ASSESSMENT OF ENERGY CONSUMPTION OF PELLETS AND BRIQUETTES PRODUCTION IN COMPRESSING DEVICES[1]

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A R T I C L E   I N F O

A B S T R A C T

Assessment of energy consumption of pellets and briquettes production from plant raw materials was presented. Wheat, rye, rape straw and meadow hay were used for their production. The investigated raw materials were ground before briquetting with the use of a station drum straw cutter and theoretical length of cutting of 20 mm, whereas before pelleting – with the use of a beater grinder equipped with sieves of 6 mm meshes diameter. Analysis of moisture of raw materials and their calorific value were carried out according to binding norms. Moisture of compacted raw materials was within 10.1-13.3%, whereas the calorific value was from 16.1 to 17.9 $MJ \cdot kg^{-1}$. Pellets were produced in a pelleting machine with an immobile flat matrix and driven compressing rolls, whereas briquettes were produced in a screw briquetting machine with a heated compressing chamber. The following values of temperature of the compressing chamber of a briquetting machine were assumed: 200, 225 and 250℃. For measurement of energy consumption of the raw materials compression process power, time and electric energy converter Lumel 3000 was used. Average values of energy consumption during production of pellets were from 0.145 $kWh \cdot kg^{-1}$ for rape straw to 0.176 $kW \cdot kg^{-1}$ for meadow hay. In case of production of briquettes the lowest value of energy intake was reported for wheat straw compressed in temperature 250℃ (0.128 $kWh \cdot kg^{-1}$), whereas the highest value of energy intake for meadow hay compressed in temperature 200℃ (0.182 $kWh \cdot kg^{-1}$).

Introduction

Renewable energy sources are included in the sources of energy, the resources of which are renewed in natural processes. They are more frequently used for production of heat and electric energy and the main reason of their growing popularity is a non-harmful impact on the natural environment and practical infinity. Whereas, in case of conventional sources,

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their exploitation leads to climatic changes of a globe and to their complete exhaustion in future. Thus, economic development should be based on a sustainable model, in which economic reasons will constitute a balance for ecological reasons. Taking into consideration the above facts, alternative energy sources are more frequently searched for (Grzybek, 2004; Kołodziej and Matyka, 2012).

Production of the so-called "green energy" brings many positive properties for development of national economy. It is commonly considered that development of the power industry based on renewable sources may cause solution of many problems resulting from conventional power industry. Thus, one may aim to introduce technology of energy plants cultivation and the use of what remains after agricultural production. Special attention is paid to the possibility of solid biofuels production from materials of plant production. Fuels, which were formed in the process of agglomeration, compete with their properties with conventional fuels and their excavation is cheaper. Thus, in times when depletion of non-renewable energy sources is possible, production of pellets and briquettes from plant raw material may play a significant role in protection of environment and energy production in the country (Denisiuk, 2007; Frączek 2010; Hejft 2006; Kowalik, 2003; Niedziółka and Szpryngiel 2012; Winnicka et al., 2005).

Biomass, which is in majority obtained from side products of forestry and agriculture, is the biggest source of renewable energy. In order to increase the possibility of obtaining biomass, also energy plants, which are characterized with a big increase in a year and low soil demands are cultivated. Solid biofuels, obtained from plant material provide ca. 11% of total world energy, due to which they belong to a group of the most important energy sources. Such materials as: firewood and wood waste, energy crops, agricultural crops, municipal waste and waste of paper industry, which may be combusted in various technologies are included there. On account of the above, the assumed objectives of Directive 28/2009/EC forced on the territory of the EU countries, specific actions which lead to minimization of fossil fuel consumption, which increased the demand for biomass (Niedziółka and Zaklika 2012; Stolarski et al., 2008, Szyszlak-Bargłowicz et al., 2012; Terlikowski, 2012).

In order to use the chance, which biomass management for energy purposes provides, machines and devices, which facilitate and considerably speed up cropping and plant processing designated for this purpose, are necessary. It is however related to high financial and energy inputs, which the most frequently closes the way for many farmers and producers interested in obtaining green energy. Therefore it is important to introduce appropriate legal provisions enabling setting up a plantation, obtaining funds and solid fuels circulation as a result of biomass management (Grzybek, 2004; Gałecki, 2004; Nowak, 2005; Zarajczyk, 2013).

