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THE INFLUENCE OF MOISTURE CONTENT OF SELECTED ENERGY CROPS ON THE BRIQUETTING PROCESS PARAMETERS

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Summary. The following paper examines the effect of pressure agglomeration process on some energy crops (miscanthus, prairie cordgrass, Virginia mallow). The materials susceptibility to briquetting was assessed, together with the relevant energy consumption levels needed for the agglomeration processes as well as the quality of the final product. The lowest electrical energy consumption was observed at the briquetting of powdered miscanthus (average 412.87 kJ·kg^{-1}), and the highest consumption was observed for Virginia mallow at about 629.23 kJ·kg^{-1}. The briquetted Virginia mallow has shown to possess the highest value of mechanical durability at about 91.45%.

Key words: energy crops, briquetting, pressure agglomeration, energy consumption, briquette quality.

INTRODUCTION

Recently, an increase in the demand for biomass of agricultural origin has been observed (Junginger et al, 2008; Kowalska, 2010; Schenkel et al, 2003; van Dam et al, 2007; van Dam et al 2009) and, consequently, there has been a quest for the most energy-efficient crops which are also well adapted to a variety of conditions (Kowalczyk-Juśko, 2007). At the same time, there has been more interest on the part of farmers and the energy sector in new plant species, among which perennial grasses with C4 photosynthesis have received the most attention. An example of such a plant is *Miscanthus x giganteus* Greef & Deuter. A major issue in its cultivation is its low resistance to low temperatures, especially in its first year of vegetation (Clinton-Brown and Lewandowski, 2000). In rather severe climatic conditions of central and eastern Europe, species more resistant to such conditions enjoy popularity, such as *Miscanthus sacchariflorus* (Maxim.) Benth. & Hook.), prairie cordgrass (*Spartina pectinata* Link.) and the perennial plant - Virginia mallow (*Sida hermaphrodita* Rusby) (Borkowska and Styk, 2006; Kościk, 2003; Lewandowski et al, 2000). The species are treated as energy crops and as fuel material both by the energy sector and in the light of the Polish law (Rozporządzenie… 2008). The plants are characterized by significant durability, estimated in the relevant sources as lasting from several to over twenty years. The yield of prairie cordgrass in eastern England was estimated at the level of 12-14 $Mg \cdot ha^{-1}$ (Potter et al, 1994) and in northern Germany at about 12.8 $Mg \cdot ha^{-1}$ (El Bassam, 1998). Its resistance to unfavourable environmental conditions is often emphasized; inevitably such conditions will lead to lower yields, nevertheless its durability is adequate. Miscanthus is the species characterized by great expansiveness and durability and thanks to its strong shrubbing properties it replaces weeds, which in turn lowers the overall cost of plantation. In optimal soil moisture conditions, the plant can yield crops at the level of 20 $Mg \cdot ha^{-1}$ (El Bassam, 1998). Virginia mallow is found in certain areas of the United States of America as a wild, uncultivated plant, and its cultivation records in Russia and Ukraine date back to 1930s (Spooner et al, 1985). Great hopes have recently been pinned on its cultivation for energy purposes in Poland (Borkowska and Styk, 2006; Kościk, 2003).

An effective use of plant biomass in professional energy generation is closely related to the need of the biomass to be agglomerated, which allows for “energy densification.” In relevant sources there is no explicit assessment of the susceptibility of the above- mentioned plant species to pellet and briquette compacting.

In the case of pressure agglomeration processes (compacting), physical and chemical properties of the processed material are of primary importance (above all, chemical composition and moisture content) (Mani et al, 2006; Niedziółka et al, 2008; Relova et al, 2009; Szymanek and Kachel-Jakubowska, 2010) as they essentially impact both the efficiency of the process and the durability properties of the final product. In terms of chemical composition of the material, the agglomeration process is determined mainly by the content levels of fats, fibres, proteins and starch (Kaliyan and Morey, 2009). Materials rich in protein and starch and low in fibre content are especially suited to such processing (Kulig and Laskowski, 2006). A fat content of 2-3% is also advisable, as the values below 1% make the pellet compacting significantly more difficult (Kulig and Laskowski, 2005). Naturally, such conditions cannot be met by energy crops whose main content is fibre. The compacting of such materials requires considerable energy expenditures.

