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Effect of mineral matter content on specific density of forest biomass

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Abstract: *Effect of mineral matter content on specific density of forest biomass.* Utilization of waste forest biomass as a source of energy is unimportant at present. It results from both the spatial scattering of this material and from its variable chemical and physical properties. The undertaken analysis concerns the investigations on a dependence between the fraction size of shredded forest wastes and their specific density. The investigations showed that fine fractions are characterized by higher specific density. In order to explain this phenomenon, the mineral matter content in particular fractions was investigated. The results of experiments proved that an increase in specific density of biomass obtained from forest wastes was inversely proportional to fraction size and directly proportional to mineral matter content.

Key words: forest biomass, specific density, ash content

INTRODUCTION

On various stages of forest production process there is produced the biomass of small commercial value. It takes place during execution of cultivation operations, particularly in the tree stands of younger age classes (early and late cleanings) and during timber harvesting, both the cutting and pre-cutting operations. Apart from various timber assortments, during these operations a substantial amount (volume) of so-called wastes is produced. These are young trees removed during cultivation operations, branches cut off during debranching or damaged fragments of bolts. This biomass cannot remain on forest sites in non-shredded form, since it makes difficult carrying out further silviculture operations and can enhance development of pests or diseases and also increases the fire hazard on forest sites. At the same time, one can find a constantly rising demand of country's economy (as well as of individual consumers) for biomass designed for energetic purposes [Barwicki and Gach 2010]. So far the sawmill or furniture wastes have been commonly used for this purpose, as well as raw materials originated from special growing of energetic plants. Utilization of waste forest biomass for this purpose is unimportant so far. From one hand, it results from its substantial scattering (logistic problems), and very diversified composition resulting in diverse physical and chemical properties. Recently, one can find the growing interest in waste forest biomass as an energetic raw material. Gendek and Zychowicz [2014] investigated calorific value of forest wastes. In the case of spruce biomass it amounted to about 14.64 $MJ \cdot kg^{-1}$, while for pine biomass to about 19.53 $MJ \cdot kg^{-1}$. Similar investigations were carried out by Aniszewska and Gendek [2014]. They analyzed calorific value of the cones of selected forest tree species and compared the results with calorific value of wood

obtained from these trees. The investigations showed no significant differences between particular measurements.

Biomass of forest origin is the waste substance; its basic component is wood. Depending on type of this waste it contains also various amount other components as sand, litter of conifer needless or bark. Moisture content of the waste forest biomass is important from the viewpoint of its management [Głowacki and Gendek 2011]. Irregularity of biomass state of aggregation and moisture content are affected by intramolecular and external pores of wood that store water and air [Malczewski 1990]. Depending on fraction size, the shredded wood mass can be included among the loose materials, thus, it is difficult to describe the waste biomass of forest origin from statistical point of view. This paper presents results of investigations on composition and structure of waste forest biomass. The investigations aimed at determination of possible biomass utilization as an energetic raw material; as the main direction of this utilization there was assumed production of fuel in the form of briquettes. Therefore, the investigations carried out on shredded forest wastes were focused on bulk and specific density measurements.

In the biomass density measurements the characteristic of apparent volume is not sufficient. Ratio between apparent volume and specific volume of wood is significant and amounts to 0.3–0.5; it results from irregularity of arrangement of the loose plant material stalks. In measurements on raw material specific density the immersion method was used. Measurements on specific volume and mass of biomass enabled to determine the specific density. Preliminary investigations on harvested and shredded forest wastes pointed out at the need of dividing of produced chips into fractions of various size and carrying out investigations separately for each of them. Parallel to density measurements there were carried out investigations on the mineral matter content in the investigated material.

MATERIAL AND METHODS

Prior to measurements on raw material specific density, the entire mass of chips was divided into fractions of various size. The four fractions of following size were isolated:

- below 1 mm,
- from 1 to 4 mm,
- from 4 to 8 mm,
- from 4 to 16 mm.

The measurement on specific density was executed in the same way in three repetitions for every fraction. The moisture content of all investigated samples amounted to 15 %.

The biomass sample (pine) of specific mass about 20 g was poured into a beaker containing 400 ml of water. Each time the mixture was pressed down with a strainer to shift the poured chips under water-level surface. Then, the reading of measuring vessel was corrected by the volume of strainer with handle.

