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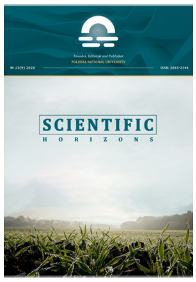

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Determination of Length of Individual Pellets and Pellets' Lengths Distribution

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Abstract. A form and dimensions of fuel particles influence the intensity of their burning and approaches to the mathematic description of the process. Known methods do not allow correctly measuring all pellets' lengths and describing pellets' lengths distribution. The purpose of the study is to substantiate method for determining the individual pellet length and to specify statistical characteristics of pellets' lengths distribution. The purpose was achieved by applying the proposed method of indirect determination of the length of each pellet by weighing it, followed by calculation of the equivalent length and modal cluster analysis of the distribution of pellets by length, based on the probability density distribution. The most noteworthy results are that the experimental calculation of the equivalent length gives results that coincide with direct measurements for pellets of the correct shape, but in contrast to direct measurements can also be used to determine the equivalent lengths of irregularly shaped pellets and their fragments. Clustering allowed grouping pellets around objectively existing local maxima in the probability density distribution, which can be identified at intervals of pellet lengths not exceeding 2 mm. The importance of the obtained results is that the indirect method of determining the length of pellets allows replacing the measurement of pellet lengths by their weighing, which eliminates subjective factors when measuring the length of irregularly shaped pellets and their fragments. Clustering characterised the granulometric composition of pellets with histograms of probability, mass fraction, and average length by clusters. Upon using proposed approaches, granulometric composition of industrially produced pellets was specified and increased probabilities were noted for 8 mm pellets in clusters of smaller lengths, compared to 6 mm pellets; while straw pellets are characterised by a higher probability in clusters with shorter lengths compared to wood pellets

Keywords: pellets, length measurement, length determination, probability density distribution, clustering, histograms, pellets lengths distribution

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INTRODUCTION

A considerable part of the territory of Ukraine is located in the steppe zone with intensive grain production, so the energy use of cereal straw is promising, the annual resources of which, according to various estimates, amount to more than 10 million toe. According to the authors of this study, in 2020, in Ukraine, boilers with periodic burning of whole bales consumed up to 20,000 tons of straw. An alternative approach may be to produce pellets from straw and use them as fuel. Pellets are more convenient and safer for transportation and storage, allow achieving complete mechanisation and automation of processes.

The combustion of wood pellets in a stationary bed has been studied in detail, and the technologies of their combustion in retort burners or on moving grates have reached technical perfection [1-3]. Attempts to burn straw pellets instead of wood pellets in retort burners and burners with moving grates led to agglomeration of ash due to low temperature characteristics of its melting, to disruption of work with a considerable decrease in heat output and energy efficiency, increased *CO* emissions [4; 5]. These obstacles necessitated more detailed studies on the differences in the properties of wood and straw, differences in their combustion processes. Many papers are devoted to the study of the composition of the mineral part of wood and straw, transformations of the mineral part during the formation of ash, temperature characteristics of its melting [6-8].

The size and shape of fuel particles also affect the combustion process. When considering the combustion of single particles, they usually took their spherical shape, which allow simplifying the mathematical model to a one-dimensional one. In [9], it is shown that when the particle size is more than a few tenths of a millimetre, the spherical approximation unsatisfactorily reflects the features of combustion. In [10], a mathematical model of thermal conversion of biomass particles is described, which considers their shape and size. In [11], it was experimentally found that at the same mass, cylindrical particles lose mass faster than spherical ones, and it is believed that the duration of their complete burnout decreases with increasing surface area. The importance of the proper granulometric composition of pellets is indicated in [12; 13] and it is noted that the presence of small particles can affect the processes of storage, supply, combustion efficiency, and emission of pollutants. General requirements for the granulometric composition of pellets are established by the standard [14]. Pellets can be produced in nominal diameters of 6, 8, 10, 12, and 25 mm with particle lengths up to (40 … 45) mm. Within the same class of pellets, their actual diameter may differ by ±1 mm in diameter [14-16].

