Scientific quarterly journal e-ISNN 2449-5999

Agricultural Engineering

2015: 1(153):141-150

Homepage: http://ir.ptir.org

DOI: http://dx.medra.org/10.14654/ir.2015.153.115

IMPACT OF DIAMETER OF PRESSING CHANNELS AND MOISTURE ON PARAMETERS OF PELLETING PROCESS OF VIRGINIA MALLOW BIOMASS

Grzegorz Zając*

Department of Power Engineering and Vehicles, University of Life Sciences in Lublin

**Contact details: ul. Głęboka 28, 20-612 Lublin; e-mail: grzegorz.zajac@up.lublin.pl*

ARTICLE INFO

Article history:
Received: January 2015
Received in the revised form: February 2015
Accepted: March 2015

Keywords:
biomass
pellets
energy consumption
quality of pellets

ABSTRACT

The objective of the paper was to evaluate the impact of biomass subjected to pelleting and diameter of pressing openings of a matrix of a pelleting machine on unit consumption of energy and quality of pellets. Virginia mallow biomass (*Sida hermaphrodita* R.) was investigated. The pelleting process was carried out on a pelleting machine with a flat matrix with the set of pressing rolls. Matrices with three diameters of pressing channels 6, 8, 10 mm were used for pelleting. Pelleting attempts were carried out at the material moisture which was 10, 15 and 20%. It was found out that energy consumption of the process of pellet production from Virginia mallow biomass depended on the raw material moisture and on diameter of pressing channels in the matrix of a pelleting machine. Unit consumption of electric energy during the pelleting process was within 45.3 and 70.2 $Wh \cdot kg^{-1}$. The lowest value was reported for moisture of 15% and diameter of pressing channels of 10 mm. Durability of the obtained pellets was within 88.9-93.5% of pellets. The highest durability was in case of pellets obtained at the moisture of 15% but higher durability was obtained at lower diameters of pressing openings. The highest relative density was in case of pellets obtained at the moisture of 15% and it was 1133.6-1094.8 $kg \cdot m^{-3}$ but density got reduced along with the increase of a diameter of channels.

Introduction

The use of plant biomass for production of heat and electric energy has become more important on account of partial replacement of fossil fuels and striving to reduce emission of carbon dioxide to atmosphere (Smeets et al., 2007; Stelte et al., 2011a; Nunes et al., 2014; Blaschke et al., 2013).

Solid biomass is presently obtained from forestry, agriculture, wood industry, urban greenery waste and some amount from segregated organic municipal waste. Balance of biomass supply on the power industry market may be supplemented by obtaining it from perennial domestic plants plantations and those introduced to Poland (Niedziółka et al., 2015). Biomass advantage consists in local production, however, it has low density and low calorific value (referred to volumetric unit) thus high transport costs and an impeded manner of charging boilers. These problems may be solved through appropriate processing and pressure agglomeration- briquetting and pelleting. Main advantages from biomass agglomeration include higher energy density and lower costs of transport and storing (Stelte et al., 2011b; Niedziółka and Szpryngiel, 2012; Niedziółka and Szpryngiel, 2014).

Pellets have become popular in many countries, particularly in Europe, their use has been systematically increasing recently (Liu et al., 2014; Stelte et al., 2011a; Stelte et al., 2011b). Demand for this type of fuel results mainly from comfort of use and possibility of using it both in heating individual installations and in heating systems. In comparison to traditional calorific wood, pellets may ensure possibility of automation and optimization of combustion, similar to calorific oil or natural gas along with high combustion efficiency and low amount of combustion residue.

Basic raw material for production of pellets is wood waste, presently energy plants and post-production farm waste is also used.

Processes of pressure agglomeration cause many difficulties with respect to technique, technology and exploitation, which result from complexity and variability of issues which occur during the process, carried out in working systems with various structures. Variability of physical, chemical and biological materials subjected to agglomeration is an impediment (Hejft, 2011). Except for information concerning the course of agglomeration process, information concerning energy inputs incurred in the process is important.

The objective of the paper was to evaluate the impact of biomass subjected to compaction and diameter of pressing openings of a matrix of a pelleting machine on unit consumption of energy and quality of Virginia mallow pellets (*Sida hermaphrodita* R.).

