briquette maintains its compactness only when tensile strength of the outer layer of the roll is greater than its tensile forces caused by expansion of the material located inside the roll. In turn, tensile strength of the roll layer is dependent, on the one hand, on the strength of the fibres themselves, and on the other hand, on friction forces between the fibres, these forces being greater with the increase of the pressure present inside the roll. For the cereal straw, the strength of the outer layer is lower than for the aforementioned materials, which causes its rapid unrolling and loss of obtained compaction and shape of the briquette [9]. Therefore, not many research works on the use of the method of rolling the cereal straw have been conducted. For this reason, there are not any domestic or foreign literature references. The only information about the possibility of using machines of this type to compact straw can be found in many patent specifications on field machines, equipped with units for briquetting materials on a rolling basis. An analysis of these constructions can be found in a few works [3, 4, 5, 6, 10, 11, 14, 15].

The most important in solving the problem is to obtain a suitable mechanical strength and a desired specific (volumetric) density of briquettes formed by rolling cereal straw in order to obtain briquettes having the best functional properties.

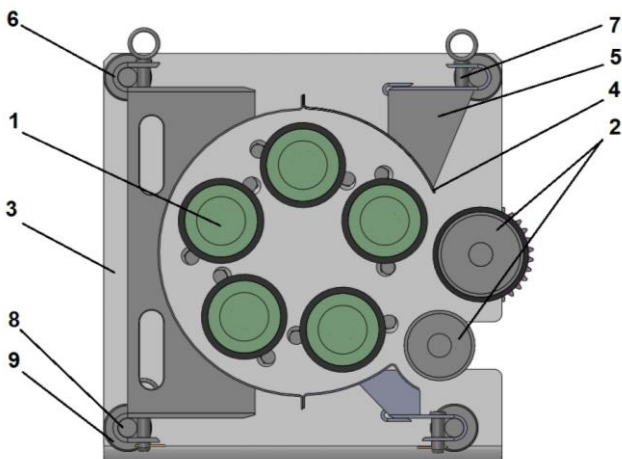
2. Purpose and scope of the study

The aim of the study was to determine and analyse operating parameters of the developed unit for compacting biomass by rolling, consisting of five briquetting rollers. The scope of work includes a study on the process of briquetting unchopped straw by rolling for two different twist angles of a rotating plate $\beta=5^\circ$ and $\beta=7^\circ$, which is equivalent to the twisting of axes of the briquetting rollers relative to the axis of the briquetting chamber by an angle of β' . The study was conducted on a prototype stationary briquetting machine which is also a professional test bench.

3. Subject of study

Briquetting rollers (Fig. 1), whose side surfaces are made of appropriately processed steel rods coated with a 10 mm rubber layer having an adequate hardness are the main operating elements of the briquetting unit. The rollers, on the side from which they are driven, are mounted by pivots in bearings on a fixed side plate. From the output side of the briquetting chamber, pivots of rollers are mounted in bearings located on the rotating plate used to change the angle of their orientation.

To the side plates, also two rollers introducing material into the briquetting chamber are mounted. The upper roller was covered with a rubber layer, and the lower one has a smooth steel side surface.



Source: own work / Źródło: opracowanie własne

Fig. 1. Cross section of the briquetting unit: 1- briquetting rollers, 2- introducing rollers, 3- input side plate, 4- cover, 5- cover support, 6- mounting bracket of the cover, 7- bolt, 8- coupler, 9- coupler flange

Rys. 1. Przekrój przez zespół brykietujący: 1- wałki brykietujące, 2- walce wprowadzające, 3- płyta boczna wejściowa, 4- osłona, 5- wspornik osłony, 6- uchwyt mocujący osłony, 7- sworzeń, 8- łącznik, 9- kołnierz łącznika

As already mentioned, the mobile plate in which pivots of operating rollers are slidably fitted with bearings is able to rotate relative to the fixed plate by an angle which is designated by β . This changes the position of the rollers from parallel (at an angle $\beta=0$) to warped position. The angle included between the axis of the rolling chamber and the axis of one of the rollers is designated by β' . The value of this angle is determined from the following relation (1):

$$\operatorname{tg} \beta' = \frac{AA'}{AA''} = \frac{2AE}{l'} = \frac{2 \frac{D_w + d_k}{2}}{l'} \sin \frac{\beta}{2} = \frac{D_w + d_k}{l'} \sin \frac{\beta}{2}. \quad (1)$$

Method of determining the angle of β' , its value and designation is shown in Fig. 2. For the calculations, the following assumptions have been made: $D_w = 120$ mm; $d_k = 110$ mm; $l' = 770$ mm according to the structural dimensions of the briquetting unit.

