SIEVE ANALYSIS OF BIOMASS: ACCURATE METHOD FOR DETERMINATION OF PARTICLE SIZE DISTRIBUTION

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Abstract. Increasing interest in biofuels made of agricultural organic waste and energy crops is accompanied by general need for better and more comprehensive knowledge of biomass material properties. Particle size and particle size distribution (PSD) are important physical characteristics playing essential roles in flow ability, bulk density, compressibility of bulk solid material and durability of densified products. Sieve analysis is considered as a traditional and standard method to assess dimensional and morphological features of particulate materials. The aim of the present paper was to determine PSD of different grinded biomass sources such as industrial hemp (fibrous annual plant), miscanthus (perspective perennial energy crop) and pine sawdust (wooden biomass) via the sieve analysis. Horizontal vibrating sieve shaker comprising seven sieves with opening sizes of 0.63, 1.5, 3.15, 4.5, 6.7, 8 and 10 mm were used for the analysis of the biomass materials with initial fractional size of 12 mm. Data were processed using MS Excel and the obtained results were tabulated and graphically plotted. Size distribution of pine sawdust particles was quite uniform; the particles' spherical shape decreased screen opening size resulted in really decreased particle sizes. Contrarily, analysis of hemp and miscanthus did not yield absolutely reliable results of real PSD. In case of hemp it was due to its fibrous nature – more than half of the material stayed on the first sieve (i.e. 10 mm); in case of miscanthus it was caused by needle-like shape of its particles, since this method did not obviate a "falling-through" effect of longer particles through smaller sieve apertures. Due to these limitations, utilization of more accurate method for determination of PSD – machine vision and image analysis is discussed. Even though the method of the sieve analysis was not so accurate and consistent, the results generally contributed to better knowledge of input material for solid biofuel production.

Keywords: size classification, particle size distribution, mechanical screening, sieving, shape, machine vision, image analysis.

Introduction

Nowadays, there is an increasing interest in biofuels made of various types of biomass including agricultural organic waste and energy crops [1-3] that is accompanied by rising demand for high-quality products with good mechanical, chemical and energy properties [4]. Knowledge of material properties is critical in understanding and controlling the manufacturing operation. This information can help improve the modes, parameters and technological aspects of the necessary equipment and, above all, may ensure higher quality of biofuel with appropriate technological properties.

Particle size and particle size distribution (PSD) are counted among major factors affecting many properties of particulate as well as densified materials and provide important information about quality and performance [2; 5-7]. They play important roles in flow ability, bulk density, compressibility, and durability of densified products. And since biomass particles are characterized by diverse range of sizes and shapes [8], it is important to determine and control distribution of the particle size.

PSD analysis is considered as a standard method to assess dimensional characteristics and morphological features of particulate materials [3; 9]. Generally, outputs from PSD analysis comprise percentage of particles captured on sieves with diverse opening sizes, cumulative undersize distribution, geometric and arithmetic mean value and related standard deviation, as well as many other parameters, which in unique way characterize the distribution of particles [9]. PSD of biomass is standardly determined by the mechanical screening (sieve analysis) method [10]. Many authors reported PSD results of various biomass materials, e.g., switchgrass, wheat straw, and corn stover [11], barley straw [12], *Cynara Cardunculus* L. [13] and hemp [14]. Several authors assert that this traditional method is not suitable for PSD of biomass, because of their irregular shapes, and suggest that more precise outcomes can be obtained by machine vision and image analysis [3; 8; 9; 13; 15-18].

The aim of the present paper was to determine PSD of different grinded biomass materials such as industrial hemp, miscanthus and pine sawdust via the sieve analysis and to identify preciseness of the method in case of these materials and altogether to contribute to better knowledge of biomass material properties.

Materials and methods

Sieve analysis, according to the standard [10], was used to determine PSD of hemp (*Cannabis sativa* L.) – fibrous annual plant, miscanthus (*Miscanthus × giganteus* L.) – perspective perennial energy crop, and, pine sawdust (*Pinus* L.) – wooden biomass, the materials obtained from the Czech Republic. Materials were grinded by hammer mill 9FQ-40C (Pest Control Corporation company; input 5.5 kW) with initial fraction size of 12 mm and their moisture content (w.b.) was 9.91 %, 8.82 %, and 10.35 %, respectively.