Methodology and conditions of research

The researched raw material was Virginia mallow biomass, which came from the field experiment. Initial fragmentation of biomass was carried out with the use of a beater grinder. Target raw material fraction was obtained in a hammer mill H111 equipped with sieves with 3 mm meshes.

The pelleting process was carried out on a pelleting machine with a flat matrix with the set of pressing rolls. The pelleting machine was equipped with a matrix with 380 mm diameter and three pressing rolls, which ensure capacity up to 300 $kg \cdot h^{-1}$ (sawdust with 13% moisture and fraction up to 5 mm), electric engine power was 12 kW.

Matrices with three diameters of pressing channels 6, 8, 10 mm and length of 36 mm each were used for pelleting. Pelleting attempts were carried out at the material moisture which was 10, 15 and 20%.

It allowed preparation of 9 measurement variants presented in table 1. Measurements were carried out in 5 iterations for each variant. Biomass was moistened in the conditioning process with the use of a steam generator. Moisture during research was determined with the use of a moisture meter WTR-1N.

Table 1.
Measurement variants of research

Measurement variant	Moisture (%)	Diameter of pressing channels (mm)
1	10	6
2	10	8
3	10	10
4	15	6
5	15	8
6	15	10
7	20	6
8	20	8
9	20	10

In order to determine unit energy consumption, electric energy consumption charged by an electric engine, which drives the device was registered. Measurements of electric energy were made when the device reached stable speed. Power converter A/C Lumel P13P was used for measurement and registration of electric energy. This system enabled registration of active power collected by the device and visualization of actual value on the computer screen with the use of Lumel 3000 software. In order to determine energy consumption for fighting over own resistance of the device, instantaneous power was recorded during idle running. During pelleting of each of the tested raw materials, values of instantaneous power in one second intervals were recorded. Energy consumption was determined in relation:

$$E_j = \frac{E_p - E_{op}}{m} \tag{1}$$

where:
E_j – energy consumption of the process, ($Wh \cdot kg^{-1}$)
E_p – energy inputs during the process, ($W \cdot h$)
E_{op} – energy inputs during light running, ($W \cdot h$)
m – mass of the obtained pellets, (kg)

In order to determine mechanical properties of the obtained Virginia mallow pellets the following were determined:
- Specific density – with the use of a set for determination of density of solid bodies of RADWAG company WPS 510/C/1 model, where the measurement was based on the measurement of the mass of a sample in air and in liquid with known density.
- Durability – with the use of Pfost apparatus. In the container which is mechanically rotated, samples of 0.5 kg mass were placed and it was set in rotary motion with the speed of 50 rpm for 10 minutes. After the tester was stopped, the sample was sieved and the mass of not damaged granules was determined. By referring the mass of the remaining pellets to the mass of the entire sample kinetic resistance of pellet was obtained.

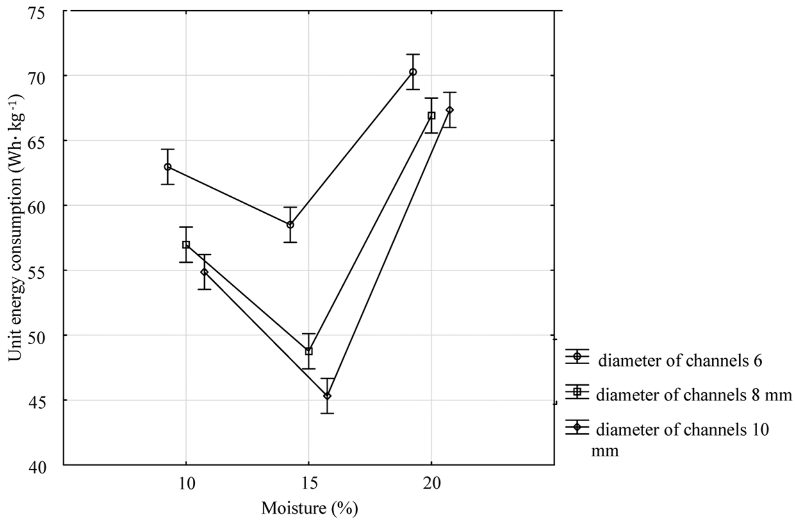
The obtained results of measurement of energy consumed for production of pellets from the investigated plant materials were subjected to statistical analysis with the use of analysis of variance and Tukey's test. In all analyses the level of significance was assumed as $\alpha=0.05$ The obtained results 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.