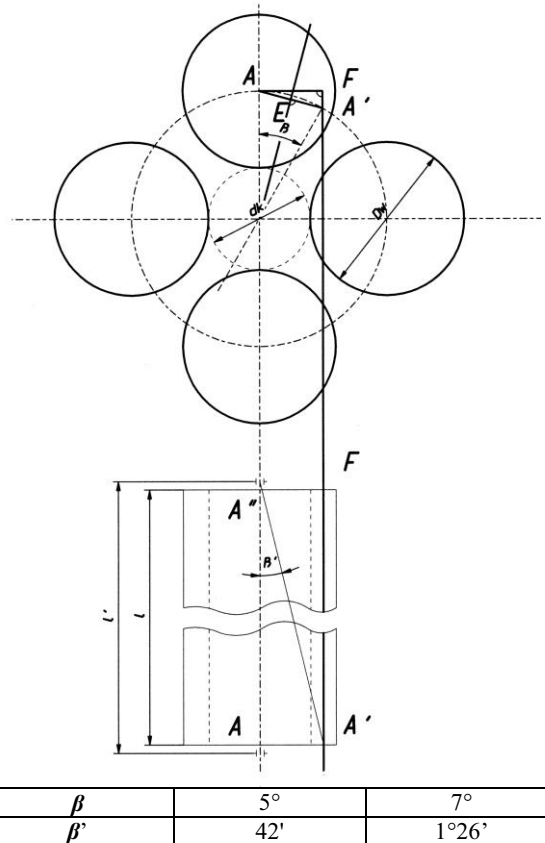


Fig. 2. Determination of angle β' between the roller axes and the axis of the rolling chamber after their twisting [7, 14]

Rys. 2. Wyznaczenie kąta β' pomiędzy osiami wałków a osią komory zwijania po ich skręceniu [7, 14]

Changing the orientation of the rotating plate which results in the change of the position of the roller axes relative to the axis of the rolling chamber, from parallel to warped position, makes these rollers form an operating chamber in the shape of a rotation hyperboloid.

4. Study methodology

The study was conducted following the methodology described in works [1-4].

The study on briquetting was conducted for barley straw on a stationary machine for briquetting by rolling, developed at IIAE based on results from previous studies, constituting at the same time a professional laboratory stand for studying the process of briquetting unchopped biomass by rolling. View of the stand in the course of the study is shown in Fig. 3.



Source: own work / Źródło: opracowanie własne

Fig. 3. The stationary briquetting machine during the study
Rys. 3. Stacjonarna maszyna brykietująca podczas badań

Description of the test bench and its equipment can be found in works: [1, 2, 3, 4].

The following study assumptions have been made:

1. The study will be conducted on straw taken from a rolled bale.
2. Straw which was harvested with a round baler from a field evenly overgrown with cereal will be used in the study.
3. Natural variability of moisture level of the briquetted straw for each bale was in the range of 13-18%.
4. The study was conducted at a rotational speed of briquetting rollers $n_w=175 \text{ min}^{-1}$.
5. The study was conducted for the angles of orientation of the rotating plate of the briquetting rollers $\beta=5^\circ$ i $\beta=7^\circ$.
6. During the study, capacity of the briquetting unit, specific (volumetric) density of briquettes γ , coefficients of their mechanical strength D_u were determined.

Measurement of specific (volumetric) density of briquettes γ

After each briquetting series carried out, 5 briquettes were randomly chosen and were weighed on laboratory scale WS-21. Then, their geometrical dimensions - length and diameter - were measured (in 3 - 4 places) and the average value of the briquette diameter was calculated. On the basis of obtained data, the volume of briquette was calculated, and then, based on the mass and the volume, its specific (volumetric) density γ , in $\text{kg}\cdot\text{m}^{-3}$, was determined [14, 15].

Measurement of mechanical strength (durability) of briquettes D_u

The mechanical strength (durability) of briquette was determined by means of mass loss after study cycle according to standard [16].

Measurement of capacity of the briquetting unit

Capacity of the briquetting unit was also determined, which constitutes both the performance of the test bench and of the very process of compacting the straw by rolling.