Assessment of energy consumption of pellets and briquettes production from selected plant raw materials was the objective of the paper.

Methodology and conditions for research

For production of pellets and briquettes the following types of plant material was used: wheat straw, rye and rape straw and meadow hay. Plant material was ground before briquetting with a station straw drum cutter with a theoretical cut length of 20 mm, whereas

before pelleting with the use of a beater grinder equipped with two sieves of the meshes diameter of 6 mm. Pellets were produced in a pelleting machine with an immobile flat matrix and driven compressing rolls, whereas briquettes were produced in a screw briquetting machine with a heated compressing chamber. Three values of temperature of the compressing chamber of a briquetting machine were assumed: 200, 225 and 250ºC. Technical and exploitation data of compressing devices were presented in table 1 and 2.

Table 1
Technical-exploitation data of a pelleting machine with a flat matrix

Specification	Unit of measure	Parameters
Diameter of pellets	(mm)	8.0
Diameter of a matrix	(mm)	225.0
Thickness of matrix	(mm)	25.0
Length of compressing rollers	(mm)	50.0
Diameter of rollers	(mm)	100.0
Rotational speed of rollers	$(rot \cdot min^{-1})$	110.0
Engine output	(kW)	7.5
Performance of a pelleting machine	$(kg \cdot h^{-1})$	100-150
Dimensions of a pelleting machine (L×B×H)	(mm)	1300×650×1020
Mass of a pelleting machine	(kg)	250

Table 2
Technical-exploitation data of a screw briquetting machine

Specification	Unit of measure	Parameters
Type of a briquetting machine	(-)	JW- 08
Diameter of a compression chamber	(mm)	80.0
Length of a guide which stabilizes briquettes	(m)	5.0
Output of an engine of a compression screw	(kW)	4.0
Output of an engine of a raw material feeder	(kW)	1.1
Output of electric heaters	(kW)	3.0
Productivity of a briquetting machine	$(kg \cdot h^{-1})$	60-100
Dimensions of a briquetting machine (L×B×H)	(mm)	1200×1000×1300
Mass of a briquetting machine	(kg)	320

A special measurement system was used for the measurement of energy consumption of the compression process of the investigated plant materials (fig. 1). In this system, a converter of power, time and electric energy Lumel 3000 type which cooperates with a computer recording instantaneous power intake, was used. Measurements of active power intake were recorded following achieving an assumed temperature by a compression chamber of a briquetting machine. Measurements of total intake of electric energy during heating the compression chamber and during the process of raw material compression were also recorded with the use of a three-phase current meter. The obtained results of measurements of electric energy intake were calculated per a unit of mass of the produced agglomerate.
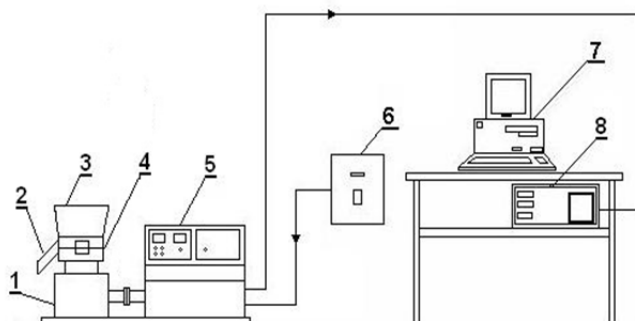
Figure 1. Schematic representation of the measurement stand: 1 – toothed gear, 2 – pellets spout, 3 – charging hopper, 4 – compressing mechanism, 5 – control cabinet with electric engine, 6 – frequency transducer of electric power, 7 – computer, 8 – recorder of active power

Figure 2 presents pellets produced of the investigated plant material.

a)   b)

c)   d)

Figure 2. Pellets produced of the investigated plant raw material: a) wheat straw, b) rye straw, c) rape straw, d) meadow hay

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Figure 3 presents briquettes produced of the investigated plant material.

a)

b)

c)

d)

Figure 3. Briquettes produced of the investigated raw materials: a) wheat straw, b) rye straw, c) rape straw, d) meadow hay

The obtained results of measurement of energy consumption of producing pellets and briquettes from the researched raw plant material were subjected to statistical analysis with the use of analysis of variance and Tukey's test. In all analyses the level of significance was assumed as $\alpha=0.05$. For this purpose statistic programme SAS Enterprise Guide 5.1. The obtained results were presented in tables of analysis of variance and tables which include appropriate means along with determination of their impact on statistically significant differences of analysed properties.