Results of the research

Figure 1 presents results of the research of energy consumption of pellets production depending on the moisture of raw material and diameter of pressing channels. The lowest unit energy consumption which amounts to 45.3 $Wh \cdot kg^{-1}$ was obtained for moisture of 15% and ϕ10 mm. The highest energy consumption – 70.27 $Wh \cdot kg^{-1}$ was in case of the compaction process for biomass moisture of 20% and ϕ 6 mm.

High energy consumption at the moisture of 20% resulted from unstable operation of a pelleting machine. While at the moisture of 10% before compaction of material, rolls of the device additionally milled material which caused a buildup of material and reduction of capacity of the compaction process.

Reduction of energy consumption for matrices with higher diameters of pressing channels may be justified by decrease of friction force, which results from the reduction of the total area of friction of agglomerate by areas of all compacting channels (Frączek, 2010).



Vertical columns stand for 0.95 confidence interval

Figure 1. Relation of unit energy consumption to moisture of raw material and diameter of pressing channels of matrix

In order to determine the impact of biomass moisture fed to a pelleting machine and diameter of pressing channels on energy consumption of the process, two-way analysis of variance (ANOVA) with interaction was carried out. Results of the analysis were presented in table 2. The analysis of variance which was carried out proved that both moisture of raw material as well as diameter of pressing channels and their interaction significantly influence unit energy consumption.

Table 2
Analysis of variance of unit energy consumption in relation to moisture and diameter of pressing channels

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	P ($F > F_0$)
Moisture	2	2264.8	1132.4	510.35	0.000000
Diameter of channels	2	543.0	271.5	122.35	0.000000
Moisture* diameter of channels	4	134.9	33.7	15.20	0.000000
Error	36	79.9	2.2		0.000000

The procedure of Tukey's test which compares results of research on the energy consumption of the pelleting process obtained in particular measurement variants (1-9) formed seven unit groups (table 3): first group – measurement variant 2 and 3, second: measurement variant 2 and 4, third: measurement variant 8 and 9, fourth: measurement variant 7 and 9, fifth: measurement variant 6, sixth: measurement variant 5 and seventh: measurement variant 1.

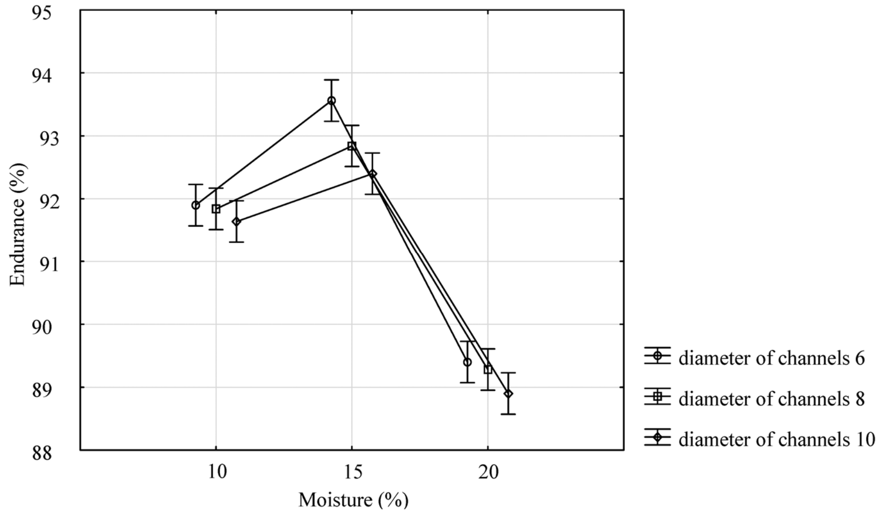
Table 3
Average values of energy intake during production of pellets ($Wh \cdot kg^{-1}$)