5. Analysis of the study results

Increasing the twist angle of axes of the briquetting rollers directly influences the change (decrease) in the value of

the obtained specific density of briquette, which is caused by an increase in the linear velocity of the briquette moving out of the briquetting chamber. Variable specific density of briquette also entails variable mechanical strength thereof. The obtained results of measurements for the two twist angles of axes of briquetting rollers were subjected to the analysis of variance with F test (Fisher-Snedecor) for the level of significance of $\alpha = 0.05$, in order to verify the occurrence of statistically significant differences between measured values for these two selected twisting degrees of rollers.

The results of measurements and calculations are presented in Tab. 1-3.

The analysis and statistical inference were conducted to verify the following null hypothesis that between average values obtained from measurements of:

- capacity of the briquetting unit,
 - specific density of briquettes,
 - mechanical strength of briquettes,
- there are not any significant differences.

For each case, before conducting the analysis of variance, an analysis of results to reject questionable results was conducted with Dixon's Q test. This analysis conducted for a range of small series showed that, with the assumed probability of $\alpha = 0.95$, all results of measurements, collected in Tab. 1-3, have values allowing them to be considered as elements of the series. This allows further statistical analyses to be conducted for all the collected values.

Determined value of test function F^0 , for the assumed level of significance of $\alpha = 0.01$, is between limit values read and determined for the number of replications (degrees of freedom) occurring in the experiment. Therefore, statement that there is no basis to reject the hypothesis of equality of variances can be assumed. Therefore, the null hypothesis significance for the significance of differences between capacity values for the two twist angles of the rotating plate can be checked. Performed analysis gives rise to the conclusion that the change in the twist angle of the rotating plate significantly affects the capacity of the briquetting unit.

Standard uncertainty of measurement of type A, determined based on calculations of measurement results presented in Tab. 1, indicates that in case of capacity of the briquetting unit, for the twist angle of briquetting rollers $\beta = 5^\circ$, interval of uncertainty of measurement has a range of $226 \pm 1.8 \text{ kg}\cdot\text{h}^{-1}$, and for the angle of $\beta = 7^\circ$ - $316 \pm 2.2 \text{ kg}\cdot\text{h}^{-1}$.

Specific density of briquettes is another analysed parameter of the process of briquetting biomass by rolling using a five-roller briquetting unit. The obtained results of statistical analyses for this parameter are included in Tab. 2.

Determined value of test function F^0 , for the assumed level of significance of $\alpha = 0.01$, is between limit values read and determined for the number of replications (degrees of freedom) occurring in the experiment. Therefore, statement that there is no basis to reject the hypothesis of equality of variances can be assumed. This allows checking the null hypothesis significance for the significance of differences between values of specific density of briquettes for the two twist angles of the rotating plate. Performed analysis gives rise to the conclusion that the change in the twist angle of the rotating plate significantly affects the specific density of briquettes formed in the five-roller briquetting unit.

Table 1. Results of the statistical analysis for the study of capacity values, in $\text{kg}\cdot\text{h}^{-1}$, for a five-roller briquetting unit
 Tab. 1. Wyniki analizy statystycznej badania wartości przepustowości, w $\text{kg}\cdot\text{h}^{-1}$, dla pięciowalkowego zespołu brykietującego

No.	Twist angle of the rotating plate $\beta = 5^\circ$		Twist angle of the rotating plate $\beta = 7^\circ$	
	Capacity $\text{kg}\cdot\text{h}^{-1}$	Random variable of Dixon Q-Test	Capacity $\text{kg}\cdot\text{h}^{-1}$	Random variable of Dixon Q-Test
	Q_{mb}	Q	Q_{mb}	Q
1.	224		310	
2.	232	0.45	323	0.38
3.	226		315	
4.	227		318	
5.	221	0.27	314	0.31
Average value	\bar{x}	226	316	
Standard deviation	s	4.06	4.85	
Confidence interval	E	(221.3; 230.7)	(310.4; 321.6)	
Standard uncertainty of the measurement result	u_A	1.8	2.2	
Significance test F^0	F^0	0.70		
Student's t significance test	t^0	16.14		

Source: own work / Źródło: opracowanie własne

Table 2. Results of the statistical analysis for the study of values of specific density of briquettes, in $\text{kg}\cdot\text{m}^{-3}$, for the five-roller briquetting unit

Tab. 2. Wyniki analizy statystycznej badania wartości gęstości właściwej brykietów, w $\text{kg}\cdot\text{m}^{-3}$ dla pięciowalkowego zespołu brykietującego

