INFLUENCE OF MOISTURE ON PARTICLE SIZE OF PLANT RAW MATERIALS AFTER GRINDING

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Abstract. Stem plant materials, as a common lignocellulosic raw material, are widely used both in agro-industrial production and in biofuel technologies. One of the main technological operations when using stem plant materials is grinding. The performed studies are dedicated to determining the influence of raw material moisture on the efficiency of grinding plant materials such as wheat straw, rape straw and corn stalks. A hammer grate crusher was used for the research. The diameter of the rotor was 520 mm, the diameter of the sieve holes was 7.25 mm, and the frequency of rotation of the rotor was 1470 rpm. In the upper part of the rotor, four knives are installed on a disk with slots, which preliminarily destroy the raw materials. Raw materials obtained after grinding were analysed using a sieve classifier. Grinding quality was assessed by the weighted average particle size. Experiments were conducted with wheat straw, rape straw and corn stalks with moisture obtained during crop harvesting, as well as additionally dried. Each type of raw material had three levels of moisture, and the repetition of the experiments was threefold. The moisture limits for each crop were individual and ranged from 8 to 30%. When analysing the results of the experiment, mathematical dependencies were obtained that describe the change in the weighted average length of the crushed raw material in the form of linear functions. It was established that when grinding wheat straw, rape straw, and corn stalks with a hammer crusher, an increase in their moisture content within the range of 8-30% leads to an increase in the weighted average length of particles from 1.6 to 2.4 mm, and the coefficient of determination of linear models of the influence of moisture on the change in weighted average length is in the range of 0.68-0.96.

Keywords: grinding, moisture, plant materials, hammer crusher, particle length.

Introduction

Plant materials, in particular, stem materials, are widely used [1] as fodder, technological materials, raw materials in fuel technologies, etc. Considering the purpose, type, and parameters of the material [2; 3], the requirements for its grinding differ significantly. Thus, the requirements for stem fodder are established by standards [4-6], and their moisture content can vary from 17-20% (hay) to 70-78% (silage) and is determined by both zootechnical and technological requirements. The length of hay stalks is 100-140 mm, the length of particles in haylage reaches 50-80 mm, and in silage - 10-50 mm. Precision-cutting machines are used to meet such requirements. The design, for example, of a drum cutting device, providing high productivity, allows to adjust it to a given cutting length, depending on the type of materials. Hay can be harvested without grinding, or with cutting to ensure the manufacturability of raw materials during distribution. A biter-knife cutting device is used for this, which is installed in the transport channel of a baler or a pick-up cart.

Harvesting straw for bedding [7] is similar in terms of requirements for harvesting hay. It is prepared in a pressed form, and for better compaction, it is pre-cut using a biter-knife cutting device. If necessary, the final length of the straw particles is formed during their distribution into the stalls.

The use of plant materials in fuel technologies [8-10], both solid and those obtained by fermentation methods, is becoming widespread. As a solid biofuel, plant materials are used for burning and pressed into bales, rolls, or in the form of fuel pellets or briquettes. Shredding in this case takes place in two stages: preliminary cutting during pressing in the field and final one- or two-stage grinding before pressing. This is explained by the fact that the production of high-quality pellets [11; 12] imposes strict conditions on the grinding and moisture content of the raw materials. At the same time, the length of the particles should not exceed 2-3 mm, or even 0.5-2.8 mm [13], to ensure the density of the pellets and the smoothness of the pelleting process. Before the final grinding, the raw material is dried to the moisture set by the pelleting conditions. The use of rational parameters of the moisture of stem raw materials allows to ensure the quality indicators of the produced solid biofuels, reduces energy consumption during their production, increases the heat of combustion, and reduces the formation of harmful emissions into the atmosphere [14].

The use of plant raw materials in the technologies of liquid and gaseous biofuels, which involve subsequent fermentation [15], imposes no less strict requirements on the quality and degree of grinding of bio-raw materials but does not require strict compliance with the requirements regarding the moisture content of raw materials, as in the production of fuel pellets.

In the works that consider the processes of grinding and compaction of plant raw materials, the influence of moisture on the geometric parameters of the ground material is usually not investigated or is taken into account approximately by an empirical coefficient [14; 16].

Although there is a constant search for shredder designs [16] that can ensure the required productivity and the quality of grinding with lower energy consumption, the final grinding of plant raw materials in the mentioned technologies is carried out mainly by hammer crushers, which differ by the relatively high specific energy consumption of the grinding process. The humidity of the material being ground has a significant influence on the energy costs [17].

Thus, in the work [18], devoted to the study of the influence of the moisture of wheat straw on the specific energy consumption for its grinding, it was established that with fine grinding (up to 0.25-1.42 mm) the grinding process corresponds the Rittinger law, and the Rittinger constant has the power-law dependence on the biomass moisture.