Keeping the above-stated facts in mind, in the present paper we endeavour to examine the efficiency of briquetting process of the selected energy crops at their varying moisture content. We believe that the examination will be a valuable contribution to the popularity of the cultivation of energy crops, and that our work will provide highly needed advice for farmers, companies and staff involved in the search and production of energy efficient briquettes.

MATERIALS AND METHODS

The research material was the powdered miscanthus, prairie cordgrass, and Virginia mallow plant material. The plants under investigation came from the experimental fields of the University of Life Sciences in Lublin, Faculty of Agricultural Sciences in Zamość, Department of Agribusiness and Plant Production, and were harvested after the fifth year of vegetation (in January 2010), which means they were in their full crop capacity. The harvesting was conducted when Virginia mallow had lost its leaves, and the grasses were withered.

The material was cut into shreds of 20mm in length, and subsequently was ground in a beater mill (type ML-500), fitted with a sieve with ϕ 4mm holes. After grinding, the material's moisture was determined, using the drier method complying with the norm PN-ISO 712:2002.

The briquette compacting was conducted in the laboratory at the Department of Food Industry Machinery Operation (KEMPS) in the University of Life Sciences in Lublin. The agglomeration process was conducted with the use of a hydraulic briquette press type PBH-100. The working densification pressure was 50 MPa. Briquettes produced in this way measured 60 mm in diameter and 80 mm in length.

During the briquetting process the conditioning with water was applied. Before pressing the examined material was brought to five distinct levels of moisture content, that is 12, 14, 16, 18, and 20%, with ±0,5% accuracy. The quantity of added water was determined based on the following formula:

$$M_w = M_1 \frac{W_2 - W_1}{100 - W_2}, \tag{1}$$

where: M_w – weight of added water, g,
M_1 – weight of material sample, g;
W_1 – moisture content of material sample, %,
W_2 – required moisture content of material sample, %.

The samples were stored for 24 h in tight containers to evenly distribute moisture throughout the material.

The quality of the agglomerates was estimated on the basis of their physical properties. The density of briquette was determined on the basis of the measurement of its external dimensions and mass, after 24 hours since its production. The moisture content of the input material was determined by the drier method, according to the norm PN-ISO 712:2002. The examination of mechanical durability of briquettes was conducted according to the norm PN–EN 15210-2:2011. The measurements of agglomerate mechanical strength was conducted in test grip "brazilian " (Li et al, 2000, Ruiz et al, 2000), with the use of a Zwick Z020/TN2S tensile tester in the range of 0÷500 N tension. Individual briquette, after having their length (*l*) and diameter (*d*) measured with $\pm 10^{-1}$ mm accuracy, were placed horizontally on a stationary table and they were subsequently crushed with a measurement head moving at a steady speed of 10 mm/min. The measurement was conducted until the maximum tension (F_n) was obtained, after which the agglomerate was disintegrated. Mechanical strength of briquette [MPa] was determined using the following formula:

$$o_m = \frac{2 \cdot F_n}{\pi \cdot d \cdot l}. \tag{2}$$

In order to establish energy consumption demands for the compacting processes (electrical energy), the value of energy required by a given device was measured in the same period of time as the measurement of its efficiency. The measurements were made with the use of network parameter meter Vega 76, equipped with HT96U meter clamp.

An analysis of the dependence between the moisture content of raw materials and the parameters of the briquetting process was performed using the statistical procedures included in the STATISTICA program, at the significance level of $\alpha_i = 0.05$.

RESULTS AND DISCUSSION

The results obtained during the investigation of the briquette compacting process point to the fact that the materials under examination are suitable for this form of agglomeration. In the case of all materials under study, the technological process of briquetting was successful and the end product was a durable agglomerate. The only exception was miscanthus briquettes produced from loose material with 12% moisture content. In this case, the product leaving the compacting machine did not retain the briquette shape and crumbled. However, with other moisture levels, the process was more successful. The results of the examination of the influence of moisture content in the loose input material on the briquetting compacting process are set out in Figures 1 to 5.

