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Pressure Compaction of Sugar Beet Pulp – Process Parameters and Quality of the Agglomerate

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Summary: This paper presents the results of analyses investigating the effect of moisture content (10 to 22%) and the addition of the binder such as molasses (5%) and calcium lignosulphonate (2%) on the compaction parameters of sugar beet pulp. The experiments were performed with the use of the ZWICK Z020/TN2S universal strength tester and a closed compression die assembly. An increase in moisture content led to an increase in material density in the compression chamber and agglomerate density (by 28% on average). The lowest energy outcomes were noted during compaction of sugar beet pulp without content of binder (average 17,71 $J\cdot g^{-1}$), and the highest ones during compaction of sugar beet pulp with addition of the molasses– at about 23,53 $J\cdot g^{-1}$. The agglomerated sugar beet pulp with addition of the calcium lignosulphonate, at the moisture of 19%, was shown to have the highest value of mechanical strength of about 2.2 MPa.

Key words: compaction, sugar beet pulp, moisture content, binder, calcium lignosulphonate, LignoBond DD, molasses.

INTRODUCTION

The main direction of utilization of sugar-beet pulp is to use it in the feeding of farm animals [2, 5]. In this case the sugar pulp is to be preserved by acidification or drying. Subsequently, the dried pulp can be subjected to briquetting or pelleting. This form is the most convenient for transport and feeding [3, 10].

However, due to the observed decrease in livestock populations and rapidly growing market of biomass [1, 13, 18, 19], an alternative direction to use the compacted pulp may be its assignment for energy purposes. During the manufacture of pulp pellets, molasses may be added in an amount from 5 to 15%. As a result, on the one hand the energy value of the product increases, on the other hand the addition of molasses favors the formation of agglomerates with high mechanical strength. Molasses is used mainly by sugar mills producing feed pellets. However, for energy purposes, due to possible technical difficulties, molasses can be replaced by the addition of lignin binders [14, 17, 20], what results in improved viscosity of processed material. as well as reduced sensitivity of formed agglomerates to humidity changes. Hence, there is a possibility of agglomeration of material at higher moisture without the risk of decreasing mechanical durability of the final product.

During compacting of plant biomass its moisture plays a fundamental role [4, 11 , 12, 15] . Inadequate moisture can lead to losses in energy consumption and results in the formation of agglomerate with inadequate strength properties. In earlier works the results of studies on the influence of moisture and addition of binders on the efficiency of compaction of biomass of various origins were presented [6, 7]. This work is a continuation of the research in this field. Hence, the aim of the study is establishment of parameters characterizing the compaction process of sugar-beet pulp (with the addition of binders) at different moisture contents.

MATERIALS AND METHODS

The experimental material was sugar beet pulp from the sugar factory "Krasnystaw". The raw material was dried in accordance with the requirements of standard PN-EN 14774-1:2010, to achieve a moisture content in the range of 10% to 22% (every 3% +/-0.2%). The required moisture content was determined using the equation for mass change over time based on the following dependence:

$$m_1 = m_0(\frac{100 - w_0}{100 - w_1}) \text{ (g)}, \quad (1)$$

where: m_0 – initial mass of material, g; m_1 – mass of material after drying, g; w_0 – initial moisture content of material, %; w_1 – moisture content of material after drying, %.

The binding agent (calcium lignosulphonate – LignoBond DD and molasses) was added to material samples with various moisture content as the calcium lignosulphonate (amount of 2%) and the molasses (amount of 5%). Material without the binder served as the control. The research materials prepared in this way for the purposes of further analysis are marked as: sugar beet pulp without the binder – Z_l=0%; sugar beet pulp plus calcium lignosulphonate – Z_l=2%; sugar beet pulp plus molasses – Z_l=5%.

The pressure compaction methodology was described in the authors' previous study [8]. The experiment was performed with the use of the Zwick Z020/TN2S tensile test machine equipped with a pressing unit and a closed die with a cylinder (compaction chamber) diameter of 15 mm. The test parameters were as follows: mass of material sample – 2 g, cylinder (compacted material) temperature – 20ºC, piston speed – 10 mm·min^{-1}, maximum unit piston pressure – 113 MPa. Every compaction process was performed in three replications.

The results were plotted on a compaction curve showing the correlation between compaction force and piston speed. The curve was used to determine the maximum material density in the chamber ρ_c and total compaction effort L_c. The coefficient of susceptibility to compaction k_c ($k_c = L_c'\cdot(\rho_c-\rho_n)^{-1}$ was calculated, where: $L_c' = L_c\cdot m^{-1}$ – specific compaction effort, m – weight of material sample, ρ_n – initial bulk density of the raw material. The agglomerate density after 48 of storage (ρ_a) was determined.

