DETERMINING MEAN VALUE OF MISSING PARTICLE SIZE FOR WEIGHT CALCULATION

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Abstract. Dehydrated digestate from an agricultural biogas plant and crushed *Miscanthus Giganteus* L. (MG) particles are divided by screen analysis to particle size groups of both biomass materials. The particle shape of both materials with maximum size of 0.5 mm is geometrically similar to cube. Particles of larger sizes (higher than 0.5 mm) have at the same width one predominant dimension – length. The width corresponds to the size of the mesh of the sieve used. The weight of the particles is thus largely dependent on the third dimension – thickness. Its value however is not available at image analysis because three-dimensional (3D) objects are observed (in this case, particles of both materials). In this process they are transferred by the scanner camera to planar (2D) objects. If we want to know the weight of the observed material texture part, it is important to replace the missing value of particle thickness by a relevant value, which is discovered by the other way. The presented article represents one attempt to determine the missing value of particle thickness. The value thus obtained is the mean value of thickness for the size category in particulate materials. As well, dependence of particle thickness on their length, width and material type, possibly even on the grinding degree of MG or its moisture, was observed. This study suggests a method to state the size distribution of particles to the whole volume of the material, thus this method seems to be appropriate and should be tested larger.

Keywords: image analysis, dehydrated digestate, particle thickness, screen analysis.

Introduction

The need for better and more comprehensive knowledge of the characteristics of biomass materials is generally known [1]. And that is as well the purpose of this study. With the development of biomass use this need has highlighted, because the result of biomass successful use depends on its respective properties. That is why new methods and ways are investigated; we have to find how to gain this information [2]. For rough characterization of texture properties, like in this case, it is enough to know just some properties of biomass material or its final product. That is why in this paper the knowledge is reduced to mechanical properties of the material, dimensions and shape of its particles, which mainly refers the texture of biomass material. Until recent time (at other laboratories) not so successful experiments have been carried out attempting to specify the relationship between the texture of the processed material and the properties of the final product [1]. Maybe because the used methods were very labor hard and approximate. As the basic method for texture determination the image analysis has been chosen. This method is universal and allows easier comparison and quantification of similar properties but different materials and easier to determine relations between the texture elements [3; 4].

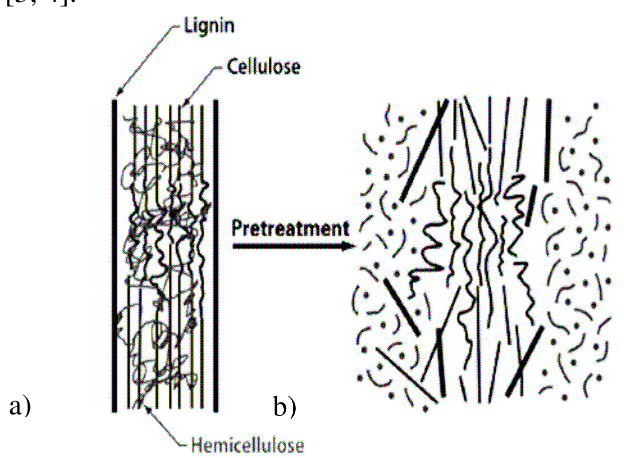

Fig. 1. **Lignocellulosic materials:** a) compact plant stem and b) treated stem [5]

The aim of the image analysis is among others quantification and expression of comprehensive information on materials by using simple quantitative data, e.g., in graphic form or numeric form (as size distribution or average, or mean value of monitored variables) [6; 7]. Projection is the basic technique how to obtain the shape and size data about each particle by the microscopic image analysis [4]. In case of anisometric particles, e.g., fibrous, needle-form etc. it is important to appreciate that particle orientation during the measurement is not random and samples are prepared by special methods [7]. For example, at particles of cubic or cuboidal shape the height is not visible in theimage [3]. The materials used in this paper are dehydrated digestate (DG) and *Miscanthus Giganteus* L. (MG) which particles contain lignocellulose substances (Fig. 1). The particles have approximately geometric shapes. Small particles of both materials with maximal size of 0.5 mm are similar to cube. Particles of larger sizes (bigger than 0.5 mm) have the same width but another dimension is prevalent, it is the length [6; 8]. The width corresponds to the size of the sieve mesh used for this experiment. The weight of particles is thus largely dependent on the third dimension – thickness. Its value however is not at image analysis available because three dimensional (3D) objects are observed (in this case, both materials particles). In this process they are transferred by a scanner camera to planar (2D) objects. If we want to know the weight of the observed material texture part, it is important to replace the missing value of particle thickness by a relevant value, which is discovered by the other way [9; 10]. Important properties and dimensions of material particles, just like shape, size and inner substances are very important in the next stages of mechanical treatment of material, like briquetting [11]. The shape of the particle contains form and habitus, as well as convexity and surface roughness [7].