Basing on read off results there was calculated the specific density (ρ_w) with the following dependence [Molteberg 2004]:

$$\rho_w = \frac{m}{V_r}$$

where:
ρ_w – specific density [g/cm^3];
m – mass [g];
V_r – real volume [cm^3].

An example of research methodic described above is presented in Figure 1.

FIGURE 1. Determination of biomass real volume

In reading of liquid volume with the immersed biomass a computer program for digital analysis of image was used. To this end each time a photo was made with digital camera placed at the level of water-level. Then, the obtained image was subjected to digital analysis. This method enabled to increase accuracy of carried out measurements.

The carried out investigations included also the analysis of mineral particle content in particular fractions of chips.

One of the method for determination of mineral matter content is incineration of biomass sample. The ash created at high temperature contains only the mineral parts, therefore, its mass can be directly used in determination of their content in the investigated material.

Ash is a substance of fine consistency created during thermal processing of biomass for heating purposes. General content of ash affects significantly the specific density and – which is particularly important – the energetic value of solid carriers [Grzybek et al. 2007]. The ash content determines the mineral saturation of biomass. As reported by Babiarz and Bednarczuk [2013], the plant material contains such mineral substances as: silicon, iron, aluminum, calcium, magnesium, sodium, potassium.

The ash content was measured with a method of slow incineration [Trawczyński 2008]. A sample of 5 g (weighed with accuracy of 0.0001 g) was placed in a melting pot of known mass and incinerated at temperature 805°C during two hours. The created content was placed in exsiccator to cool it. Then, the mass of pot with ash was determined. The percent share of ash in the sample (Z_p) was calculated with equation:

$$Z_p = \frac{m_3 - m_1}{m_2 - m_1} 100\%$$

where:
Z_p – percent share of ash [%];
m_1 – mass of empty pot [g];
m_2 – mass of pot filled with wood biomass sample [g];
m_3 – mass of pot with ash [g].

RESULTS AND DISCUSSION

The investigations were carried out in three repetitions for each isolated fraction. Table 1 presents results of mass and specific volume measurements of particular samples and their specific

TABLE 1. Results of mass and volume measurements of shredded biomass

Fraction [mm]	Mass of sample [g]	Volume of sample [cm^3]	Specific density [g/cm^3]	Mean specific density [g/cm^3]
0–1	42,35	45.22	0.94	0.91
	34.61	39.72	0.87	
	28.9	31.55	0.92	
1–4	38.16	43.20	0.88	0.79
	39.75	49.28	0.81	
	30.37	44.62	0.68	
4–8	27.59	36.87	0.75	0.68
	22.46	37.69	0.60	
	21.7	30.67	0.71	
8–16	36.24	57.41	0.63	0.65
	34.77	52.79	0.66	
	32.95	49.54	0.67	

Source: Own investigations.

density. As it is evident from given data, the biomass specific density decreases with an increase in fraction size of particles. The fraction 0–1 mm is lower than water density only by 0.09 g/cm^3; in opinion of the authors, it can be connected with high mineral saturation of fraction. Decreasing of specific density with an increase in fraction size was found in all analyzed cases. Considering mean values one can find, that difference between the least and the highest fraction amounts to about 0.3 g/cm^3 (30 % in relation to specific density of finest fraction).

Mean specific density of particular fractions illustrates Figure 2.