The compaction degree of the analyzed material in the chamber S_{zm} and the compaction of the resulting briquette S_{za} were determined as the quotient of density ρ_c and ρ_a, and initial density in the compression chamber ρ_n ($S_{zm} = \rho_c\cdot \rho_n^{-1}$, $S_{za} = \rho_a\cdot \rho_n^{-1}$). The mechanical strength of a briquette δ_m was determined in the Brazilian compression test using the Zwick Z020/TN2S tensile testing machine (with piston speed of 10 mm·min^{-1}). The briquette with diameter d and length l was compressed transversely to the axis until breaking point, and maximum breaking force F_n was determined. Mechanical strength δ_m was calculated using the following formula [9, 16]:

$$\sigma_n = \frac{2F_n}{\pi\, dl} \text{ (MPa)}, \qquad (2)$$

The correlations between the moisture content, the binder content of the examined material and compaction parameters were analyzed in the STATISTICA program at a significance level of $\alpha_i = 0.01$.

RESULTS

Regression equations describing the correlations between compaction parameters, the moisture content in the experimental material and the binder content are presented in Table 2. The regression analysis revealed that the studied correlations can be described by a quadratic equation of the second degree or logarithmic equation. The analyzed correlations are presented in Figures 1-4.

DENSITY OF MATERIAL IN THE CHAMBER AND BRIQUETTE DENSITY

From the test results shown in Figure 1, it is evident that for each studied material the increase in moisture content resulted in increased density of the material in the chamber, ρ_c. Additionally, higher moisture caused a decrease in differences in the values of the parameter ρ_c , depending on the type of material being processed. However, in the case of density of agglomerate $r_{a,}$, the largest density increase was observed at moisture content ranging from 10 – 16%. In turn, a further increase of moisture practically did not influence the density of the agglomerates obtained from the pulp with the addition of binders. At 16 and 19% of moisture the values of agglomerate density were not statistically different ($p > 0.01$). Likewise, agglomerate density proved to be statistically insignificant and upon the nature of

Table 1. Regression equations describing the correlations between density ρ_c, ρ_a, compactive effort L_c', coefficient k_c, degree of compaction S_{zm}, S_{za}, and mechanical strength δ_m, moisture content w, binder content Z_l, and the values of determination coefficient R^2

Feature	Binder content	Regression equation	R^2
Density of material in the chamber, ρ_c	Z_l=0%	ρ_c = 0,431 ln w + 0,473	0,891
	Z_l=2%	ρ_c = 0,303 ln w + 0,865	0,897
	Z_l=5%	ρ_c = 0,243 ln w + 1,061	0,927
Density of agglomerate after 48 h., ρ_a	Z_l=0%	ρ_a = -0,006w^2 + 0,201w – 0,599	0,853
	Z_l=2%	ρ_a = -0,004w^2 + 0,131w – 0,037	0.951
	Z_l=5%	ρ_a = -0,004w^2 + 0,14w – 0,088	0,878
Compression work, L_c'	Z_l=0%	L_c' = 0,103w^2 – 5,035w + 69,9	0,998
	Z_l=2%	L_c' = 0,056w^2 – 3,411w + 60,46	0,993
	Z_l=5%	L_c' = 0,056w^2 – 3,244w + 60,19	0,995
Coefficient of susceptibility to compaction, k_c	Z_l=0%	k_c = 0,143w^2 – 6,128w + 72,38	0,995
	Z_l=1%	k_c =0,108w^2 – 4,922w + 63,39	0,998
	Z_l=2%	k_c = 0,085w^2 – 4,098w + 57,31	0,992
Degree of compaction of material, S_{zm}	Z_l=0%	S_{zm} = -0,015w^2+0,538w+ 1,822	0,967
	Z_l=2%	S_{zm} = -0,015w^2+0,363w+ 3,571	0,954
	Z_l=5%	S_{zm} = -0,007w^2+0,256w+ 4,618	0,958
Degree of compaction of agglomerate, S_{za}	Z_l=0%	S_{za} = -0,024w^2+0,76w-2,005	0,848
	Z_l=2%	S_{za} = -0,015w^2+0,529w-0,033	0,831
	Z_l=5%	S_{za} = -0,014w^2+0,497w+0,146	0,932
Agglomerate mechanical strength, δ_m	Z_l=0%	δ_m = -0,011w^2 +0,422w – 2,831	0,983
	Z_l=2%	δ_m = -0,014w^2 +0,495w – 2,424	0,978
	Z_l=5%	δ_m = -0,012w^2 +0,431w – 1,873	0,936

the binder used (calcium lignosulfonate 2 % or 5% molasses). However, during compaction of beet-pulp without addition of binders, in the range of 16-22% moisture a sharp decrease in the density of the final product occurred. In each experiment higher values of the analyzed parameters were characteristic for the pulp with binder. Parameter ρ_c ranged from 1.42 to 1.79 g·cm^{-3} and parameter ρ_a from 0.83 to 1.2 g·cm^{-3}.