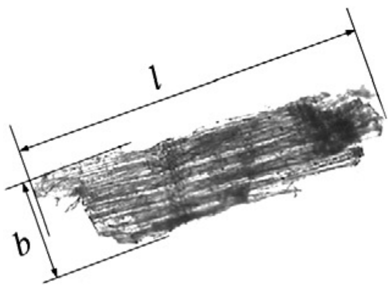

Fig. 2. **Measurement of width (b) and length (l) of biomass particle [13]**

Because of high content of cellulose, hemicellulose and lignin the material of biomass is anisotropic in the inner structure [11-13]. Size diversion of particles can be expressed thanks the histogram or by continual curves. The size of particles of different shape has to be clearly established by measure procedures [7]. To determine the missing value of particles quantitative methods are used (Figure 2) describing the particles [11]. Until recent time most of the scientists described particles mainly qualitatively (as in the form of flakes, rods or "needle"), but use of quantitative methods to study biomass is very rare [10; 11]. The tool for dimension measurement is a digital microscope and program for basic image analysis – "ImageJ". Thanks to using the image analysis we are able to quite accurately measure the dimensions of smaller particles by eye and handling more difficult measurable. Image J is a program developed by the National Institutes of Health designed specifically for processing and image analysis based on Java. This program can calculate the area and pixel statistics in a user-defined selection. It allows to measure distances, angles, can create histograms line profiles and other features [14]. In the process of biomass processing biomass properties of individual particles play an important role, it influences their properties as final product. An important mechanical process is grinding, where the biomass particle shape cannot be ignored because of the next usage as transport, mixing etc. [11]. The next process is mechanical compression, which increases the density and thus the efficiency of transport, handling and storage of biomass in the defined form. It is important to define the properties of biomass in compressed form and even in form before compression. It is investigated that mechanical compression influences the particle structure by decreasing of porosity and, on the other hand, it does not damage cells [6].

This study is just one of other parts to help learn internal space of compressed biomass material. It is important to investigate how a particle behaves in uncompressed and compressed form. To state its behavior we have to know the dimensional and mechanical properties. Next studies should be focused on sorption properties of these materials and the influence on storage conditions. But first, the knowledge of internal space will help to solve this issue.

Materials and methods

Dehydrated digestate (DG) form agricultural biogas plants (BGP) was entirely dried and split at the screening machine AS 200 to various size fractions. Sizes of square sieve eyes were 0.1, 0.25, 0.5, 1.0 and 2.5 mm. Particles smaller than 0.1 mm were captured into the bowl with a fixed bottom. Weight share of each size fraction was expressed as a percentage relative to the weight of initial sample. By the same way the sample of crushed plant *Miscanthus Giganteus* L. (MG) was processed. The crushing process was held at hummer biomass crusher of the FQ type, equipped by a sieve with circular holes of the diameter 8 mm. For particle quantity determination in the sample, the direct measurement method of particle size was used. Particle thickness and length were measured by digital caliper and width was measured by the digital microscope Bresser from digital image. All values were measured at few places of the particle and the final value is average of these components. For each particle its weight was measured in accuracy of one tenth mg. For measuring of this small weight were used the scales KERN ABJ, model 124-4M. For each particle density and volume was calculated from the measured data. Measurement of particle file in scale 30-60 pieces was repeated several times and statistically processed. The result is represented by average values of volume and density of the particle [15]. The particle dimension measurement technique was modified during the experiment several times, to ensure the most realistic data of average material density. The particle sample (e.g., 60 pieces) has been selected by mechanical gradual reduction of its size, in order to maintain the condition of random particle selection. Its histogram was made. Thanks to knowledge of average value of material particle density (in corresponding size category determined by sieve eyes), it was possible to determine with pretty good precision its number in another file (with corresponding particle size). Necessary condition for such a procedure was to determine an average material particle density for a variety of differently sized files. By this condition we determine the smallest possible size of the file (given by the number of particles or file weight), which average density value is not so variable as at other same sized files [16]. Therefore, the assumption is used that the value of average density of particle material is investigated by the direct method, by measuring of the given sample (applies to the entire amount of experienced material). All measurements and verifications described above were exercised on two materials (MG and DG), their particles retained on a sieve mesh size of 1.0 mm. The size of the sieve mesh influenced mainly the width of the particles, which were very flat. The length was determined mainly due to mechanical treatment before the next stage of the process (anaerobic digestion DG and compression MG). This direct method of density detection is labor intensive, but more reliably compares to other methods and could be used as a comparative method. A critical factor in this method could be precision of diameter measuring. Particle weight measuring is a smaller issue. Specifying the number of particles in the sample by using the weight value is burdened with a greater error, and assumes at least approximate knowledge of particle distribution according to their weight or proportions.