Measurement variant	Moisture (%)	Diameter of channels (mm)	Average energy consumption ($Wh \cdot kg^{-1}$)
6	15	10	45.32 [a]
5	15	8	48.76 [b]
3	10	10	54.86 [c]
2	10	8	56.97 [c,d]
4	15	6	58.50 [d]
1	10	6	62.96 [e]
8	20	8	66.91 [f]
9	20	10	67.35 [f]
7	20	6	70.28 [f,g]

Letters a, b, c, d, e, f, g in brackets stand for uniform groups
(average values of properties differ significantly between groups)

Relation between the durability of pellets and moisture for the applied matrices was presented in figure 2. Durability of the obtained pellets was within 88.9% to 93.56%. The lowest durability (<90%) was obtained for moisture of 20% independently from the applied matrices. Such low durability practically disqualifies them as fuel for use in household heating systems. The highest durability was obtained by pellets at the moisture of 15% for the matrix with a diameter of pressing channels of 6 mm – 93.56%.

Reduction of durability at moisture of 20% was caused by expansion of pellet after its passing through the matrix channel. Similar relations are presented in works (Kulig and Skonecki, 2011; 2010).



Vertical columns stand for 0.95 confidence interval

Figure 2. Relation of durability of obtained pellets to moisture of raw material and diameter of pressing channels of matrix

Impact of the moisture of raw material and diameter of pressing channels on thre durability of the obtained pellets was analysed with the use of a two-way analysis of variance (ANOVA) results of which were presented in table 4. Based on the obtained results it was found out that both the moisture of raw material and diameter of pressing channels had significant impact on the durability of the obtained pellets at 95% confidence interval. Effect of interaction of the moisture and diameter of pressing channels had no significant impact on durability of pellets.

Table 4
Analysis of variance of pellets durability in relation to moisture and diameter of pressing channels

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	P $(F > F_0)$
Moisture	2	110.2	55.1	421	0.000000
Diameter of channels	2	3.1	1.5	12	0.000119
Moisture* diameter of channels	4	4	0.3	2	0.074729
Error	36	4.7	0.1		

Table 5
Average values of durability of the obtained pellets (%)

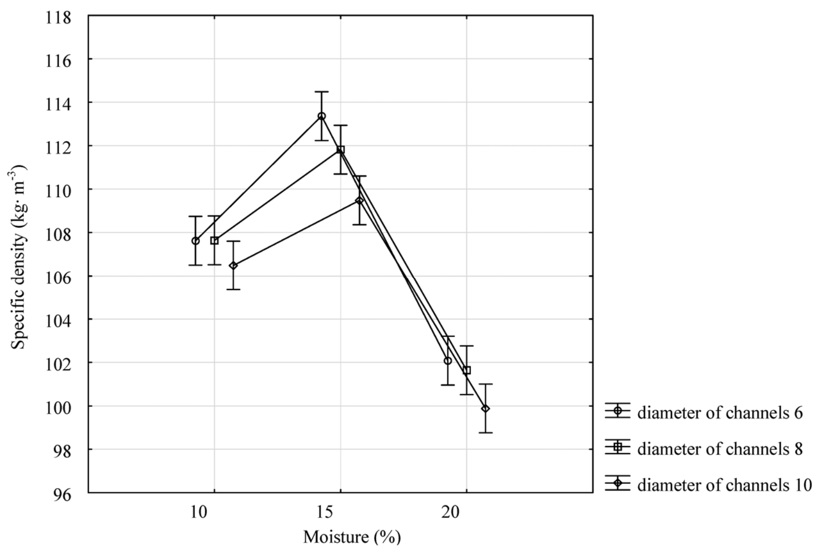
Measurement variant	Moisture (%)	Diameter of channels (mm)	Average durability (%)
9	20	10	88.90 [a]
8	20	8	89.28 [a]
7	20	6	89.40 [a]
3	10	10	91.64 [b]
2	10	8	91.84 [b,c]
1	10	6	91.90 [c]
6	15	10	92.40 [d]
5	15	8	92.84 [d]
4	15	6	93.56 [e]

Letters a, b, c, d, e in brackets stand for uniform groups
(average values of properties differ significantly betweengroups)

The applied Tukey's procedure which compares results of research on the durability of pellets obtained in particular measurement variants formed 5 uniform groups (table 5): first – measurement variant 7,8,9, second – measurement variant 1,2,3, third – measurement variant 6, fourth – measurement variant 5 and fifth measurement variant 4.