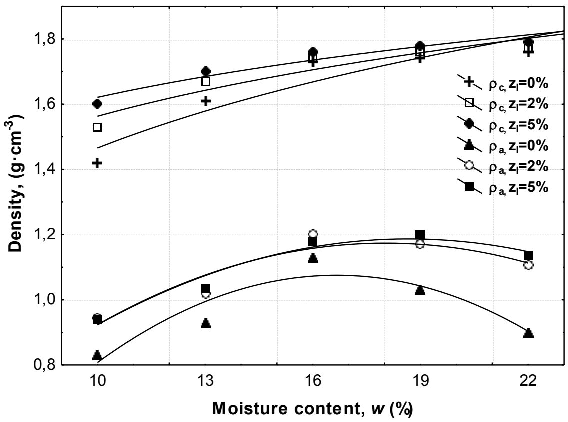

Fig. 1. Correlation between material density in the chamber (ρ_c), agglomerate density (ρ_a) and moisture content (w) at various binder content levels (z_l)

DEGREE OF AGGLOMERATE COMPACTION

Changes in the degree of compaction of the material in the chamber and the agglomerate after storage are illustrated in Figure 2. For all materials tested the highest values were found at 16% of moisture content, and the smallest at moisture of 10%. The maximum density of the material in the chamber, ρc for the application of 16% moisture content is on average 6.7 times higher than the initial density material ρ_n, regardless of amount of binder addition. It should also be noted that at higher moisture contents, differences in the degree of compaction resulting from type of raw material diminished.

The highest compactions level of the agglomerate S_{za} were achieved for pulps with addition of binders and compacted at moisture 16 and 19%. In such processing conditions the density of agglomerate was about 4.5 times of the initial pulp density.

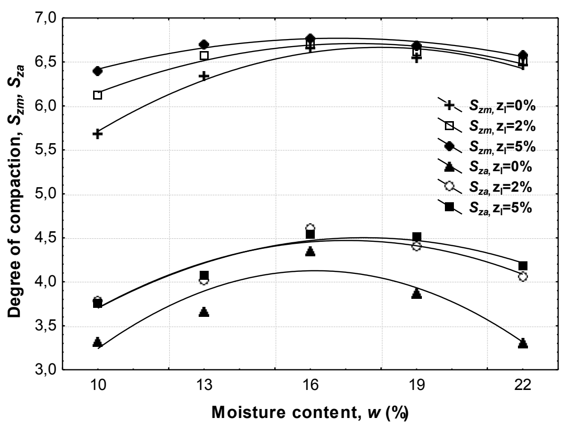

Fig. 2. Correlation between the degree of material compaction (S_{zm}), agglomerate compaction (S_{za}) and moisture content (m) at various binder content levels (z_l)

COMPACTION EFFORT AND SUSCEPTIBILITY TO COMPACTION

Data presented in figure 3 show that the increasing of moisture content of beet pulp resulted in an increase of its ability to compaction. Probably, due to the increase of water content material becomes more soft (plastic), and consequently the energy inputs required for its compaction decreases. The value of the specific work of compaction L_c' ranged from 9.23 to 33.87 J·g^{-1}. The highest values of the energy were obtained for the pulp containing 5% of molasses, and the smallest for the pulp without addition of binders. It can be assumed that addition of binders caused an increase of the coefficient of internal friction of the material particles as well as the increase of friction of the die wall. Consequently, this led to the increased inputs of specific compaction work and reduction of the material susceptibility to compaction (fig. 3). The obtained values of the coefficient k_c ranged from 6.04 to 25.64 (J·g^{-1})·((g·cm^{-3}))$^{-1}$. Wherein at the moisture content of 10% there was no statistically significant differences in the values of k_c resulting from type of compacted material ($p > 0.01$). However, further increase of moisture caused that the highest susceptibility to compaction was each time observed for the beet pulp without binders.

