THE EFFECT OF PARTICLES SIZES ON THE DENSITY AND POROSITY OF THE MATERIAL

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Abstract
The aim of the study was to determine the specific and bulk density and the porosity of the shredded material from Miscanthus according to its particle sizes distribution. The moisture content of the plants was 20%. For the purpose of evaluation of cut particle size distributions a sieve separator was used with a horizontal sieve oscillation and research methodology in accordance with the requirements of ANSI/ASAE S424.1, compatible with the European standard PN-EN 15149-1. It was found that the bulk and specific density and porosity of the shredded material from Miscanthus were depended on its particles size. In the tested range, the Miscanthus particles has a minimal porosity (approx. 90%) and a maximum bulk density (75 kg·m^{-3}) at sizes 6 − 8mm. The highest specific density 910 kg·m^{-3} was obtained for the finest tested particles (approx. 0,8 mm).

Key words: biomass, cut, compression, density, porosity.

INTRODUCTION

Physical properties such as bulk, specific density and porosity are important to understand the quality of feedstock delivered to the biorefinery or for co-firing plants. LAM ET AL. (2008) indicated that bulk density is a major physical property in designing the logistic systems for biomass handling. They concluded that biomass material is dependent on size, shape, moisture content, individual particle density and surface characteristics. Physical properties such as bulk density also have an impact on storage requirements, sizing of the material handling systems and on the final conversion process (MCKENDRY, 2002). The study of RYU ET AL. (2006) on the effect of bulk density on combustion characteristics of biomass indicated that ignition front speed is inversely proportional to bulk density.

LANG ET AL. (1993), and SOKHANSANJ AND LANG (1996) indicated that bulk density of biomass is dependent on material composition, particle shape and size, specific density, and moisture content. The bulk density depends on the packing of the material, namely on the granulometric composition of the particles (KOWALSKA AND LENART, 2003). ANDREJKO (2005) noted that the particle size and its variation may effect on the increasing or decreasing the specific density, depending on the type of material.

One of the main purposes of the compaction process studies is the influence of the material characteristics on the quality of the agglomerated product. Because of that the knowledge of the material properties is necessary to ensure the minimum energy consumption during the agglomeration process (SOKHANSANJ ET AL., 2005). Compaction of the shredded materials of high bulk density increases efficiency and allows to obtain a higher density of the agglomerates what is involved with less displaced air and consequently requires less pressure compaction. Similar as in the case of agglomerates density, the increase in bulk density reduces the energy demand (OBIDZIŃSKI, 2005). The raw materials with a low bulk density cause their irregular feeding and disruptions in the pellets production. This leads to an increase in demand to supply the raw material to feeding the system of matrix and compacting rolls to maintain the required level of the production (LARSON ET AL., 2008).

The aim of the study was to determine the specific and bulk density and the porosity of the shredded material from Miscanthus according to its particle size distribution.

MATERIALS AND METHODS

Miscanthus plants were harvested by a trailed forage harvester Z374 from plots at the Experimental Station in Skierniewice, which belongs to the Warsaw University of Life Sciences. The chopping unit of the forage harvester was equipped with 5 knives. The cutting disc rotational speed amounted to 1000 rpm. The set working parameters allowed for a cutting frequency at 83 Hz and a theoretical length of chopped plant material particles of 8.8 mm (LISOWSKI AND ŚWIĘTOCHOWSKI, 2014).

For the purpose of evaluation of cut particle size distributions a sieve separator was used with a horizontal sieve oscillation and research methodology in accordance with the requirements of ANSI/ASAE S424.1 (ASABE STANDARDS, 2011A), compatible with the European standard PN-EN 15149-1 (PN-EN 15149-1, 2011).

Moisture content (wet basis) was determined in accordance with the ASAE S358.2 standard (ASABE STANDARDS, 2011B). During harvesting and separation the moisture content of the cut Miscanthus material amounted to 20.9 % and 20 %.

Methodology of the investigations included determination of bulk and specific density and porosity of the cut material. The bulk density of the cut plant material was determined by twice repeated weighing of empty container (of 10 dm^3 volume) and container with a sample, on electronic scales with accuracy of 0.1 g.

$$\rho_L = \frac{m - m_n}{V} \tag{1}$$

where: ρ_L − bulk density of shredded plant material, $kg \cdot m^{-3}$; m − mass of container with material, kg; m_n − mass of container, kg; V − volume of container, m^3.