The changes of the agglomerate density were presented in Figure 1. For all the studied materials the highest values of the parameter were found for moisture 16%, and the smallest for moisture 20%.

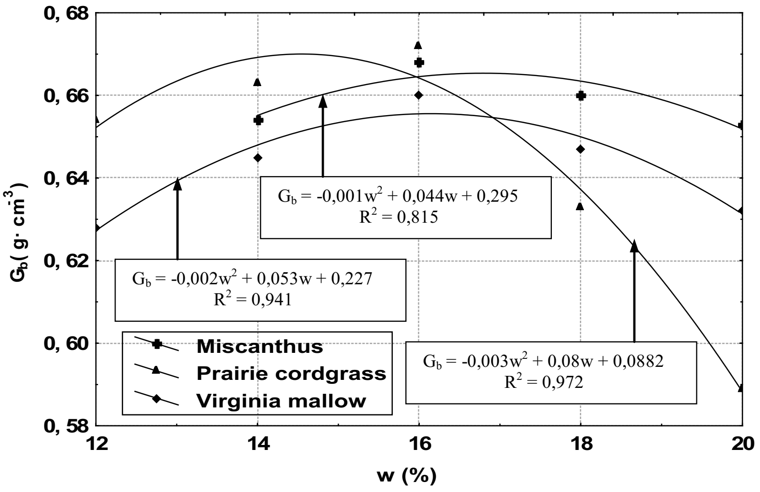

Fig. 1. Correlation between density (G_b) and moisture content (w)

Virginia mallow briquettes were characterized by the highest values of resistance parameters (Fig. 2). In the case of mechanical durability, no significant influence of moisture content was found on the value of the parameter under investigation (p>0,05), and the obtained differences were in the error margin.

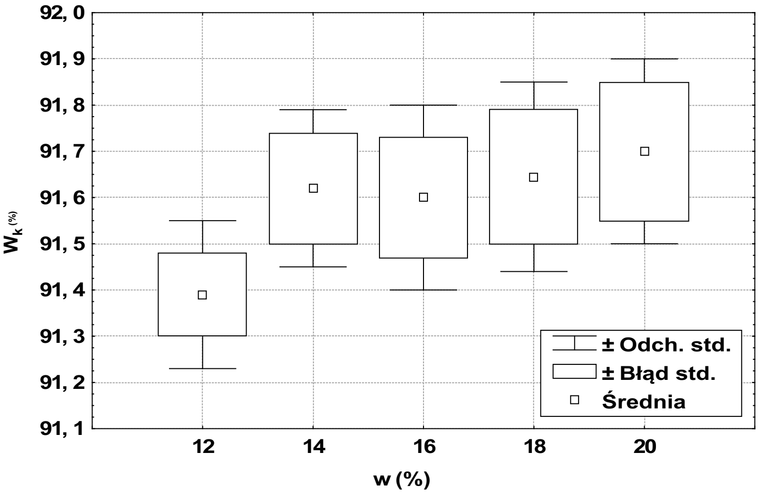

Fig. 2. Correlation between mechanical durability of Virginia mallow (W_k) and moisture content (w)

In relation to other materials (Fig. 3), the influence was more noticeable, especially in the case of miscanthus, where the increase of moisture content from 14% to 20% allowed to obtain a briquette with the mechanical durability increased by 20 proportional points.