A horizontal vibrating sieve shaker Retsch AS 200 comprising seven sieves with opening sizes of 0.63, 1.5, 3.15, 4.5, 6.7, 8, 10 mm and a bottom pan (< 0.63) was used. For each material, two same tests (repetitions) were applied. Before testing, all sieves and the bottom pan were weighted on a laboratory scale KERN (readout 0.01 g). For each test, a representative weighed sample from each material was poured into the top sieve with the largest screen opening size and 30-minute sieve shaking time and amplitude 3.0 mm·g^{-1} was applied. After the shaking process, each sieve with captured material was weighted and the weight of sieves themselves was subtracted. The captured sample weight on each sieve was calculated as arithmetic mean of these two tests. This result was then divided by the total weight to give a percentage of material retained. The data were processed using MS Excel and the obtained results were tabulated and graphically plotted.

Results and discussion

Hemp

Average PSD of hemp is shown in Fig. 1. More than half of the material was captured on the sieve with the largest opening size (i.e. 10 mm). However, it was caused owing to fibrous nature of hemp; long hemp bast fibres were not ground well and created tangled masses, which could not fail through the openings and thus stayed on the first sieve (Fig. 2).
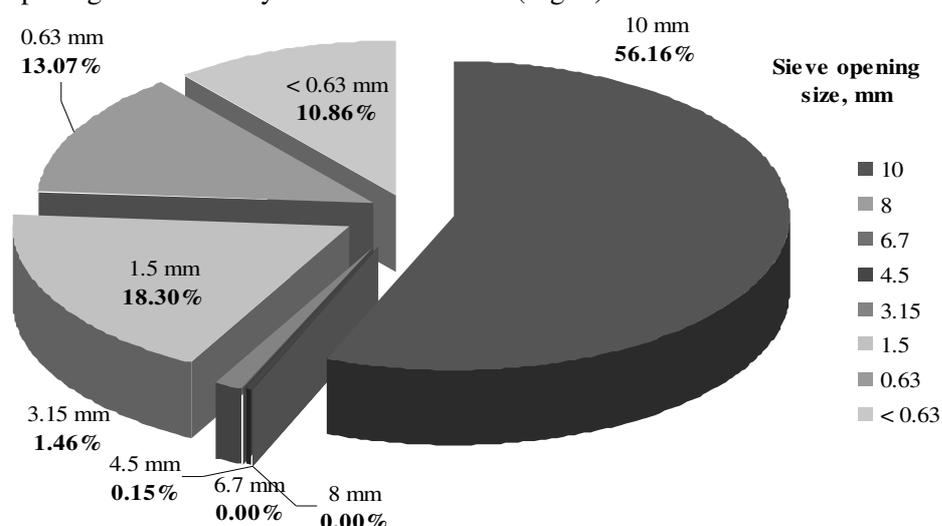
Fig. 1. **Pie chart of particle size distribution of hemp material**

In both tests, the following sieves (opening sizes 8 and 6.7 mm, respectively) did not catch any material. Almost all the rest of the non-fibre part of the stem and leaf tissues, i.e. epidermis, cortex, phloem, xylem, and mainly pith, passed through the sieves (however, some of them were caught and tangled by bast fibres on the first sieve) and the sieve with opening size 1.5 mm captured the most of these non-fibre based particles, followed by the sieve with aperture 0.63 mm and the bottom pan (< 0.63 mm). It was caused by hemp's parallelepiped shape [19], when the particle diameter was less than the size of the square opening in the screen, thus non-fibre particles passed up to the sieves with smaller aperture sizes. Similar results were observed by the author [14], in his study around 90 % of hemp mass passed on sieves between 1 mm and 4 mm and less than 3 % material stayed above 4 mm. These results showed that this procedure cannot identify the length and width of the parallelepiped shape of hemp particles and is not accurate to determine precisely PSD of hemp particles since there was a lot of hemp material passing through a given screen that had lengths much larger than the screen

opening sizes. The author [14] also analyzed hemp particles via image analysis with more exact results.