At the same time, with high requirements for the quality of grinding, the importance of predicting the influence of the moisture content of the stem raw material on the weighted average length of the crushed particles when grinding with hammer sieve crushers is increasing.

Materials and methods

The purpose of the research was to experimentally determine the influence of the moisture content of plant raw materials on the quality of grinding with a hammer sieve crusher for the further use of raw materials in biofuel technologies.

The analysis of the research and publications was carried out using the monographic method. Research on the grinding process was carried out using the method of a one-factor experiment with the determination of the moisture content of raw materials immediately after grinding. The sizes of crushed raw materials were analysed by the sieve analysis using DSTU 4877:2007, DSTU EN 15149-1:2013 [19; 20]. Grinding quality was assessed by the weighted average particle size using statistical methods, and graphical and regression analyses.

A hammer sieve crusher was used for the research (Fig. 1). The diameter of the crusher rotor was 520 mm, the diameter of the sieve holes was 7.25 mm, and the rotor speed was 1470 rpm. A disk with four knives was installed on the rotor of the crusher to ensure preliminary grinding of raw materials.

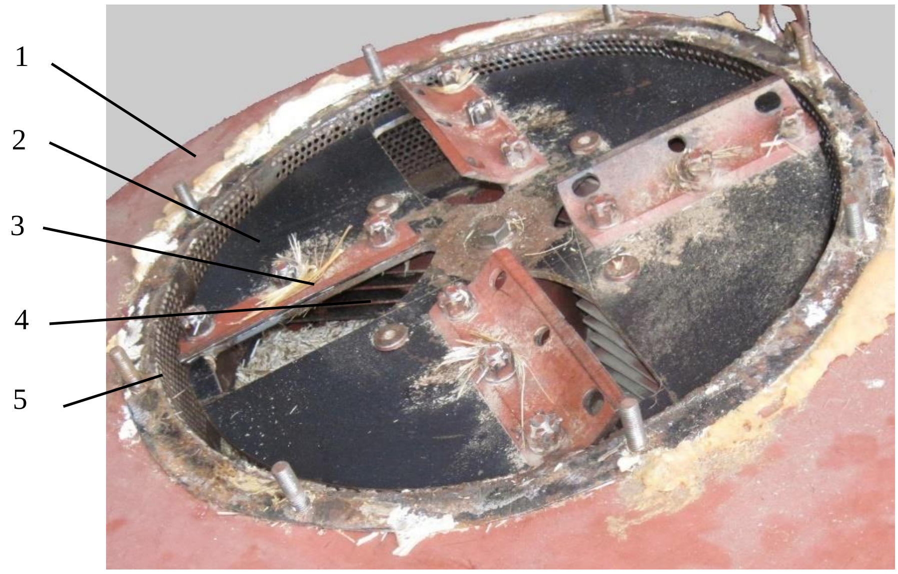

Fig. 1. **Hammer grinder of plant raw materials (with the loading neck removed):**
1 – body; 2 – disk with slots; 3 – pre-grinding knife; 4 – package of hammers; 5 – sieve

The raw materials obtained after grinding were analysed using the sieve analysis. Grinding quality was assessed by the weighted average particle size L_{wal} (1), which was determined according to the dependence [20]:

$$L_{wal} = \frac{\sum_{1}^{n}\left(l_{i+1} - l_{i}\right)M_i}{2\sum_{1}^{n}M_i}, \quad (1)$$

where: l_1, l_2, ..., l_i, $l_{(i+1)}$ – sizes of the holes on the sieves, mm;
M_i – mass of the i-th fraction, g;
i – faction number;
n – number of fractions.

Experiments were conducted with wheat and rapeseed straw, and corn stalks with the moisture obtained during crop harvesting, as well as additionally dried. Each type of raw material had its own moisture range, wheat straw – 8.27%, 12.38%, 15.94%, rape stalks – 9.70%, 15.67%, 17.13%, corn stalks – 12.08%, 15.97%, 30.28%.

Statistical data processing was performed using Microsoft Excel. All experiments were performed in three repetitions. Based on the analysis of the experimental data, regression equations were obtained. The correspondence of the obtained models to the experimental data was evaluated by the coefficients of determination.

A typical set of flat sieves with round holes with a diameter of 10, 7, 5, 4, 3, 2, 1 mm, metal woven sieves with a cell size of 0.5, 0.25 mm, and a pallet were used for the analysis. The working height of the sieves after installing them in the block is 2.5 cm.