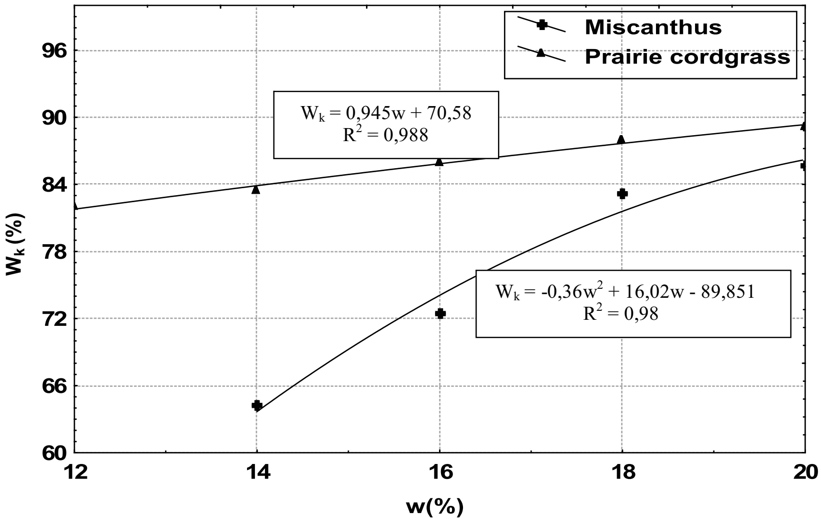

Fig. 3. Correlation between mechanical durability (W_k) and moisture content (w)

Such tendency was also observed in the examination of the mechanical strength of briquette (Fig. 4). For all the materials the highest values of mechanical strength were noted with 16% moisture content of the loose input material.

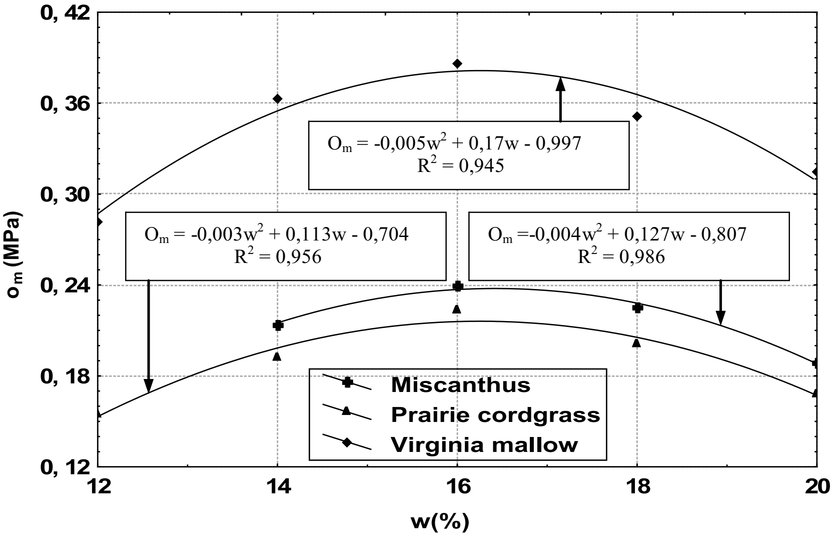

Fig. 4. Correlation between mechanical strength (O_m) and moisture content (w)

Also, in case of energy consumption, an increase in the moisture content of the loose material leads to a significant reduction in the energy expenditure required for pressing (Fig. 5).

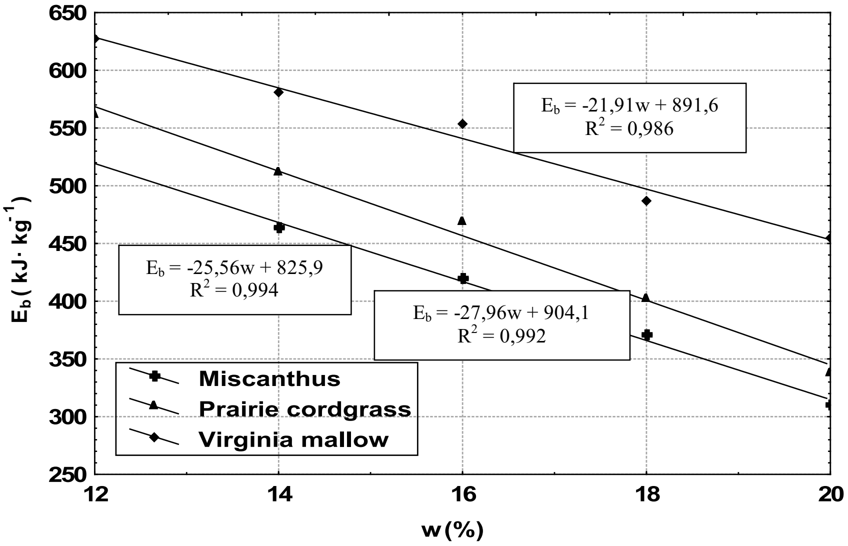

Fig. 5. Correlation between energy consumption *(E_b)* and moisture content (*w*)