Results and discussion

Table 1 represents some results using the method of measuring dimensions and weight of *Miscanthus Giganteus* L. (MG) particles, as described in Materials and methods. The same table was made for digestate (DG) samples; just measured values of each dimension are different compared to those presented in Table 1. In Table 1 purposely files of ten particles are measured to show how it changes the value of average density and other variables with the size of the file. Each such small file is processed separately; just last line in Table 1 shows the values for three files of particles. Average density value for first tenth is ρ_o = 0.3034 g·cm^{-3}, the second tenth ρ_o = 0.3158 g·cm^{-3} and third tenth ρ_o = 0.3787 g·cm^{-3}. The table composition and content have been developed gradually depending mainly on the gained experimental experiences. The measured values of width by the image analysis and calculated average value (1.2017 mm) can show accuracy of measuring (sieve mesh eye size is 1.0 mm). Standard error in the measurement of individual particle dimensions and their weight is, with more careful procedure, in scale of several percent. We are talking mainly about measuring of width of particles in units of tenths or hundredths of a millimeter. Conversely, the length is in the order units or tens of millimeters (average 6.2728 mm). Composed quantities as average density of the sample or particle volume are determined with larger relative error, as following the error theory and as verified. The greatest differences arise by application of the average density value of the entire sample to individual particles of any other sample (compared to the density of the individual particles of a sample generated by measuring their dimensions and calculation). Mean density value of the entire sample is also dependent on its size and the method of statistical data processing as noted in [16], it is important during processing of small particle samples. That is why the histogram is identified for each file sample, see Fig. 3.