No.	Twist angle of the rotating plate $\beta = 5^\circ$		Twist angle of the rotating plate $\beta = 7^\circ$	
	Specific density of briquettes $\text{kg}\cdot\text{m}^{-3}$	Random variable of Dixon Q-Test	Specific density of briquettes $\text{kg}\cdot\text{m}^{-3}$	Random variable of Dixon Q-Test
	γ	Q	γ	Q
1.	374.5	0.35	287.9	0.34
2.	421.9		238.3	
3.	433.8		267.9	
4.	397.3		220.7	0.07
5.	439.0	0.08	225.5	
Average value	\bar{x}	413.3	247.5	
Standard deviation	s	27.0	28.4	
Confidence interval	E	(382.3; 444.3)	(214.8; 280.1)	
Standard uncertainty of the measurement result	u_A	12.1	12.7	
Significance test F	F^0	0.90		
Student's t significance test	t^0	4.55		

Source: own work / Źródło: opracowanie własne

Table 3. Results of the statistical analysis for the study of mechanical strength of briquettes for the five-roller briquetting unit

Tab. 3. Wyniki analizy statystycznej badania wytrzymałości mechanicznej brykietów dla pięciowalkowego zespołu brykietującego

No.	Twist angle of the rotating plate $\beta = 5^\circ$		Twist angle of the rotating plate $\beta = 7^\circ$	
	Mechanical strength	Random variable of Dixon Q-Test	Mechanical strength	Random variable of Dixon Q-Test
	ψ	Q	ψ	Q
1.	0.83	0.50	0.78	0.20
2.	0.85	0.50	0.83	0.60
3.	0.84		0.79	
4.	0.85	0.50	0.80	
5.	0.83	0.50	0.80	
Average value	\bar{x}	0.84	0.80	
Standard deviation	s	0.01	0.02	
Confidence interval	E	(0.83; 0.85)	(0.78; 0.82)	
Standard uncertainty of the measurement result	u_A	0.005	0.008	
Significance test F	F^0	0.28		
Student's t significance test	t^0	2.64		

Source: own work / Źródło: opracowanie własne

Standard uncertainty of measurement of type A, determined based on calculations of measurement results presented in Tab. 2, indicates that in case of specific density of briquettes, for the twist angle of the axes of briquetting rollers $\beta = 5^\circ$, interval of uncertainty of measurement has a range of $413.3 \pm 12.1 \text{ kg}\cdot\text{m}^{-3}$, and for the angle of $\beta = 7^\circ$ - $247.5 \pm 12.7 \text{ kg}\cdot\text{m}^{-3}$.

Mechanical strength of briquettes obtained as a result of carrying out the briquetting of barley straw in the five-roller briquetting unit was another studied parameter. The obtained results of statistical analyses for this parameter are included in Tab. 3.

Determined value of test function F^0 , for the assumed level of significance of $\alpha = 0.01$, is between limit values read and determined for the number of replications occurring in the experiment. Therefore, statement that there is no basis to reject the hypothesis of equality of variances can be assumed. This allows checking the null hypothesis significance for the significance of differences between values of mechanical strength for the two twist angles of the rotating plate. Performed statistical analysis gives rise to the conclusion that the change in the twist angle of the rotating plate significantly affects the mechanical strength of briquettes formed of unchopped straw by rolling in the five-roller briquetting unit.

Standard uncertainty of measurement of type A, determined based on calculations of measurement results presented in Tab. 3, indicates that in case of mechanical strength of briquettes, for the twist angle of the axes of briquetting rollers $\beta = 5^\circ$, interval of uncertainty of measurement has a range of 0.84 ± 0.005 , and for the angle of $\beta = 7^\circ$ - 0.80 ± 0.008 .

6. Conclusions

Principal conclusions drawn from this study are the following:

A developed and studied operating unit, consisting of five rollers in the form of truncated cones, located at different angles in space, constitutes the right direction aimed at solving the problem of effective compaction of straw intended for combustion in low power boilers.

The study results show that there are significant differences between the values of the obtained degree of compaction of briquettes for studied twist angles of the rotating plate. Greater degree of compaction were obtained for the angle of $\beta = 5^\circ$.

The obtained average values of coefficients of mechanical strength (durability) confirm previous observations that the briquettes obtained by rolling from unchopped straw are characterised by a good durability, also referred to as mechanical strength. By analysing the effect of the twist angle β of the rotating plate, a significant effect of change in the angle β on the value of coefficient of mechanical strength of the briquettes obtained has been demonstrated.

It was observed that the briquettes made for the angle of $\beta = 7^\circ$ had a lower average durability.

Analysis of capacity of the briquetting unit made it possible to demonstrate the presence of significant differences in values of this parameter depending on the size of the twist angle β of the rotating plate.

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