The highest reduction in energy demands (40%) related to an increase in moisture content was noted for prairie cordgrass. It is also worth noting that in the case of Virginia mallow, the value of the reduction is 27%. However, it must be noted that briquettes produced with lower energy expenditure are characterized by higher moisture content, which in turn lowers their calorific value.

CONCLUSIONS

On the basis of the results of the present examination, the following conclusions can be formulated:

1. It has been found out that pressure energy consumption during pressure agglomeration is dependent both on the moisture content and the type of input material, and consequently, its physical and chemical properties.
2. The increase in moisture content of the input material in the investigated range leads to a decrease in energy required for agglomeration. The highest levels of such a reduction are seen in miscanthus and prairie cordgrass briquetting (38% and 40% respectively). In the case of Virginia mallow, the reduction is 27%.
3. The lowest energy consumption per unit needed to produce agglomerate have been noted in the case of miscanthus and are 23% lower on average than in the case of Virginia mallow briquetting.
4. It has been found that with the increase in moisture content of the input material there is an increase in mechanical durability of agglomerates. The best results in durability are obtained by Virginia mallow agglomerate.

5. A proper miscanthus briquette compacting requires the loose input material moisture content to be at the level of about 14%. In the case of prairie cordgrass and Virginia mallow, a similar quality of agglomeration is possible at lower moisture content, which was observed at 12%.

REFERENCES

1. Borkowska H., Styk B., 2006: Ślazowiec pensylwański (*Sida hermaphrodita* Rusby) uprawa i wykorzystanie. Wydawnictwo AR w Lublinie.
2. Clinton-Brown J.C., Lewandowski I., 2000: Overwintering problems of newly established *Miscanthus* plantations can be overcome by identifying genotypes with improved rhizome cold tolerance. New Phytologist, 148:287-94.
3. El Bassam N., 1998: Energy plant species. James and James Science Publishers, London.
4. Junginger M., Bolkesjø T., Bradley D., Dolzan P., Faaij A., Heinimö J., Hektor B., Leistad Ø., Ling E., Perry M., Piacente E., Rosillo-Calle F. Ryckmans Y., Schouwenberg P.P., Solberg B., Trømborg E., da Silva Walter A., de Wit M., 2008: Developments in international bioenergy trade. Biomass and Bioenergy, 32:717-729.
5. Kaliyan N., Morey V.R., 2009: Factors affecting strength and durability of densified biomass products. Biomass and Bioenergy, 33:337-359.
6. Kościk B., 2003: Rośliny energetyczne. Wydawnictwo AR w Lublinie.
7. Kowalczyk-Juśko A., 2007: Źródła biomasy na cele energetyczne. [in:] Bioenergetyka podkarpacka. Wydawnictwo PWSZ, Jarosław.
8. Kowalska A., 2010: Overview of technological methods of energy production from biomass. Teka Komisji Motoryzacji I Energetyki Rolnictwa, tom 10: 209-215.
9. Kulig R., Laskowski J., 2005: Wpływ zawartości tłuszczu na proces granulowania materiałów paszowych. Inżynieria Rolnicza, 7(67):59-68.
10. Kulig R., Laskowski J., 2006: Wpływ zawartości włókna na proces granulowania materiałów paszowych. Inżynieria Rolnicza, 5(80):365-374.
11. Lewandowski I., Clinton-Brown J.C., Scurlock J.M.O., Huisman W., 2000: Miscanthus: European experience with a novel energy crop. Biomass and Bioenergy, 19:209-227.
12. Li Y., Wu D., Zhang J., Chang L., Wu D., Fang Z., Shi Y., 2000:Measurement and statistics of single pellet mechanical strength of differently shaped catalysts. Powder Technology, 113: 176–184.
13. Mani S., Tabil L.G., Sokhansanj S., 2006: Effects of compressive force, particle size and moisture content on mechanical properties of biomass pellets from grasses. Biomass and Bioenergy, 30:648-654.
14. Niedziółka I., Szymanek M., Zuchniarz A., Zawiślak K., 2008: Characteristics of pellets produced from selected plant mixes. Teka Komisji Motoryzacji I Energetyki Rolnictwa, tom 8: 157-162.
15. Potter L., Bingham M.J., Baker M.G., Long S.P., 1994: The potential of two perennial C_4 grasses and a perennial C_4 sedge as lingo-cellulosic fuel crops in N.W. Europe. Crop establishment and yields in E. England. Annals of Botany, 45:111-19.
16. Relova I., Vignote S., León M. A., Ambrosio Y., 2009: Optimisation of the manufacturing variables of sawdust pellets from the bark of Pinus caribaea Morelet: Particle size, moisture and pressure. Biomass and Bioenergy, 33:1351-1357.
17. Rozporządzenie Ministra Rolnictwa i Rozwoju Wsi z dnia 14 marca 2008 r. w sprawie plonów reprezentatywnych roślin energetycznych w 2008 r.