Research results

Characteristic of agglomerated plant material was placed in table 3. Average moisture of raw material in a fresh state was within 16.8% for meadow hay to 21.2% for rye hay. While, average moisture of dry raw material was from 11.2% for rye straw to 12.3% for the

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remaining raw material. Whereas, average calorific value was within 16.2 MJ·kg^{-1} for rye straw to 17.5 MJ·kg^{-1} in case of rape straw.

Table 3
Properties of agglomerated plant raw materials

Type of raw material	Moisture in a fresh state, (%)	Moisture in a dry state, (%)	Calorific value in a dry state, (MJ·kg^{-1})
Wheat straw	18.4-20.6	11.5-12.8	16.7-17.4
Rye straw	20.3-22.4	10.1-12.4	16.1-16.6
Rape straw	17.6-19.8	11.2-13.3	17.2-17.9
Meadow hay	16.3-17.5	12.0-12.8	16.3-16.8

The analysis of variance which was carried out proved that the plant material, used in the research, significantly influence the energy intake during the process of pelleting (tab. 4). Statistically significant differences were found in case of energy intake during production of pellets for all agglomerated plant material (tab. 5).

Table 4
Analysis of variance of energy intake during production of pellets from the investigated raw materials

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	p (F> F_0)
Raw material	3	0.00326	0.00109	47.71	<0.0001
Error	20	0.00045	0.00002		
Total	23	0.00371			

Table 5
Comparison of average values of energy intake during production of pellets (kWh·kg^{-1})

Type of raw material	Wheat straw	Rye straw	Rape straw	Meadow hay
Average	0.153[A]	0.164[B]	0.145[C]	0.176[D]
Standard deviation	0.0068	0.0047	0.0035	0.0032

Figure 4 presents results of the research of energy consumption of pellets production depending on the type of agglomerated plant material. The lowest energy consumption was in case of pellets produced from rape straw (0.145 kWh·kg^{-1}), wheat straw pellets with a slightly higher (0.153 kWh·kg^{-1}) and rye straw (0.164 kWh·kg^{-1}), and pellets from meadow hay with the highest (0.176 kWh·kg^{-1}). Increase of energy intake in case of pellets from wheat straw was approx. 5% for pellets made of wheat straw, for rye straw pellets approx. 13%, whereas for meadow hay pellets approx. 21% with reference to energy intake for rape straw pellets.
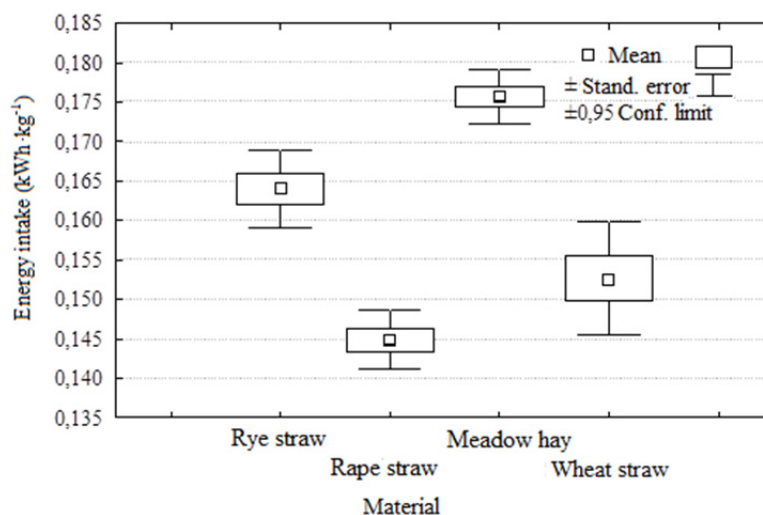
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Figure 4. Values of energy intake during production of pellets from the investigated raw materials