Fig. 2. **Particle size distribution of hemp:** particles retained on the sieve with the largest aperture on the right, with the smallest aperture on the left side; sieves with no captured material (8 and 6.7 mm) were omitted

Miscanthus

PSD of miscanthus material is presented in Figure 3. Minimum of material was captured by the sieves with the largest opening sizes, i.e.10, 8 and 6.7 mm. As well as the following sieves (4.5 and 3.15 mm) caught a small part of the mass (about 5 %). On the other hand, more than 50 % of the material was retained on the sieve with aperture 1.5 mm. Followed by the last sieve and the bottom pan, which captured together the rest of the material (approximately 44 %).
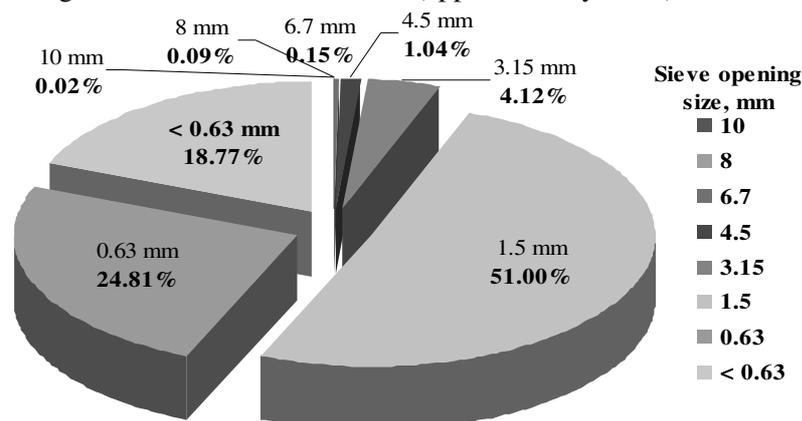
Fig. 3. **Pie chart of particle size distribution of miscanthus material**

Although the largest screens (10, 8, 6.7, 4.5 mm) captured minimum of the material (less than 1.3 %), from visual assessments (Fig. 4) it is evident that the lengths of many particles exceed the largest sieve opening size and that the lengths of the particles captured on the sieves did not correspond to the opening size of the screens. As was stated, more than 50 % of miscanthus was retained on the sieve with aperture 1.5 mm, i.e. the size of the particles should be less than 3.15 mm and more than 1.5 mm, however, it does not reflect the real size of the particles as can be seen in Figure 4. This effect was reported by the authors [17], they observed particle lengths of *Miscanthus floridulus* and others materials up to 17 times exceeding opening dimensions of standard sieves.

It indicates that the mechanical screening procedure did not determine real sizes of miscanthus particles well due to their needle-like shape. This method was already previously presented as not obviating the "falling-through" effect of longer particles through smaller apertures on sieves [9]. Several studies have shown sieve analysis based approach for PSD, notwithstanding it is considered as a standard testing procedure [10], as not a precise method of classifying the particulate materials by length [9; 17; 18]. Biomass particles are characterized by diverse range of sizes and shapes [8], however, the screening procedure assumes sphericity of material [13]. For these reasons, several authors propounded that machine vision and image analysis techniques could provide more accurate measure of size connected with shape [8; 9; 17; 18].

Fig. 4. **Particle size distribution of miscanthus:** particles retained on the sieve with the largest aperture are on the right, with the smallest aperture are on the left side

Pine sawdust

The distribution of pine sawdust particles was more uniform than that of the previous materials (Fig. 5 and 6). Owing to the spherical shape of pine sawdust particles, decreased screen opening size resulted in really decreased particle sizes, as expected.
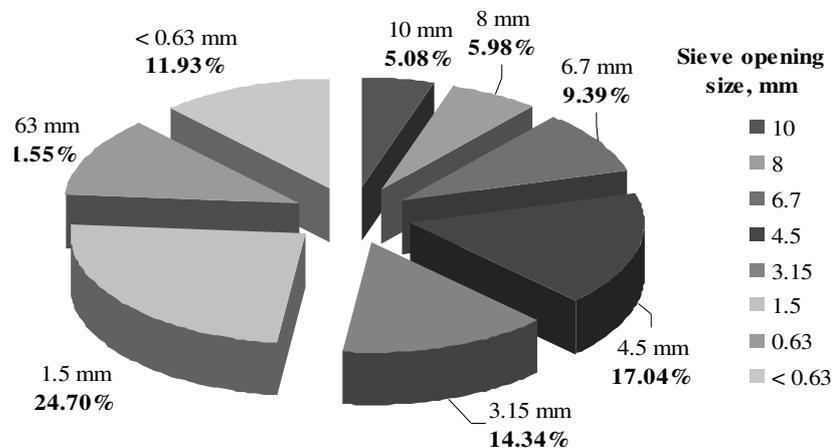
Fig. 5. **Pie chart of size distribution of pine sawdust particles**

More than 60 % of the material was captured by last three sieves and the bottom pan (with apertures 3.15, 1.5, 0.63 and < 0.63 mm respectively).