According to the content of small particles, pellets are divided into 7 classes with a fine content from 1 to 6 and more than 6% by weight. The content of small particles should be determined by sieving with holes with 3.15 mm diameter round holes [17]. For non-industrial (domestic and equivalent) wood pellets, the content of fine particles is limited to 1% [15]. For non-wood pellets (including straw pellets), the content of small particles is limited to (2 … 3)% by weight [16].

The length and diameter of pellets should be measured with a calliper with a resolution of at least 0.1 mm, and the average length and average diameter of pellets should be rounded to 0.1 mm. In addition, it is necessary to determine the standard deviation of the length, the mass fraction of pellets less than 10 mm long in the test portion [18], selected and prepared in accordance with the standards [19; 20]. In the standard [18], by default, it is accepted that pellets have the cylindrical shape with a convex protrusion at one end and depression at the other, while the length of the pellet is usually measured manually with a calliper as the distance along its axis from the top of the protrusion to the end with a depression (Fig. 1). In this study, this form of pellets is generally called correct.

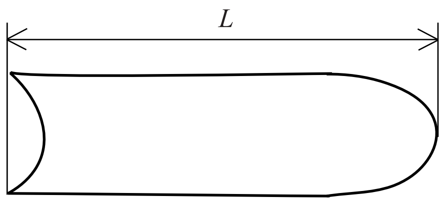

***Figure 1**. Pellet of the correct shape and measurement of its length from the top of protrusion to the end with depression by the standard method*

The length measured by the standard method includes the pellet body, the spaces in the depression and around the protrusion that are not filled with fuel. The edges of the pellets at the end with depression are thin and uneven, they are easily destroyed by touch or pressure. Therefore, the result of measuring the length depends on subjective factors: the position of the pellet during measurement and the pressing force of the calliper jaws. In this regard, it is impossible to correctly determine the mass of fuel in the pellet from the length of the pellet measured by the standard method. In the standards [15; 16], it is accepted that pellets that remain on a sieve with round holes with a diameter of 3.15 mm have a length of more than 3.15 mm. This means that for fragments of pellets and very short pellets that remain on the sieve and have a shape close to a thin disk, a length of 3.15 mm should be taken. With a considerable content of short pellets and debris, this can considerably affect the determination of the average length.

According to R.C. Akdeniz and O. Esmer pellets may break during production with the formation of bevelled and torn edges. Due to deviations in the technological process, pellets with cracks of different orientations can form at the output of the matrix, and the geometric shape may differ from the cylindrical one [21]. In [18], there are no instructions for measuring the length of irregular fragments and pellets, and therefore there is a need for a more objective but simple method for determining the length, which would be suitable for all pellets and their fragments.

L. Sikanen and T. Vilppo noted that pellets do not break on perfectly flat surfaces at an angle of 90° to the axis, so they measured the length between the midpoints on the fault surfaces [22]. When measuring manually, this approach causes subjective errors. To characterise the granular feed T. Winowiski proposed to weigh 10 grams of pellets, count their number and then calculate the average weight of one, but if the pellet does not have a full diameter, it is not considered [23]. With this approach, some pellets were subjectively excluded from the measurements. H. Gilvari et al. developed an image processing technique to determine the length of individual pellets – as the distance between two lines taken from the end points of the pellet shadow image perpendicular to its axis [24]. A long pellet on a horizontal screen gives a shadow, the size of which characterises its length with a certain approximation, and a short one lies like a flat disk and its shadow characterises its diameter rather than length.