Specific density is one of the most important qualities of pellets. One of the factors influencing specific density is moisture and size of particles.

Figure 3 presents the obtained relation between specific density of pellets and moisture of raw material for the applied matrices.



Vertical columns stand for 0.95 confidence interval

Figure 3. Relation of specific density of the obtained pellets to moisture of raw material for diameters of pressing channels of matrix used in research

The highest values of the parameter were determined for moisture of 15% for all diameters of pressing channels – 1133.6-1094.8 kg·m^{-3}, whereas the lowest for moisture of 20% – 998.8-1002.8 kg·m^{-3}.

Low values of density at 20% moisture result from extension of agglomerate after being pushed from the matrix.

Kulig and Skonecki (2011) when investigating the compaction process of various energy plants including Virginia mallow determined similar relations by obtaining density exceeding 1000 kg·m^{-3} within the scope of moisture of 13-16%.

ANOVA analysis of variance (table 6) proved that moisture of raw material and diameter of pressing channels had significant impact ($p<0.05$) on specific density of the obtained pellets. Whereas for interaction of factors no statistically significant differences were determined.

Table 6
Analysis of variance of specific density of pellets in relation to moisture and diameter of pressing channels

Source of variability	Degrees of freedom	Sum of squares	Root mean square	Value F_0	P ($F> F_0$)
Moisture	2	81151	40575	264.9	0.000000
Diameter of channels	2	4647	2323	15.2	0.000017
Moisture* diameter of channels	4	967	242	1.6	0.201309
Error	36	5514	153		

Table 7
Average specific density of the obtained pellets

Measurement variant	Moisture (%)	Diameter of channels (mm)	Average specific density (kg·m^{-3})
9	25	10	998.8 ^{a}
8	25	8	1016.4 ^{a}
7	25	6	1020.8 ^{a}
3	15	10	1064.8 ^{b}
1	15	6	1076.2 $^{b, c}$
42	15	8	1076.4 $^{b, c}$
6	20	10	1094.8 $^{c, d}$
5	20	8	1118.2 $^{d, e}$
4	20	6	1133.6 ^{e}

Letters a, b, c, d, e in brackets stand for uniform groups
(average values of properties differ significantly between groups)

The procedure of Tukey's test which compares results of research on specific density of pellets obtained in particular measurement values (1-9) formed five uniform groups (table 7): first group – measurement variant 7-9 – measurement variant 1-3, third measurement variant 6, fourth 5 and sixth group measurement variant 4.

Conclusions

1. Analysis of the obtained results proved that energy consumption of the process of pellet production from Virginia mallow biomass depended on the raw material moisture and on the diameter of pressing channels in the matrix of a pelleting machine. Unit consumption of electric energy during the pelleting process was within 45.3 and 70.2 $W \cdot kg^{-1}$. The lowest energy consumption was obtained at the moisture of 15% and diameter of pressing channels of 10 mm.
2. The lowest durability was in case of pellets obtained at the moisture of 20% – 88.9-88.4%, the highest was in case of pellets obtained at the moisture of 15% 93.5-92.4%. The highest durability was obtained at lower diameters of pressing openings.
3. The highest specific density was obtained for pellets obtained at the moisture of 15% and it was 1133.6-1094.8 kg m^{-3}. The lowest density was obtained at the moisture of 20% – 998.8-1020.8 kg m^{-3} but density got reduced along with the increase of the diameter of pressing channels.

References

Blaschke, T., Biberacher, M., Gadocha, S., and Schardinger, I. (2013). "Energy landscapes": Meeting energy demands and human aspirations. *Biomass Bioenergy* 55, 3-16.

Frączek J. (red.) (2010). Produkcja biomasy na cele energetyczne. Kraków, PTIR, ISBN 978-83-917053-8-4.

Hejft, R. (2011). Granulowanie i brykietowanie słomy. Inż. Apar. Chem. 50, 13-14.