Particle density of the milled material was measured using a gas stereopycnometer (Quantachrome Instruments, Boynton Beach, USA) by measuring the pressure difference when a known quantity of helium under pressure is allowed to flow from a previously known reference volume (V_A) into a sample cell (Vc) containing the cut material. The real volume of the sample (Vp) was calculated from Eq. (2). The particle density of the sample was its mass divided by Vp and was expressed in $kg \cdot m^{-3}$. Each measurement was repeated three times on the same sample.

$$V_P = V_C + \frac{V_A}{1 - \left(\frac{p_1}{p_2}\right)} \tag{2}$$

where: V_P − volume of investigated material, m^3; V_C − volume of measuring chamber, m^3; V_A − volume of datum chamber, m^3; p_1 − pressure in measuring chamber, MPa; p_2 − pressure in the datum chamber, MPa.

The plant material specific density was determined from the dependence:

$$\rho = \frac{m}{V_P} \tag{3}$$

Porosity of the investigated material was calculated on the basis of bulk and specific density:

$$\varepsilon_L = 100\left(1 - \frac{\rho_L}{\rho}\right) \tag{4}$$

where: ε_L − porosity of the material, %; ρ_L − bulk density, $kg \cdot m^{-3}$; ρ – specific density, $kg \cdot m^{-3}$.

Data analysis was carried out using Statistica v.12 computer program, with application of variance analysis procedure and Duncan test.

RESULTS AND DISCUSSION

Particle size distribution of the Miscanthus cut material was characterized by right-sided skewness (skewness coefficient was 1.6) and was relatively leptokurtic (steep), with a kurtosis coefficient of 0.9 (Fig. 1). Particle size geometric mean values of the cut Miscanthus material was 10.47 mm, whereas the dimensionless standard deviation of these averages amounted to 1.86.

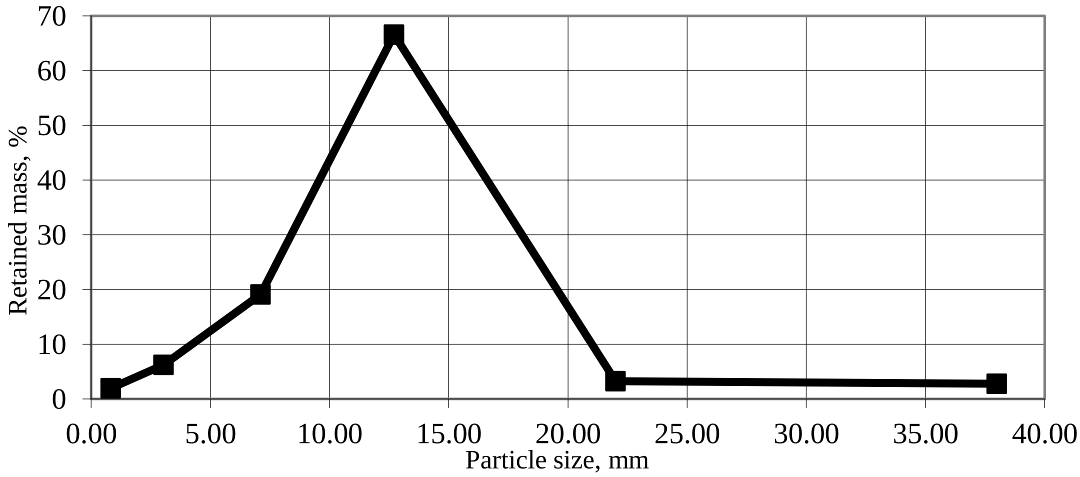

Fig. 1. – Particle size distribution of cut Miscanthus material

On the basis of the results of the analysis of variance (Tab. 1) it could be state, that the material fragmentation had statistically significant influence on values differentiation of its bulk density ($F_{v1=4,v2=45}$=712.1, at p<0.0001), specific density ($F_{v1=4,v2=45}$=488.7, at p<0.0001) and porosity ($F_{v1=4,v2=45}$=485.0, at p<0.0001).

Tab. 1. – The results of the analysis of variance of the particle size affecting on bulk density - ρ_L, specific density - ρ and porosity of the material - ε_L

Parameter	Source	Sum of squares	Degree of freedom	Mean square	Test F	p-value
Bulk density, ρ_L	Particle size	10153.1	4	2538.3	712.1	<0.0001
	Error	160.4	45	3.6		
Specific density, ρ	Particle size	495233	4	123808	488.7	<0.0001
	Error	11400	45	253		
Porosity of the material, ε_L	Particle size	169.7	4	42.4	485.0	<0.0001
	Error	3.9	45	0.1		

From the detailed analysis of the mean values by Duncan test (Tab. 2) results that for the bulk and specific density of the Miscanthus material were created five separate homogenous groups. The highest bulk density (76.78 kg·m^{-3}) had the material of the average value of particles length of 7.1 mm, means sizes close to these given by SAMSON ET L. (2005) as the best to the briquettes production. However, the lowest bulk density had the material of the highest (22 mm) and the lowest (0.82 mm) tested fragmentation amounted to 32.52 and 48.53 kg·m^{-3}, respectively. In the case of specific density of the cut material of Miscanthus, with increasing fragmentation of the material was followed its growth from 600 kg·m^{-3} for particles of the average length of 22 mm to over 900 kg·m^{-3} for particles of 0.82 mm. The specific density of the Miscanthus material in the form of mixture of all fractions, measured by LISOWSKI ET AL. (2011) was approximately 720 kg·m^{-3}.