Given the dependence of the combustion intensity on the shape and size of individual particles, the use of the average length for mathematical description of the combustion of a layer of polyfraction pellets is unacceptable. L. Sikanen et al. in the experimental study of combustion characterised the granulometric composition by a histogram of distribution over narrow ranges of pellet lengths (L, mm): L<3; 3<L<5; 5<L<10; 10<L<15; 15<L<20; 20<L<25; 25<L<30; 30<L [22]. R.C. Akdeniz and O. Esmer used unequal wide intervals: L<3.15; 3.15<L≤20; 20<L≤35; 35<L≤38; 38<L≤40; 40<L≤45; 45<L [21], and H. Gilvari et al. used even fewer wide intervals of 3.15<L<15; 15<L<30; 30<L [24]. In these studies, when constructing histograms, different widths of the pellet length intervals were taken without appropriate statistical substantiation.

The purpose of this study is to substantiate the method for determining the length of single pellets, which would be suitable for all pellets and their fragments of various shapes present in the studied portion, to determine statistical characteristics of the distribution of pellets by length.

MATERIALS AND METHODS

The study was conducted using experimental and analytical methods

Experimental part

Industrial-made wood and straw pellets with nominal diameters of 6 mm and 8 mm were used to test the proposed methods for achieving this purpose. For the obtained pellets, the moisture content [25] and ash content [26] were determined by standard methods.

Substantiation of the method for determining the length of individual pellets. 4 sets of wood and straw pellets with diameters of 6 mm and 8 mm were prepared. Each set contained 12 undamaged pellets of regular shape (with a protrusion at one end and a depression at the other), ranging in length from minimum to maximum. The length of all pellets in each set was determined by three alternative methods.

The first measurement of the length of each pellet along its axis from the top of the protrusion to the end with the depression L was performed by the standard method (Fig. 1) [18] using a digital calliper with a division value of 0.01 mm. The second time, the length of each pellet was measured as the distance along the axis of the pellet from the top of the protrusion to the bottom of the depression L_1 (Fig. 2), i.e., measured the length of the pellet at which it is filled with fuel.

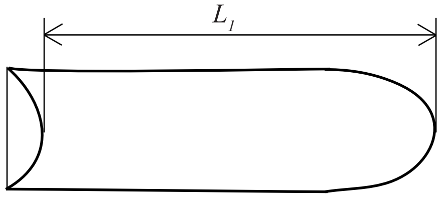

Figure 2. *Measuring the length of the pellet from the top of the protrusion to the bottom of the depression*

The third determination of the length is proposed to be conducted by an indirect method. Each pellet was weighed on a digital scale with a resolution of 0.01 g. The equivalent length Le of each pellet was calculated, that is, the length of a pellet in the form of a rectangular cylinder having a mass equal to the mass of a real pellet:

$$Le = \frac{4m}{(\rho\pi d^2)} \tag{1}$$

where: m – pellet weight, kg; d – average diameter of these pellets, m; ρ – average density of these pellets, kg/m^3.

The average diameter of pellets was determined by a method close to the standard [18]. Therewith, 20 pellets of the correct geometric shape were selected for measurements, that is, without cracks and other defects, the diameter was measured with a calliper with a division value of 0.05 mm, and the resulting average diameter value was rounded to 0.1 mm.

The density of pellets was determined by the stereometric method [27], with the difference that only long pellets of regular cylindrical shape without visible cracks were selected for measurements. At least 10 rectangular cylinders with a length of at least 20 mm were cut out of the selected pellets and their ends were ground. The length and diameter of the obtained cylindrical pellet sections were measured with a calliper with a division value of 0.05 mm and weighed on an analytical scale with an accuracy of 0.001 g. Based on these data, the density of individual pellets and the average density of pellets of the test sample were calculated. The maximum error in determining the average pellet density is estimated at ±7 kg/m^3. Next, the results of determining the length obtained by different methods were compared, and as shown below, the main method was accepted the calculation and experimental determination of the equivalent length of all pellets and their fragments present in the studied portions of wood and straw pellets.

To analyse the length distribution of pellets, a sample weighing about 1 kg was taken, and then a shortened test portion weighing at least 0.1 kg was separated from it, focusing on the fact that it contained at least 200 pellets. The content of the fine fraction was determined by sieving with 3.15 mm diameter round holes in accordance with the standard method [17]. All pellets and their fragments remaining on the sieve were weighed individually, and their equivalent lengths were calculated using equation (1).