Results and discussion

During the research, some peculiarities were revealed. Since the raw material in the crusher passes through the sieve after grinding, a large amount of crushed raw material of the same size is formed. During dispersion in the classifier, such raw material, having reached the sieve, which it does not pass, overflows it. To avoid this phenomenon, according to the guidelines [11], the sample was divided into smaller samples (subsamples) before scattering. The latter together made up the mass of the entire sample. In addition to this phenomenon, thanks to its properties, the crushed raw material rolled into a ball, which contained particles that could pass through the sieve individually, as well as smaller particles (Fig. 2). During the scattering, the ball was divided by hand into separate parts, which were alternately sifted separately from each other.

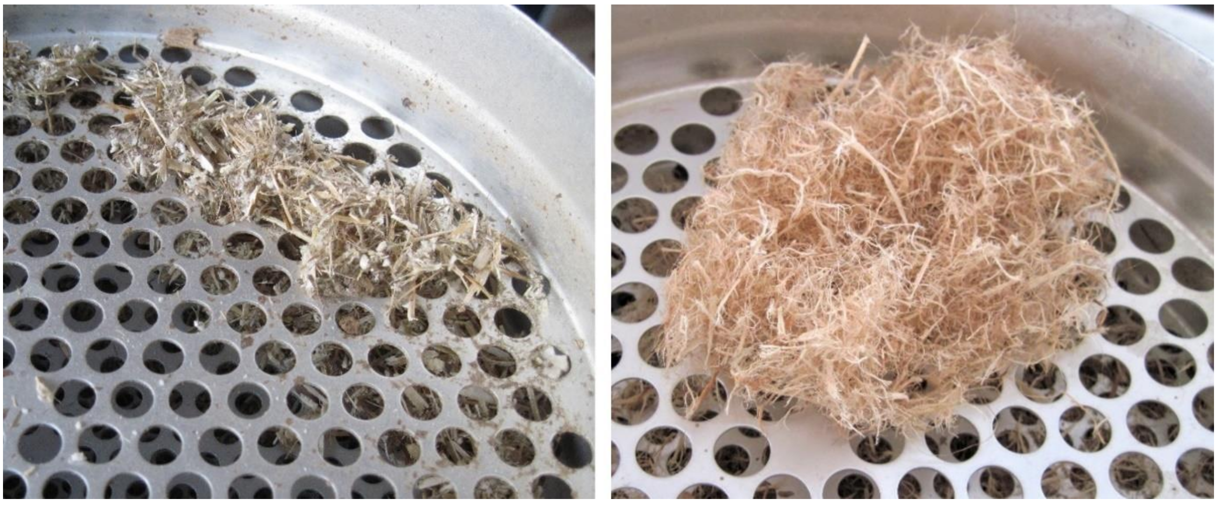

Fig. 2. **Raw materials during sieving**

After dispersing the crushed raw materials, we obtained fractions corresponding to the diameters of the sieves of the classifier (Fig. 3).

After weighing the obtained fractions, using equation (1), the weighted average length of the particles of the crushed raw material was determined for each sample of the corresponding moisture (Table 1).

The obtained results made it possible to plot the dependence of the change in the weighted average length of the particles of the crushed raw material on the moisture for wheat straw, rape stalks, and corn (Fig. 4).

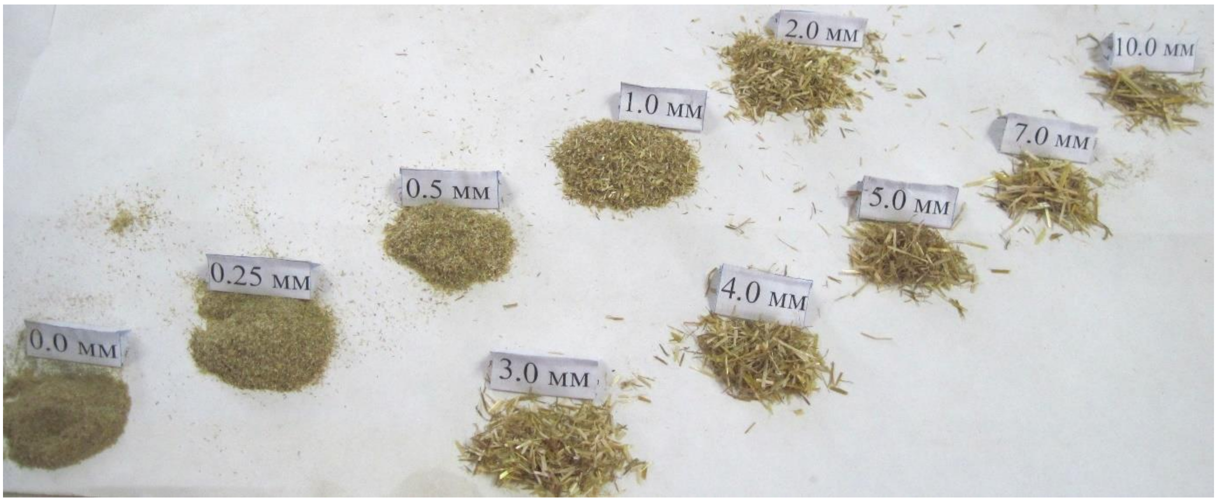

Fig. 3. **Samples of fractions of crushed wheat straw obtained on sieves with appropriate holes**