The analysis of variance, which was carried out proved that both the researched material as well as the accepted temperature and their interactions significantly differentiate the energy intake of production of briquettes (tab. 7). Statistically significant differences were reported in case of energy consumption of a briquetting process for all agglomerated plant materials. Increase of energy intake in case of briquettes from rye straw was approx. 5% for briquettes made of rape straw approx. 13%, whereas for meadow hay briquettes approx. 23% with reference to energy intake for wheat straw pellets. Moreover, statistically significant differences were reported in case of energy intake during the process of briquette production in temperature 200, 225 and 250ºC. Decrease of energy intake was approx. 7% in case of temperature 225ºC and approx. 16% for temperature 250ºC in comparison to 200ºC (tab. 8).

Table 7

Analysis of variance of energy intake during production of briquettes from the investigated raw materials in the accepted compression temperature

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	p (F> F_0)
Temperature	2	0.00583	0.00291	146.09	<0.0001
Raw material	3	0.01128	0.00376	188.38	<0.0001
Temperature×Raw material	6	0.00034	0.00005	2.90	0.0149
Error	60	0.00119	0.00001		
Total	71	0.01866			

Table 8

Comparison of average values of energy intake during production of briquettes for the investigated raw material and compression temperature

Type of raw material	Wheat straw	Rye straw	Rape straw	Meadow hay
Average	0.137[A]	0.142[B]	0.159[C]	0.168[D]
Temperature (ºC)	200		225	250
Average	0.162[A]		0.151[B]	0.140[C]

When analysing the impact of temperature in the compression chamber of a briquetting machine on the energy consumption of the process of production of briquettes, it was reported that the highest values were obtained for temperature 200ºC (0.145-0.182 kWh·kg^{-1}), lower for temperature 225ºC (0.138 to 0.169 kWh·kg^{-1}), and the lowest for temperature 250ºC (0.128 to 0.152 kWh·kg^{-1}) – respectively for wheat straw and meadow hay (tab. 9). Difference in the energy intake for the investigated plant material in the chamber temperature of 200ºC was approx. 25%, in the chamber temperature of 225ºC (approx. 22%) and in the chamber temperature of 250ºC (approx. 19%).

Table 9

Average values of energy intake during production of briquettes from the investigated raw materials

Type of raw material	Temperature (ºC)	Energy intake (kWh·kg^{-1})	Standard deviation
Wheat straw	200	0.145	0.0073
	225	0.138	0.0035
	250	0.128	0.0021
Rye straw	200	0.152	0.0047
	225	0.141	0.0044
	250	0.133	0.0060
Rape straw	200	0.171	0.0053
	225	0.157	0.0026
	250	0.149	0.0050
Meadow hay	200	0.182	0.0043
	225	0.169	0.0025
	250	0.152	0.0026

Figure 5 presents the results of measurements of energy intake depending on the temperature of the compression chamber of a briquetting machine and agglomerated plant material. Along with the increase of temperature in the compression chamber, the energy consumption of the raw material briquetting process decreased. The highest energy consumption was for briquettes produced of meadow hay compressed in temperature of 200ºC (0.182 kWh·kg^{-1}), whereas the lowest energy consumption was in case of briquettes obtained from wheat straw in temperature of 250ºC (0.128 kWh·kg^{-1}).
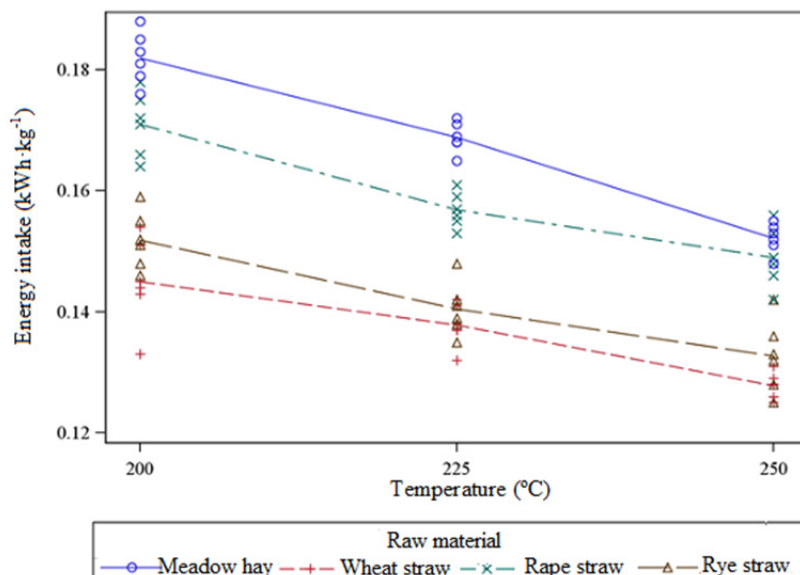
Figure 5. Relation of the energy intake to the temperature of the compression chamber of agglomerated plant raw material