Analytical part

The experiments resulted in numerical series of the determined mass of each pellet m_i and the corresponding calculated equivalent lengths Le_i for all n pellets and fragments in the studied portions. The data of individual definitions of equivalent pellet lengths of each portion were converted into ordered rows: $Le_1 \le Le_2 \le \cdots \le Le_{n-1} \le Le_n$. For the studied pellet portions, the following were determined by their equivalent lengths: the largest and smallest length, the arithmetic mean length, the standard deviation of lengths, the median and mode of lengths, the probability and mass fraction of pellets with a length of less than 3 mm, the probability and mass fraction of pellets with a length of less than 10 mm.

To describe the distribution of pellets by length, the possibility of applying various methods of cluster analysis [28] was considered and the modal method [29] was chosen. The modal method, which is based on the analysis of the probability density distribution, was developed [30; 31] and is widely used in pattern recognition and artificial intelligence systems. Regarding the cluster analysis of the distribution of pellets by length, it was proposed to find distribution of the probability density over intervals of equivalent length and, considering the achievable error in its determination, the width of the intervals was assumed $\Delta=1$ mm or more. The n pellets were distributed at j equal intervals of equivalent lengths. For the first interval: $0<Le_{j=1}\le\Delta$, for the second: $\Delta<Le_{j=2}\le 2\Delta$ etc. to cover the longest pellets present in a sample.

For each of the j intervals the number of pellets having an equivalent length within the interval n_j, the arithmetic mean equivalent length of the pellets of the interval $Le_{j,av}$, and the frequency as an estimate of the probability P_j of pellets in the interval were determined:

$$P_j = \frac{n_j}{n} \tag{2}$$

Next, the probability density of falling pellet lengths was determined by j intervals:

$$F_j = \frac{P_j}{\Delta} \tag{3}$$

Based on the obtained data, a graph of points $F_j=f(Le_{j,av})$ was constructed and connected by a smoothed line, which approximately depicts the probability density distribution function of the random length of pellets in the studied portion and in their general set.

To identify ranges with higher probability density, an additional line of average probability density F_{av} was built for the entire portion of pellets:

$$F_{av} = \frac{1}{(j \cdot \Delta)} \tag{4}$$

Considering the constructed graphs $F_j=f(Le_{j,av})$, local probability thickenings were noted, and the maximums of probability density were identified. Values of equivalent length of pellets corresponding to local maxima of probability density were taken as the centres of attraction of clusters, and each of the pellets was assigned to the cluster with the nearest centre of attraction, the number of pellets n_k in each K of the detected clusters was determined.

For each of the K clusters, there were determined the probability (frequency) of pellets entering the cluster:

$$P_k = \frac{n_k}{n} \tag{5}$$

and the arithmetic average of the pellet length of a given cluster $Le_{k,av}$, and the mass fraction of pellets in the cluster:

$$M_k = \frac{P_k \cdot Le_{k,av}}{\sum_{k=1}^{k=K}\left(P_k \cdot Le_{k,av}\right)} \tag{6}$$

Based on the results of cluster analysis, cluster histograms were constructed – histograms of the probability distribution P_k and mass fraction of pellets M_k by clusters with the calculated average pellets length $Le_{k,av.}$

RESULTS AND DISCUSSION

Characteristics of pellets

Table 1 shows the main characteristics of pellets with diameters of 6 and 8 mm – "white" pellets made of pure pine wood with cyphers WP6 and WP8, straw (made of wheat straw) – with cyphers SP6 and SP8, which were used to test approaches to determining the length of pellets and statistical characteristics of their distribution by length.