Tab. 2. – The results of the analysis of Duncan test for the mean values of the bulk and specific density and the porosity

Bulk density							Specific density							Porosity of the material		
Geometric mean, mm	ρ_L, kg·m^{-3}	Homogenous group					Geometric mean, mm	ρ, kg·m^{-3}	Homogenous group					Geometric mean, mm	ε_L, %	Homogenous group		
22	32.52	x					22	600.2	x					7.1	89.58	x		
0.82	48.53		x				12.7	714.4		x				12.7	92.72		x	
12.7	51.96			x			7.1	736.8			x			3.04	92.74		x	
3.04	56.14				x		3.04	774.2				x		22	94.58			x
7.1	76.78					x	0.82	908.4					x	0.82	94.66			x

On the basis of the previous inference, the nonlinear regression models for bulk and specific density and porosity were developed (Tab. 3). All of the models are characterized by the high rate (R from 0.948 to 0.977). The graphic interpretation of these models were presented on the Fig. 2, 3 and 4.

Tab. 3. – Analysis of regression for bulk density, specific density and porosity of the material

Parameter	ρ_L				ρ				ε_L			
	estimate	error	t-value	p-value	estimate	error	t-value	p-value	estimate	error	t-value	p-value
b_0	35.98	2.00	17.93	<0.001	946.4	9.32	101.5	<0.001	96.62	0.247	390.9	<0.001
$b_1(x)$	12.43	1.02	12.15	<0.001	-64.6	4.75	-13.60	<0.001	-2.12	0.126	-16.84	<0.001
$b_2(x^2)$	-1.27	0.117	-10.80	<0.001	5.70	0.547	10.42	<0.001	0.208	0.014	14.40	<0.001
$b_3(x^3)$	0.031	0.003	9.16	<0.001	-0.158	0.016	-9.81	<0.001	-0.005	<0.001	-12.39	<0.001
Equation	$\rho_L = b_0 + b_1 x + b_2 x^2 + b_3 x^3$				$\rho = b_0 + b_1 x + b_2 x^2 + b_3 x^3$				$\varepsilon_L = b_0 + b_1 x + b_2 x^2 + b_3 x^3$			
R	0.948				0.977				0,953			

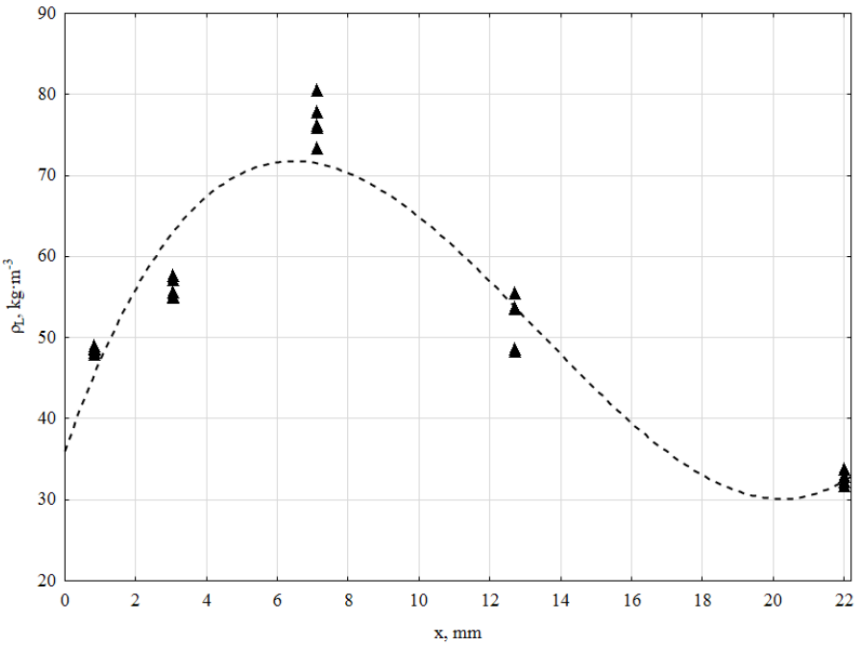

Fig. 2. – Effect of geometric mean of particle length on bulk density of shredded biomass