Conclusions

1. When analysing the obtained research results it was reported that energy consumption of the production process both of pellets and briquettes depended on the type of agglomerated plant material and on the accepted values of temperature in the compression chamber of a briquetting machine for production of briquettes.
2. Unit consumption of electric energy during the process of pelleting plant materials was within 0.245 to 0.176 kWh·kg^{-1}. The lowest energy consumption was during the rape straw compression, higher for wheat straw by 5.5% and rye straw by 13% whereas for meadow hay by 21%.
3. Unit consumption of electric energy during the process of briquetting decreased along with the increase of temperature in the compression chamber. The lowest energy consumption was during briquetting of wheat and rye straw, whereas considerably higher for rape straw and hay. Along with the increase of temperature from 200 to 250ºC, decrease of electric energy intake was from 13 to 15% for wheat, rye and rape straw and 20% for meadow hay.

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OCENA ENERGOCHŁONNOŚCI WYTWARZANIA PELETÓW I BRYKIETÓW W URZĄDZENIACH ZAGĘSZCZAJĄCYCH

Streszczenie. Przedstawiono ocenę energochłonności wytwarzania peletów i brykietów z wybranych surowców roślinnych. Do ich produkcji użyto słomy pszennej, żytniej i rzepakowej oraz siana łąkowego. Badane surowce przed brykietowaniem rozdrabniano przy użyciu stacyjnej sieczkarni bębnowej i teoretycznej długości cięcia 20 mm, natomiast przed peletowaniem – za pomocą rozdrabniacza bijakowego wyposażonego w sita o średnicy otworów 6 mm. Analizy wilgotności surowców i ich wartości opałowej przeprowadzono zgodnie z obowiązującymi normami. Wilgotność zagęszczanych surowców wahała się w przedziale 10,1-13,3%, natomiast wartość opałowa od 16,1 do 17,9 MJ·kg^{-1}. Pelety wytwarzane były w peleciarce z nieruchomą matrycą płaską i napędzanymi rolkami zagęszczającymi, natomiast brykiety wytwarzano w brykieciarce ślimakowej z podgrzewaną komorą zagęszczania. Przyjęto następujące wartości temperatury komory zagęszczającej brykieciarki: 200, 225 i 250ºC. Do pomiaru energochłonności procesu zagęszczania surowców wykorzystano przetwornik mocy, czasu i energii elektrycznej typu Lumel 3000. Średnie wartości poboru energii podczas wytwarzania peletów wynosiły od 0,145 kWh·kg^{-1} dla słomy rzepakowej do 0,176 kWh·kg^{-1} dla siana łąkowego. W przypadku wytwarzania brykietów najniższą wartość poboru energii odnotowano dla słomy pszennej zagęszczanej w temperaturze 250ºC (0,128 kWh·kg^{-1}), natomiast najwyższą wartość poboru energii dla siana łąkowego zagęszczanego w temperaturze 200ºC (0,182 kWh·kg^{-1}).

Słowa kluczowe: biomasa roślinna, pelety, brykiety, energochłonność wytwarzania