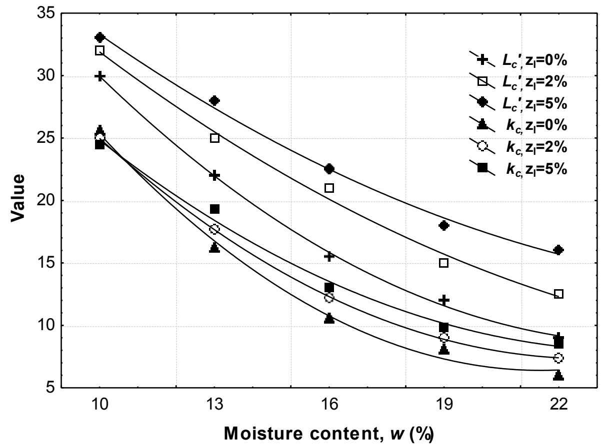

Fig. 3. Correlation between compaction effort (L_c'), coefficient of susceptibility to compaction (k_c) and moisture content (w) at various binder content levels (z_l)

MECHANICAL STRENGTH OF THE AGGLOMERATE

The results of mechanical resistance σ_n showed that, for each type of material, the agglomerate strength increased with an increase of moisture content in the range of 10 – 19% (Fig. 4). However, the increase of moisture content to 22%, for all raw materials, resulted in a decline of the parameter value. Mechanical strength ranged from 0.75 to 2.21 MPa. The highest values were observed for the agglomerates obtained during compaction of the pulp with 2% addition of calcium lignosulfonate, and at 19% moisture. Slightly lower values were noted for the agglomerate obtained from the pulp containing 5% molasses. It should also be noted that with the increase in moisture, the differences in the values of σ_n (resulting from the impact of the type of test material) remained stable. Addition of binder to the pulp allowed to achieve an average 34% increase of agglomerate strength σ_n compared to the control material.

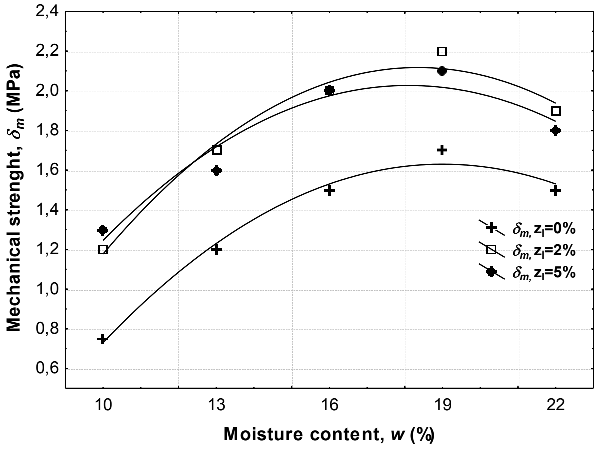

Fig. 4. Correlation between mechanical strength of agglomerate (δ_m) and moisture content (w) at various binder content levels (z_l)

CONCLUSIONS

The following conclusions can be drawn from the results of the study:

1. It was found that the density of the material in the compaction chamber – both for the pulp with and without binders – increases with increasing moisture content, about 16% on average. The increase of moisture in the range 10-16% results in an increase in density of the agglomerate (average of 28%). In the case of r_a a significant role of binders addition was also confirmed and the resulting average rise of the density achieved 13.5%.
2. The density of agglomerate obtained from the pulp with binder addition was on average 4.2 times higher than the initial material density ρ_n. For the control sample, the parameter S_{za} was on average 3.6 higher.
3. Specific work of compaction and material susceptibility to compaction decreased with increasing moisture content of the material. Mean changes were -61% and -70%, respectively.
4. It was shown that increasing moisture content from 10 to 19% favors higher mechanical strength of agglomerates (on average 83%). Addition of binders to the pulp increases the value of σ_n on average by 34%.
5. In the case of density and mechanical strength of agglomerates, application of molasses in amount of 5% gives results comparable to the use of 2% calcium lignosulfonate additive. However, with regard to the specific work of compaction, better results were obtained for the pulp with addition of calcium lignosulfonate.