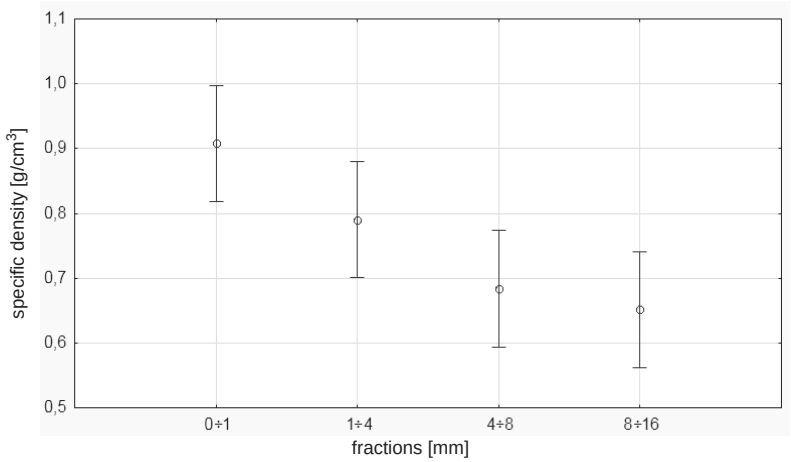

FIGURE 2. Mean specific density of investigated material

Preliminary analysis of investigated samples showed, that this phenomenon could result from various content of mineral parts in particular fractions of shredded biomass, since the fine fractions (especially of dimensions below 1 mm) contained large amount of parts that were not biomass (mineral parts). Also the chemical structure of particular elements can be different – they come from various layers of shoot cross section. Therefore, a hypothesis was made that the content of mineral parts in particular fractions of shredded biomass could affect their specific density. Specification of mineral particles in the form of ash is presented in Table 2.

In order to prove the made hypothesis, the obtained values of factors were subjected to statistical tests using analysis of variance method (ANOVA). In determination of correlation a program package for statistical analyses was used (Statistica). Analysis of variance for differences between the factors and quality variable enabled to carry out a post hoc test, based on multiple comparisons.

Among available post hoc tests for classification of particular factors, the Duncan test was selected as the most suitable tool. It consisted in comparison between a control variable and particular factors, with assignment of variables to particular homogeneous groups

TABLE 2. Specification of mineral particles in the form of ash

Fraction [mm]	Mass of empty pot [g]	Mass of pot filled with wood biomass [g]	Mass of pot with ash [g]	Ash content [%]	Mean ash content [%]
0–1	12,15	13.22	12.18	2.43	2.26
	11.97	12.99	12.00	2.37	
	12.50	13.53	12.53	1.98	
1–4	12.43	13.55	12.45	0.89	0.89
	14.16	15.17	14.17	0.89	
	14.80	15.83	14.81	0.89	
4–8	13.73	14.76	13.74	0.87	0.87
	16.64	17.74	16.65	0.90	
	14.49	15.51	14.50	0.84	
8–16	16.23	17.48	16.23	0.40	0.37
	15.44	16.46	15.44	0.37	
	16.64	17.66	16.64	0.35	

Source: Own investigations.

Assuming that the level of mineral saturation determines the percent ash share in analyzed situation [Kowalczyk-Juśko 2009], according to methodic described above there was investigated the ash content in particular fractions of biomass. The mean ash content is presented in Figure 3.

[Parlińska and Parliński 2011]. The isolated homogeneous groups of specific density for particular fraction intervals are presented in Table 3, while specification of homogeneous groups of ash content is presented in Table 4.

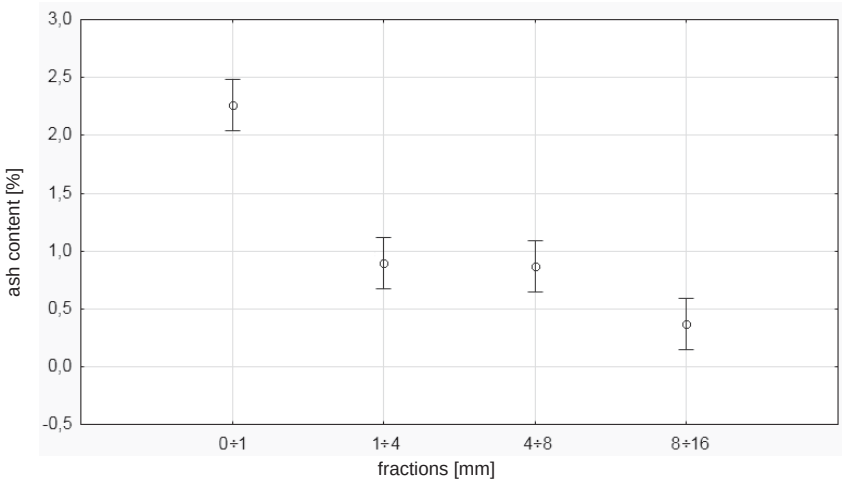

FIGURE 3. Ash content in particular fractions

It is evident from the above statistical analysis that mean specific densities and ash content are included in similar homogeneous groups of the both factors.