Kulig, R., and Skonecki, S. (2011). Wpływ wilgotności na parametry procesu zagęszczania wybranych roślin energetycznych. *Acta Agrophysica* 17 (2), 335–344.

Liu, Z., Quek, A., and Balasubramanian, R. (2014). Preparation and characterization of fuel pellets from woody biomass, agro-residues and their corresponding hydrochars. *Appl. Energy* 113, 1315–1322.

Niedziółka, I., and Szpryngiel, M. (2012). Ocena cech jakościowych peletów wytworzonych z biomasy roślinnej. *Inżynieria Rolnicza* 16 (2), 267-276.

Niedziółka, I., and Szpryngiel, M. (2014). Możliwości wykorzystania biomasy na cele energetyczne. *Inżynieria Rolnicza* 149, 145-154.

Niedziółka, I., Szpryngiel, M., Kachel-Jakubowska, M., Kraszkiewicz, A., Zawiślak, K., Sobczak, P., and Nadulski, R. (2015). Assessment of the energetic and mechanical properties of pellets produced from agricultural biomass. *Renew. Energy* 76, 312-317.

Nunes, L.J.R., Matias, J.C.O., and Catalão, J.P.S. (2014). Mixed biomass pellets for thermal energy production: A review of combustion models. *Appl. Energy* 127, 135-140.

Smeets, E.M.W., Faaij, A.P.C., Lewandowski, I.M., and Turkenburg, W.C. (2007). A bottom-up assessment and review of global bio-energy potentials to 2050. *Prog. Energy Combust. Sci*. 33, 56-106.

Stelte, W., Holm, J.K., Sanadi, A.R., Barsberg, S., Ahrenfeldt, J., and Henriksen, U.B. (2011a). A study of bonding and failure mechanisms in fuel pellets from different biomass resources. *Biomass Bioenergy* 35, 910-918.

Stelte, W., Holm, J.K., Sanadi, A.R., Barsberg, S., Ahrenfeldt, J., and Henriksen, U.B. (2011b). Fuel pellets from biomass: The importance of the pelletizing pressure and its dependency on the processing conditions. *Fuel* 90, 3285-3290.

WPŁYW ŚREDNICY KANAŁÓW ZAGĘSZCZAJĄCZYCH I WILGOTNOŚCI NA PARAMERTY PROCESU PELETOWANIA BIOMASY ŚLAZOWCA PENSYLWAŃSKIEGO

Streszczenie. Celem pracy była ocena wpływu wilgotności biomasy poddawanej peletowaniau oraz średnicy otworów prasujących matrycy peleciarki na jednostkowe zużycie energii i jakość peletów. Badanym surowcem była biomasa ślazowca pensylwańskiego (*Sida hermaphrodita* R.). Proces peletowania przeprowadzono na peleciarce z matrycą płaską z zespołem rolek prasujących. Do peletowania wykorzystano matryce o trzech średnicach kanałów prasujących 6, 8, 10 mm. Próby peletowania przeprowadzano przy wilgotności materiału wynoszącej 10, 15 i 20%. Stwierdzono, że energochłonność procesu wytwarzania peletów z biomasy ślazowca pensylwańskiego zależała od wilgotności surowca, a także od średnicy kanałów prasujących w matrycy peleciarki. Jednostkowe zużycie energii elektrycznej podczas procesu peletowania wahało w granicach od 45,3 do 70,2 $Wh \cdot kg^{-1}$. Najniższą wartość odnotowano dla wilgotności 15% i średnicy kanałów prasujących 10 mm. Trwałość uzyskanych peletów wahała się w zakresie 88,9-93,5% peletów. Najwyższą trwałością charakteryzowały się pelety uzyskane przy wilgotności 15% przy czym wyższą trwałość uzyskiwano przy mniejszych średnicach otworów prasujących. Największą gęstość właściwą uzyskano dla peletów uzyskanych przy wilgotności 15% 1133,6-1094,8 $kg \cdot m^{-3}$ przy czym gęstość malała wraz ze wzrostem średnicy kanałów.

Słowa kluczowe: biomasa, pelety, energochłonność, jakość peletów