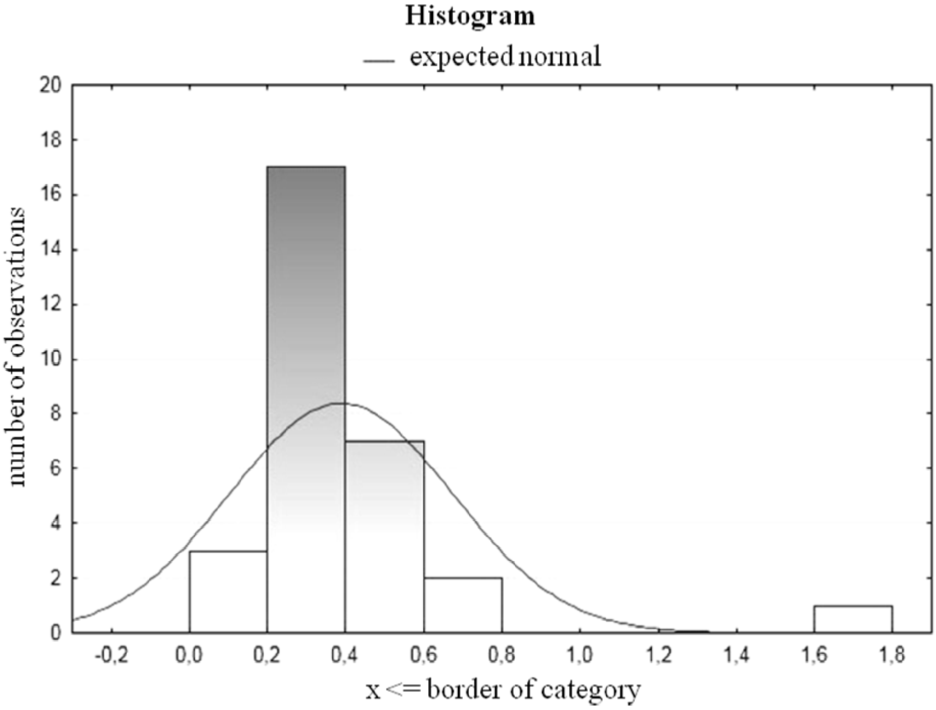

Fig. 3. **Histogram for file sample of MG**

According to the gained experiences nonparametric statistic methods are well-applied for mean value calculation. These methods do not require defined frequency distribution of the measured values and for mean value design smaller file suffice. The mean value gained by this way is not so different from parametric statistical processing of large files. The mean value of particle density, which is used for calculation of particle width, is not so variable for files larger than seventy pieces. The mean value of density was statistically calculated to ρ_o = 0.3311 g·cm^{-3} and ρ = 0.3250 g·cm^{-3}. It means that even the distribution curve of particle files of this size has a similar character. It is important to notice that the samples were evaluated by this method, where particles were bigger than 1 mm and one parameter prevailed (e.g., length). For particles smaller than 1 mm, is possible to use another method (there is not prevalent dimension). This method is partially outlined at paper-work “Dependence of the mean and confidence interval oilseed file on its size and the method of statistical processing” and “Statistics and Scientific Method” [17; 18]. Certainly, for particle files dimensionally more homogenous, where particles are not so different by size, the similarity of the distribution curve (for file of 50 particles of the sample and its material) is very good, even for repeated measurements (of next files minimally the same size). Than we are able to apply this size distribution to the whole volume of the material from which the samples become. These properties have, for example, dried separated digestate that is initially dehydrated slurry from biogas plants. At this material was enough to achieve 90 % shape match of the distribution curve by the file of 46 pieces (compared with the original material of the measured samples). Also the performed screening analysis of the material confirms higher size homogeneity in comparison to the result for digestate or *Miscanthus Giganteus* L. Miscanthus appears as the worst – dimensions of each particle are too different. And as noted by the authors Cleary and Miao et al. different particle size and texture of uncompressed biomass material have a substantial influence on behavior of compressed biomass (e.g., in the form of briquette) [6; 10]. As noted in [18] smaller particle sizes of biomass almost always during its compression lead to products with greater density, possibly with higher strength (cohesion) of these products, and other property changes [1]. We recommend comparing of particles proportions, density and mechanical properties changes for compressed and uncompressed form. The used image analysis method is universal and it is just a tool, which has to be adapted to purpose of use.

Table 1

Crushed plant (*Miscanthus Giganteus* L., MG) particle dimensions including volume *V* and density *ρ*