Fig. 6. **Particle size distribution of pine sawdust:** particles retained on the sieve with the largest aperture are on the right, with the smallest aperture are on the left side

The largest mass (almost 25 %) was captured on the sieve with aperture 1.5 mm. On the contrary, the screens with the largest apertures (10, 8, 6.7 mm) caught the least amount of material due to the spherical shape of sawdust particles, the standard oscillating method determined reliable results of more or less real sizes of the sawdust particles (Figure 6). As reported by the author [9], in case of spherically shaped particles mechanical screening provided quite comparable results with machine vision and the image analysis method.

To compare the PSD of all three studied materials, the results were collectively tabulated (Table 1) and plotted (Figure 7).

Table 1

Tabulated particle size distribution of examined materials

Material retained on sieve						
Sieve, mm	*Miscanthus*		*Hemp*		*Pine sawdust*	
	g	%	g	%	g	%
10	0.01	0.02	23.11	56.16	4.22	5.08
8	0.06	0.09	0.00	0.00	4.96	5.98
6.7	0.10	0.15	0.00	0.00	7.79	9.39
4.5	0.69	1.04	0.06	0.15	14.14	17.04
3.15	2.73	4.12	0.60	1.46	11.90	14.34
1.5	33.80	51.00	7.53	18.30	20.50	24.70
0.63	16.44	24.81	5.38	13.07	9.59	11.55
< 0.63	12.44	18.77	4.47	10.86	9.90	11.93
Total	66.27	100.00	41.15	100.00	83.00	100.00

As it can be clearly seen in Table 1, the most of the material of all three studied biomasses was caught by the sieve with 1.5 mm apertures, followed by the sieve 0.63 mm and the bottom pan (<0.63 mm).
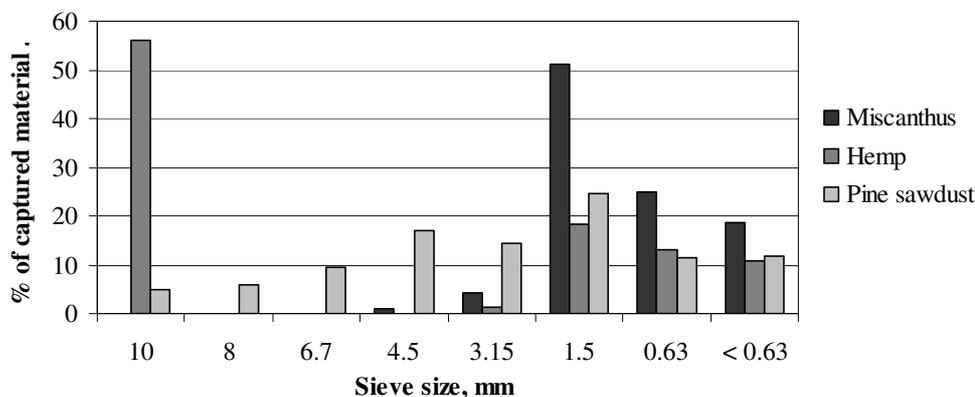
Fig. 7. **Plotted comparison of particle size distributions of examined materials**

Owing to the spherical shape of pine sawdust particles, the vibrating sieve analysis yielded uniform and consistent results. In case of hemp and miscanthus, the PSD was influenced by their structural nature and irregular shape.

Conclusions

Size distribution of pine sawdust particles was quite uniform; due to the particles' spherical shape decreased screen opening size resulted in decreased particle sizes. Distribution of retained materials on sieves was quite regular in this case. The most of material (almost 25 %) was caught by the sieve with 1.5 mm apertures. However, the analysis of hemp and miscanthus did not yield absolutely reliable results on their real PSD. In case of hemp it was due to the fibrous nature of this plant and parallelepiped shape of non-fibre particles – more than 56 % of the material stayed on the sieve with the largest opening size. In case of miscanthus it was caused by the particles' needle-like shape, since this standard method did not obviate the "falling-through" effect of longer particles through smaller sieve apertures. For this reason more than 75 % of the material was retained on the last two sieves with the smallest apertures (1.5 and 0.63 mm). In these cases, utilization of machine vision and image analysis could provide more exact results. Even though the method of sieve analysis was not so accurate and consistent in case of prolonged particles, the results generally contributed to better knowledge of input materials intended for solid biofuel production.

Acknowledgements

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