***Table 1**. Main characteristics of pellets*

Pellets	*DN*	*d*, mm	W_{ar}, %	A_d, %	ρ, kg/m³	*FP*, w-%
WP6	*D*06	6.0	4.5	0.5	1185	1.30
WP8	*D*08	8.2	6.9	0.6	1141	0.56
SP6	*D*06	6.0	9.2	10.1	1273	0.88
SP8	*D*08	8.0	10.4	7.2	1215	0.25

***Notes**: DN – pellets class by diameter; d – actual average pellet diameter; W_{ar} – a mass fraction of moisture; A_d – ash content on dry weight; ρ – average pellets density; FP – the content of fine particles less than 3.15 mm in size*

Results of choosing a method for determining the length of pellets

In Figure 3, for example, the results of determining the lengths of WP6 wood pellets of regular shape (with a protrusion and a depression) by three alternative methods are presented. For long pellets, the ratio $\frac{L}{L_1}$ was only 1.04, and for the shortest ones, it reached 1.6; which indicates a considerable influence of the depression size on the result of measuring the length of short pellets.

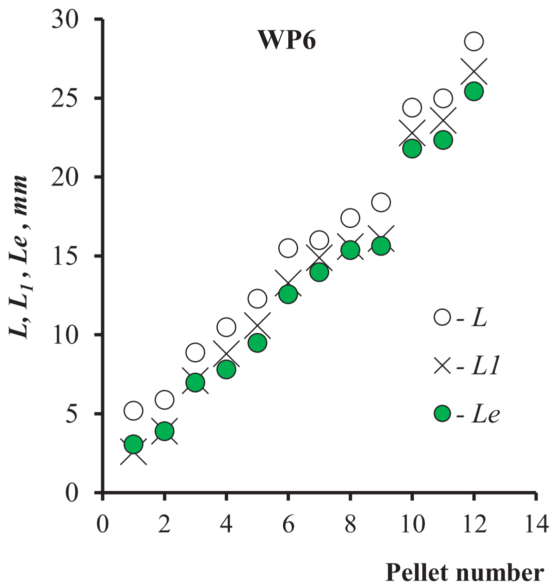

***Figure 3**. Measured L, L_1 and calculated Le lengths of WP6 wood pellets*

Length measurement results L and L_1 differed: at a diameter of *D*06 by an average of 1.8 mm for wood and 2.0 mm for straw pellets; and at a diameter of *D*08 of 2.9 mm for wood and 2.0 mm for straw pellets. Smaller values L_1 can be considered as an offset of the measurement result by excluding the axial size of the depression. Length measurement results L_1 and calculated equivalent lengths Le differed much less: with a diameter of *D*06 for wood pellets by an average of 0.7 mm and for straw pellets by 0.6 mm; with a diameter of *D*08 for wood pellets by 0.3 mm and for straw pellets by 0.2 mm. The difference between L_1 and Lewas less than the maximum possible error in determining the equivalent length. For all pairs definition L_1 and *Le*, the correlation coefficient was R^2=(0.993…0.999).

It can be concluded that for pellets of the correct shape (with a protrusion and a depression), the calculated equivalent length *Le* and the length, measured along the axis from the top of the protrusion to the bottom of the depression L_1 coincided or were close. This gives grounds to replace the direct measurements of the length of the pellets L_1 (from the top of the protrusion to the bottom of the depression) with weighing the pellets, followed by the calculation of the equivalent length Le depending on (1). For irregularly shaped pellets and fragments, only the equivalent length can be determined Le. In this regard, the calculation of the equivalent length via-weighing is proposed to be applied to all pellets and their fragments.

Characteristics of the granulometric composition of pellets

Table 2 shows the general characteristics of the granulometric composition of the studied pellets, which are obtained based on the results of calculation and experimental determination of equivalent lengths Le of all pellets and their fragments. Analysis of the dependence (1), considering the measurement errors of the values included in it, showed that for pellets with diameters of 6 mm and 8 mm weighing about 0.1 g, the maximum error in determining the equivalent length was up to 0.2 mm, and for pellets with a mass of 0.7 g up to 0.7 mm. In statistics, it is accepted that to analyse measurement results, their errors should not exceed 1/5 of the standard deviation of the results obtained. The described method was tested for pellets characterised by a standard deviation of equivalent length *STD Le* in the range from 3.9 mm to 6.2 mm (Table 2). The error in determining the equivalent pellet lengths in the described study met the requirements of the following statistical analysis of the distribution of pellets by length.