No.	$A_o \cdot 10^2$	$m_o \cdot 10^3$	h_o	h	Δh	$V_o \cdot 10^3$	$V \cdot 10^3$	$\Delta V \cdot 10^3$	ρ_o	ρ
	cm^2	g	cm	cm	cm	cm^3	cm^3	cm^3	$g \cdot cm^{-3}$	$g \cdot cm^{-3}$
1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	0.0930	0.56	0.027	0.0379	-0.0109	2.4806	3.52	-1.394	0.2257	0.2529
2	0.0782	0.38	0.015	0.0379	-0.0229	1.1474	2.96	-1.8126	0.3312	0.2529
3	0.0815	0.33	0.010	0.0379	-0.0279	0.7878	3.09	-2.3022	0.4189	0.2529
4	0.0639	1.31	0.012	0.0379	-0.0259	0.7670	2.42	-1.6530	1.7079	0.2529
5	0.1263	0.77	0.015	0.0379	-0.0229	1.8530	4.79	-2.937	0.4155	0.2529
6	0.1512	0.87	0.020	0.0379	-0.0179	3.0244	5.73	-2.7056	0.2877	0.2529
7	0.1064	0.63	0.075	0.0379	0.0371	7.9470	4.03	3.917	0.0793	0.2529
8	0.1068	1.28	0.060	0.0379	0.0221	6.3739	4.05	2.3239	0.2008	0.2529
9	0.0157	1.41	0.031	0.0379	-0.0069	4.9170	0.60	4.3170	0.2868	0.2529
10	0.0791	1.11	0.062	0.0379	0.0241	4.9058	3.00	1.9058	0.2263	0.2529
Σ	**0.9021**	**8.65**	**0.327**	**0.0379**	**-0.0520**	**34.2040**	**34.19**	**-0.3407**	**4.1801**	**0.2529**
11	0.0680	0.67	0.059	0.0413	0.0177	3.9916	2.81	1.1816	0.1679	0.3220
12	0.0985	1.05	0.042	0.0413	0.0007	4.1044	4.07	0.0344	0.2558	0.3220
13	0.0875	0.80	0.031	0.0413	-0.0103	2.7119	3.61	-0.8981	0.2950	0.3220
14	0.0228	0.41	0.037	0.0413	-0.0043	0.8527	0.94	-0.0873	0.4808	0.3220
15	0.1012	0.84	0.037	0.0413	-0.0043	3.7790	4.18	-0.401	0.2223	0.3220
16	0.0234	0.28	0.036	0.0413	-0.0053	0.8338	0.97	-0.1362	0.3358	0.3220
17	0.0296	0.57	0.035	0.0413	-0.0063	1.0373	1.22	-0.1827	0.5495	0.3220
18	0.0870	0.46	0.025	0.0413	-0.0163	2.1467	3.59	-1.4433	0.2143	0.3220
19	0.0789	2.89	0.072	0.0413	0.0307	5.6534	3.26	2.3934	0.5112	0.3220
20	0.0768	1.09	0.039	0.0413	-0.0023	3.0213	3.17	-0.1487	0.3608	0.3220
Σ	**0.6737**	**9.06**	**0.413**	**0.0413**	**0**	**28.1320**	**27.82**	**0.3121**	**3.3933**	**0.3220**
21	0.0890	1.66	0.050	0.0410	0.0090	4.4814	3.65	0.8314	0.3704	0.400
22	0.0944	0.62	0.030	0.0410	-0.0110	2.8307	3.87	-1.0393	0.2190	0.400
23	0.0687	0.38	0.013	0.0410	-0.0280	0.8701	2.82	-1.9499	0.4367	0.400
24	0.1073	3.47	0.048	0.0410	0.0070	5.1838	4.40	0.7838	0.6694	0.400
25	0.0557	0.30	0.010	0.0410	-0.0310	0.5756	2.28	-1.7044	0.5212	0.400
26	0.1325	2.59	0.051	0.0410	0.0100	6.7140	5.43	1.2840	0.3858	0.400
27	0.0392	1.11	0.046	0.0410	0.0050	1.8040	1.61	0.1940	0.6153	0.400
28	0.0737	0.60	0.045	0.0410	0.0040	3.3398	3.02	0.3198	0.1797	0.400
29	0.0424	1.03	0.068	0.0410	0.0270	2.8718	1.74	1.1318	0.3587	0.400
30	0.0732	1.12	0.048	0.0410	0.0070	3.4895	3.00	0.4895	0.3210	0.400
Σ	**0.7761**	**12.88**	**0.409**	**0.0410**	**-0.0010**	**32.1608**	**31.82**	**0.3407**	**4.0771**	**0.400**
ΣΣ	**2.3519**	**30.59**	**1.149**	**0.0410**	**-0.053**	**94.4968**	**93.83**	**0.3121**	**11.6505**	**0.3237**

$A_{\circ}$ – measured area of particle
$m_{\circ}$ – measured particle weight
$h_{\circ}$ – measured height of particle
$V_{\circ}$ – particle volume calculated from measured proportions
$\rho_{\circ}$ – particle density calculated from measured proportions and measured weight of each particle
h – calculated height of particle
V – particle volume calculated from particle height in measured area
ρ – average density of particle sample from $m_{\circ}$ and $V_{\circ}$
$\Delta h = h_{\circ} - h$
$\Delta V = V_{\circ} - V$
$\Delta \rho = \rho_{\circ} - \rho$

Conclusions

This study suggests the method that allows determining the number of particles, the volume and weight in the whole sample of uncompressed material. The texture of this material is represented by particles of dry plant stems, which maximal length is 30 mm and where particles have one prevalent dimension, in most cases length. If we know the size, volume or weight distribution in the sample of material we are able, at the base of previous direct measurements of another sample but the same material, to determine with some accuracy the number of particles and their distribution at the given sample of material. Length of the particles of this material was approximately from 1 mm to 20 mm. Dimensions of the particles were measured by digital caliper or directly deducted from image at computer monitor. For image analysis the program “ImageJ” has proved as suitable. Material with particle size smaller than 1 mm is necessary to be processed by different way than those described above to reach realistic results. The performed screening analysis of the material confirms higher size homogeneity in comparison to the result for digestate or *Miscanthus giganteus* L. Miscanthus appears as the worst – dimensions of each particle are too different. We recommend comparing of particle proportions, density and mechanical property changes for compressed and uncompressed form to attest the suggested method. The used image analysis method is universal and it is just a tool, which has to be adapted to purpose of use.

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