18. Ruiz G., Ortiz M., Pandolfi A., 2000: Three-dimensional finite-element simulation of the dynamic Brazilian tests on concrete cylinders. Int. J. Numer. Meth. Engng., 48: 963-994.
19. Schenkel Y., Crehay R., Delaunois C., Schummer J., 2003: The agricultural sector and bioenergy production. Teka Komisji Motoryzacji I Energetyki Rolnictwa, tom 3: 228-235.
20. Spooner D.M., Cusick A.W., Hall G.E., Baskin J.M., 1985: Observations on the distribution and ecology of *Sida hermaphrodita* (L.) Rusby (*Malvaceae*). Sida, 11:215-225.
21. Szymanek M., Kachel-Jakubowska M., 2010: Estimation and analysis of chosen factors of the influence on quality and energy consumption at the processing of plant materials for energy purposes. Teka Komisji Motoryzacji I Energetyki Rolnictwa, tom 10: 454-463.
22. Van Dam J., Faaij A.P.C., Lewandowski I., Fischer G., 2007: Biomass production potentials in Central and Eastern Europe under different scenarios. Biomass and Bioenergy, 31:345-366.
23. Van Dam J., Faaij A.P.C., Lewandowski I., Van Zeebroeck B., 2009: Options of biofuel trade from Central and Eastern to Western European countries. Biomass and Bioenergy, 33:728-744.

WPŁYW WILGOTNOŚCI WYBRANYCH ROŚLIN ENERGETYCZNYCH NA PARAMETRY PROCESU BRYKIETOWANIA

Streszczenie. Przedstawiono wyniki badań przebiegu procesu aglomerowania ciśnieniowego roślin energetycznych (miskant cukrowy, spartina preriowa, ślazowiec pensylwański). Oceniono podatność badanych materiałów na proces brykietowania. Wyznaczono jednostkowe nakłady energii elektrycznej ponoszone bezpośrednio w procesie wytwarzania aglomeratów oraz określono jakość gotowego produktu. Stwierdzono, iż najniższe zapotrzebowanie energii elektrycznej występuje podczas brykietowania mączki z miskanta (średnio 412,87 $kJ \cdot kg^{-1}$), najwyższe zaś odnosi się do ślazowca i wynosi średnio 629,23 $kJ \cdot kg^{-1}$. Natomiast wytrzymałość kinetyczna aglomeratu przyjmuje najwyższą wartość w odniesieniu do brykietu otrzymanego ze ślazowca - przeciętnie 91,45%.

Słowa kluczowe: rośliny energetyczne, brykietowanie, energochłonność aglomerowania ciśnieniowego, jakość brykietów.