REFERENCES

1. **Busko E. G., Pazniak S. S., Kostukevich S.B., Dudkina L. A., 2012:** Perspectives of renewable energy sources use In enhancement of environmental and energy security of belarus. Teka Commission of Motorization and Energetics in Agriculture, vol. 12: 11-20.
2. **Jiménez-Moreno E., Frikha M., de Coca-Sinova A., Garcia J., Mateos G.G., 2013:** Oat hulls and sugar beet pulp in diets for broilers 1. Effects on growth performance and nutrient digestibility. Animal Feed Science and Technology, vol. 182: 33-43.
3. **Hejft R., 2002:** Ciśnieniowa aglomeracja materiałów roślinnych. Politechnika Białostocka. Wyd. i Zakład Poligrafii Instytutu Technologii Eksploatacji w Radomiu.
4. **Kaliyan N., Morey V.R., 2009:** Factors affecting strength and durability of densified biomass products. Biomass and Bioenergy, 33:337-359.
5. **Kelly P., 1983:** Sugar beet pulp — A review. Animal Feed Science and Technology, vol. 8: 1-18.
6. **Kulig R., Laskowski J., 2011:** The effect of preliminary processing on compaction parameters of oilseed rape straw. Teka Commission of Motorization and Energetics in Agriculture, vol. 11:209-217.
7. **Kulig R., Skonecki S. Łysiak G., 2012:** The effect of binder addition on the parameters of compacted POPLAR wood sawdust. Teka Commission of Motorization and Energetics in Agriculture, vol. 12: 87-91.
8. **Laskowski J., Skonecki S., 2001.** Badania procesów aglomerowania surowców paszowych – aspekt metodyczny. Inżynieria Rolnicza, nr. 2(22), 187-193.
9. **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.
10. **MacMahon M.J., Payne J.D., 1991:** The Pelleting Handbook. Borregaard Lignotech, Sarpsborg Norway.
11. **Mani S., Tabil L., G., Sokhansanj S., 2003:** An overview of compaction of biomass grinds. Powder Handling and Processing, vol.15, 160-168.
12. **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(7), 648 – 654.
13. **Redlarski G., Wojdalski J., Kupczyk A., Piechocki J., 2012:** Efficiency of biomass energy used for heating purposes In a residential building In comparison with other energy sources. Teka Commission of Motorization and Energetics in Agriculture, vol. 3: 211-218.
14. **Restolho J.A., Prates A., de Pinho M.N., M.D., 2009:** Sugars and lignosulphonates recovery from eucalyptus spent sulphite liquor by membrane processes. Biomass and Bioenergy, vol. 133, 1558-1566.
15. **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.
16. **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.
17. **Sahoo S., Seydibeyo_M.O., Mohanty A.K., Misra M., 2011:** Characterization of industrial lignins for their uti-

lization in future value added applications. Biomass and Bioenergy, vol. 135, 4230-4237.

18. **Schenkel Y., Crehay R., Delaunois C., Schummer J., 2003:** The agricultural sector and bioenergy production. Teka Commission of Motorization and Energetics in Agriculture, vol. 3: 228-235.
19. **Sobczyk W., Kowalska A., 2012:** The techniques of producing energy from biomass. Teka Commission of Motorization and Energetics in Agriculture, vol. 3: 257-261.
20. **Van Dam J. E. G., Van den Oever M. J. A., Teunissen W., Keijsers E. R. P., Peralta A. G., 2004:** Process for production of high density/high performance binderless boards from whole coconut husk. Part 1: lignin as intrinsic thermosetting binder resin. Industrial Crops and Products, vol. 19, 207–216.

CIŚNIENIOWE ZAGĘSZCZANIE WYSŁODKÓW BURACZANYCH – PARAMETRY PROCESU I JAKOŚĆ AGLOMERATU

Streszczenie: Przedstawiono wyniki badań nad określeniem wpływu wilgotności (od 10 do 22%) i dodatku lepiszcza w postaci melasy (5%) i lignosulfonianu wapnia (2%) na parametry zagęszczania wysłodków buraczanych. Zagęszczanie przeprowadzano przy wykorzystaniu maszyny wytrzymałościowej Zwick typ Z020/TN2S i zespołu prasującego z matrycą zamkniętą. Zaobserwowano, że wraz ze wzrostem wilgotności rośnie gęstość materiału w komorze i gęstość aglomeratu (średnio o 28%). Wykazano, iż najniższa energochłonność zagęszczania odnosiła się do zagęszczania wysłodków bez dodatku lepiszcza (wartość średnia – 17,71 $J \cdot g^{-1}$). Najwyższa zaś dotyczyła wysłodków z 5% dodatkiem melasy (23,53 $J \cdot g^{-1}$). Stwierdzono, że najwyższą odpornością mechaniczna (2,2 MPa) charakteryzował się aglomerat wytworzony z wysłodków z dodatkiem 2% lignosulfonianu wapnia, zagęszczanych przy wilgotności 19%.

Słowa kluczowe: wysłodki buraczane, zagęszczanie, wilgotność, lepiszcza, lignosulfonian wapnia, LignoBond DD, melasa.