Table 1

Results of experimental research

Plant raw materials	Moisture, %	Weighted average length of the particles, mm
Wheat straw	8.27	2.22
	12.38	2.21
	15.94	2.43
Rape straw	9.70	2.08
	15.67	2.18
	17.13	2.29
Corn stalks	12.08	1.69
	15.97	1.71
	30.28	2.34

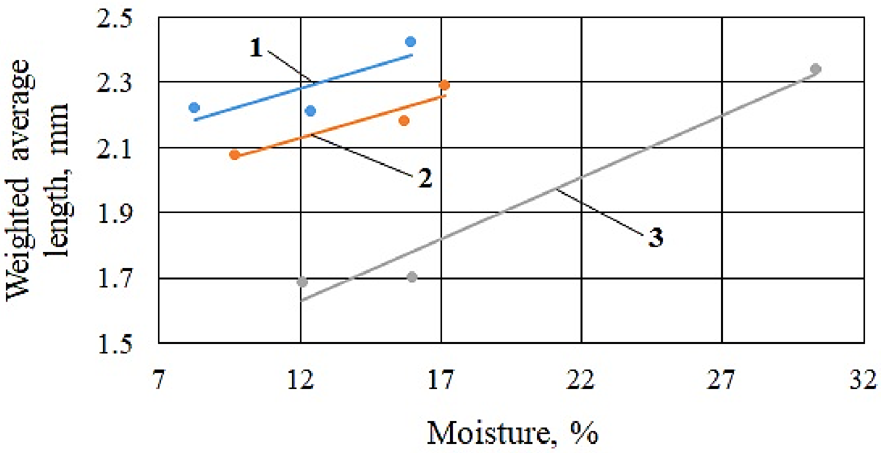

Fig. 4. **Weighted average length of particles of crushed raw materials depending on moisture:**
1 – wheat straw; 2 – rapeseed straw; 3 – corn stalks

Obviously, taking into account the measurement error, in order to obtain adequate mathematical models, it is necessary to conduct additional studies at different levels of raw material moisture.

However, the obtained data reflect a tendency to increase the weighted average length of the particles of crushed raw materials with increasing moisture content, which, with some approximation, can be represented by mathematical dependencies of the form (2-4):

- for wheat straw –

$$L_1 = 0.0261\,W + 1.9689, \quad (2)$$

- for rapeseed straw –

$$L_2 = 0.0253\,W + 1.8257, \quad (3)$$

- for corn stalks –

$$L_3 = 0.0381\,W + 1.1713, \quad (4)$$

where L_1, L_2, L_3 – weighted average length of wheat and rapeseed straw and corn stalks, respectively, mm;
W – raw material moisture, %.

The coefficients of determination for dependencies (2-4) were 0.6837, 0.8864, and 0.9671, respectively.

As it can be seen from Fig. 4, with increasing moisture, there is a tendency to increase the weighted average length of the particles of crushed plant material. The tangent of the angle of inclination of the graphs of linear dependencies describing the change in the average weighted length of grinding of different types of raw materials to the abscissa axis is 0.027 mm/% for wheat straw, 0.028 mm/% for rapeseed straw and 0.036 mm/% for corn stalks. Taking into account the studied moisture ranges, the difference can be explained by the fact that during grinding drier raw materials are destroyed with formation of a larger number of small particles.

Conclusions

1. It was established that the influence of moisture on the weighted average length of particles of crushed plant mass can be described by linear dependencies.
2. With increasing moisture, there is a tendency to increase the weighted average length of particles of crushed plant material when it is crushed by hammer crushers.
3. For the studied moisture range, the intensity of change in the weighted average particle length of the crushed raw material depending on its moisture content is 0.027 mm/% for wheat straw, 0.028 mm/% for rapeseed straw, and 0.036 mm/% for corn stalks.

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Author contributions

Conceptualization, V.K., V.B, S.S.; methodology, V.K. and S.S.; investigation, V.K., V.B., S.S. and O.K.; writing – original draft preparation, V.K., V.B.; writing – review and editing, V.K., V.B., S.S. and O.K.; project administration, V.B.; funding acquisition, V.B. All authors have read and agreed to the published version of the manuscript.

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