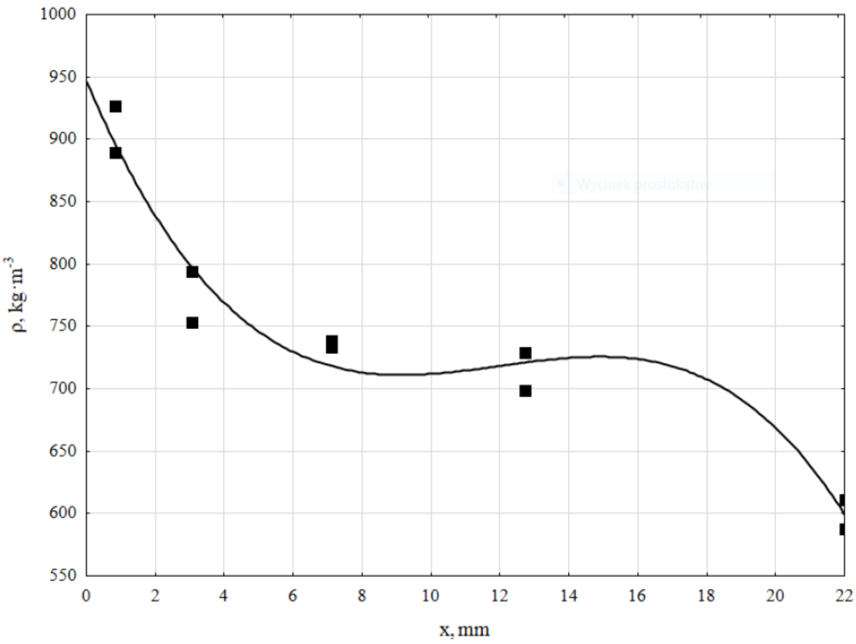

Fig. 3. – Effect of geometric mean of particle length on specific density of shredded biomass

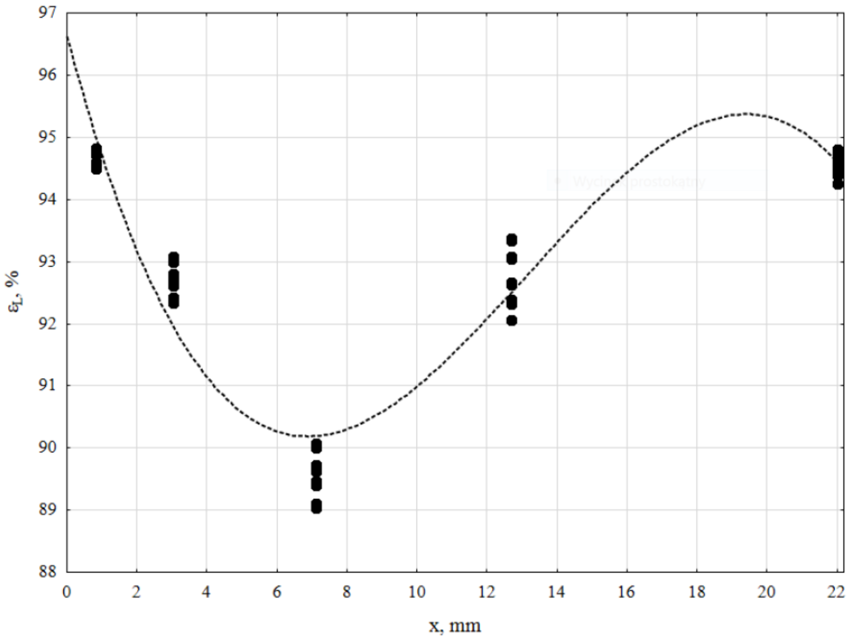

Fig. 4. – Effect of geometric mean of particle length on porosity of material of shredded biomass

The waveforms of dependence of bulk and specific density and porosity from the degree of fragmentation were differentiate. In the range of optimal material fragmentation needed to briquettes production (6-8 mm rating by SAMSON ET AL., 2005), the shredded Miscanthus material had the highest bulk density and the lowest porosity.

Recommended by MANI ET ALL (2003) mixture dedicated to production of pellets with particles dimensions not higher than 3.2 mm has the highest specific density of the material (780 – 900 kg·m^{-3}). The specific density values of this material were higher than the material for briquettes (700 – 950 kg·m^{-3}), which results that the formed fuel made of these plants in the form of pellets or briquettes should meets the requirements of density for this type of products. Presented results indicate on one of the reasons of higher density of pellets than of briquettes.

MIAO ET AL. (2011) reported that bulk density values of ground Miscanthus, switchgrass, and willow decreased with increase in the aperture size of the milling screens. The increase in tapped bulk density values of the biomass for all the sizes in the present study corroborated the observations of LAM ET AL. (2008).

CONCLUSIONS

1. The bulk and specific density and the porosity of the shredded material from Miscanthus were depended on its particle sizes.
2. In the tested range, the Miscanthus particles has a minimal porosity (approx. 90%) and a maximum bulk density (75 kg·m^{-3}) at sizes 6 – 8 mm.

The highest specific density 910 kg·m^{-3} was obtained for the finest tested particles (approx. 0,8 mm).

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