The presented investigations aimed at determination of the effect of mineral particle content (ash) on specific density of the biomass obtained of forest wastes. As Figure 4 illustrates, specific density rises with an increase in mineral particle content. At the content of about 0.4%, the specific density amounts to about 0.65 g/cm^3. An increase in mineral particle share to about 2.5% results in an increase in specific density to about 0.90 g/cm^3. It is also evident from the carried out investigations, that higher specific density is characteristic for the

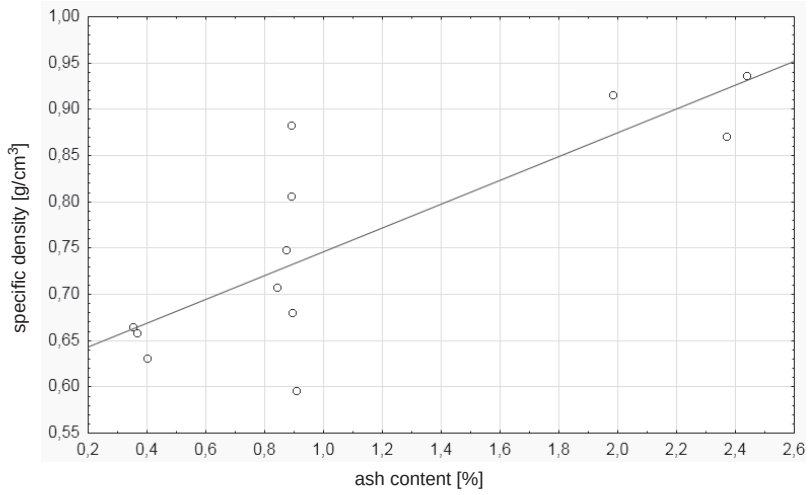

FIGURE 4. Dependence between specific density of investigated material and ash content

TABLE 3. Homogeneous groups of specific density for particular fraction intervals

Fraction [mm]	Mean [g/cm^3]	1	2	3
0–1	0.91	X		
1–4	0.79	X	X	
4–8	0.68		X	X
8–16	0.65			X

Source: Own investigations.

TABLE 4. Homogeneous groups of ash content for particular fraction intervals

Fraction [mm]	Mean [%]	1	2	3
0–1	2.26	X		
1–4	0.89		X	
4–8	0.87		X	
8–16	0.37			X

Source: Own investigations.

finer fractions; it means that they contain more mineral substances than the coarse fractions.

CONCLUSIONS

The carried out investigations on specific density and mineral matter content (ash) in the biomass of forest origin enabled to formulate the following conclusions:

1. Fine fractions of biomass obtained from forest wastes are characterized by a higher specific density than the fractions of bigger dimensions.
2. Mineral particle content decreases with an increase in fraction size of investigated forest biomass wastes.
3. The value of biomass specific density depends on the mineral particle content. An increase in mineral particle share results in an increase in specific density, therefore the made research hypothesis has been proved.
4. Analysis of homogeneous groups proved that the methodic used for determination of specific density value of biomass should include assessment of mineral particle content in percent.

Streszczenie: *Wpływ zawartości substancji mineralnych na gęstość właściwą biomasy pochodzenia leśnego.* Wykorzystanie odpadowej biomasy leśnej jako źródła energii jest obecnie niewielkie. Wynika to zarówno z rozproszenia przestrzennego tego materiału, jak i jego zmiennych właściwości chemicznych i fizycznych. Podjęta analiza dotyczy badań zależności pomiędzy wielkością frakcji rozdrobnionych odpadów leśnych a ich gęstością właściwą. Badania wskazały, że frakcje drobne charakteryzują się większą gęstością właściwą. W celu wyjaśnienia tego zjawiska przeprowadzono badania zawartości substancji mineralnych w poszczególnych frakcjach. Wyniki eksperymentów potwierdziły, że wzrost gęstości właściwej biomasy uzyskanej z odpadów leśnych jest odwrotnie proporcjonalny do wielkości frakcji i wprost proporcjonalny do zawartości substancji mineralnych.

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