From Table 2 it can be seen that even after sieving with holes of 3.15 mm, there were short particles with an equivalent length of less than 1 mm in the superlattice part of the pellets. According to the standards [15; 16], their length would need to be taken as 3.15 mm, but this would lead to a considerable overestimation of the pellet lengths.

***Table 2**. General characteristics of the granulometric composition of the studied pellets*

Pellets	Le_{min}, mm	Le_{max}, mm	Le_{av}, mm	STDLe, mm	Mn, mm	Md, mm	PNL3, %	PWL3, w-%	PNL10, %	PWL10, w-%
WP6	0.9	30.7	10.1	6.2	8.4	5.4	9	2	56	31
WP8	0.8	24.0	6.6	4.8	5.6	0.8	28	7	80	56
SP6	0.3	24.2	6.4	3.9	4.5	4.4	15	4	83	65
SP8	0.3	24.1	4.2	4.0	3.1	0.3	49	14	91	70

***Notes**: Le_{min} – length of the shortest pellet; Le_{max} – length of the longest pellet; Le_{av} – arithmetic average length of pellets; STD – standard deviation; Mn – median pellets length; Md – pellets length mode; PNL3 – pellets fraction Le<3 mm; PNL10 – pellets fraction Le<10 mm; PWL3 – mass fraction of pellets Le<3 mm; PWL10 – mass fraction of pellets Le<10 mm*

In portions of pellets with a diameter of 6 mm, the content of particles with an equivalent length of less than 3 mm ranged from 9% to 15% in terms of their number, and in pellets with a diameter of 8 mm, their content was considerably higher – from 28% to 49%. The increased content of particles with an equivalent length of up to 3 mm was more typical for straw pellets. By weight, pellets with an equivalent length of less than 3 mm were (2 … 7) w-% in wood pellets, and their content in straw pellets SP8 reached 14 w-%.

In the studied pellets with a diameter of 6 mm, the content of particles with a length of less than 10 mm ranged from 56% to 83%, in pellets with a diameter of 8 mm, there were more of them – from 69% to 91%. The increased content of particles with an equivalent length of less than 10 mm in both quantity and mass fractions was more typical for straw pellets and reached 65 w-% for 6 mm pellets and 70 w-% for 8 mm pellets. For all the pellets studied, the mean, median, and mode of equivalent length differed in value, which indicates a deviation in the distribution of their lengths from normal, which is more noticeable for pellets with a diameter of 8 mm. The average equivalent length Le_{av} of wood pellets was larger than that of straw pellets.

Distribution of the probability density of pellets by lengths

Figure 4 shows the obtained graphs of the probability density distribution of pellets by lengths $F_j=f(Le_{j,av})$ and average equivalent pellet lengths $Le_{j,av}$ at length intervals Δ=1 mm; the graphs show several local maxima. The difference between the equivalent lengths of pellets corresponding to adjacent local probability maxima was (2 … 4) mm. This may indicate that during the production and transportation of pellets, breakage does not occur in arbitrary places along the length, but in certain places, possibly along the boundaries of the layers of compressed biomass particles formed in one pass of the pressure rollers on the press matrix.

A probability density greater than the average was observed in the following ranges of equivalent lengths: for WP6 wood pellets at Le=(1.5 … 16) mm, WP8 at Le= =(0.8 … 10.5) mm, for SP6 straw pellets at Le=(0.3 … 10.5) mm, SP8 at Le = =(0.3 … 7.5) mm. To summarise, for straw pellets, the probability density above the average was shifted to the zone of shorter pellets compared to wood pellets. Wood and straw pellets with a diameter of 8 mm are characterised by an increased probability shifting to the zone of shorter pellets compared to pellets with a diameter of 6 mm.

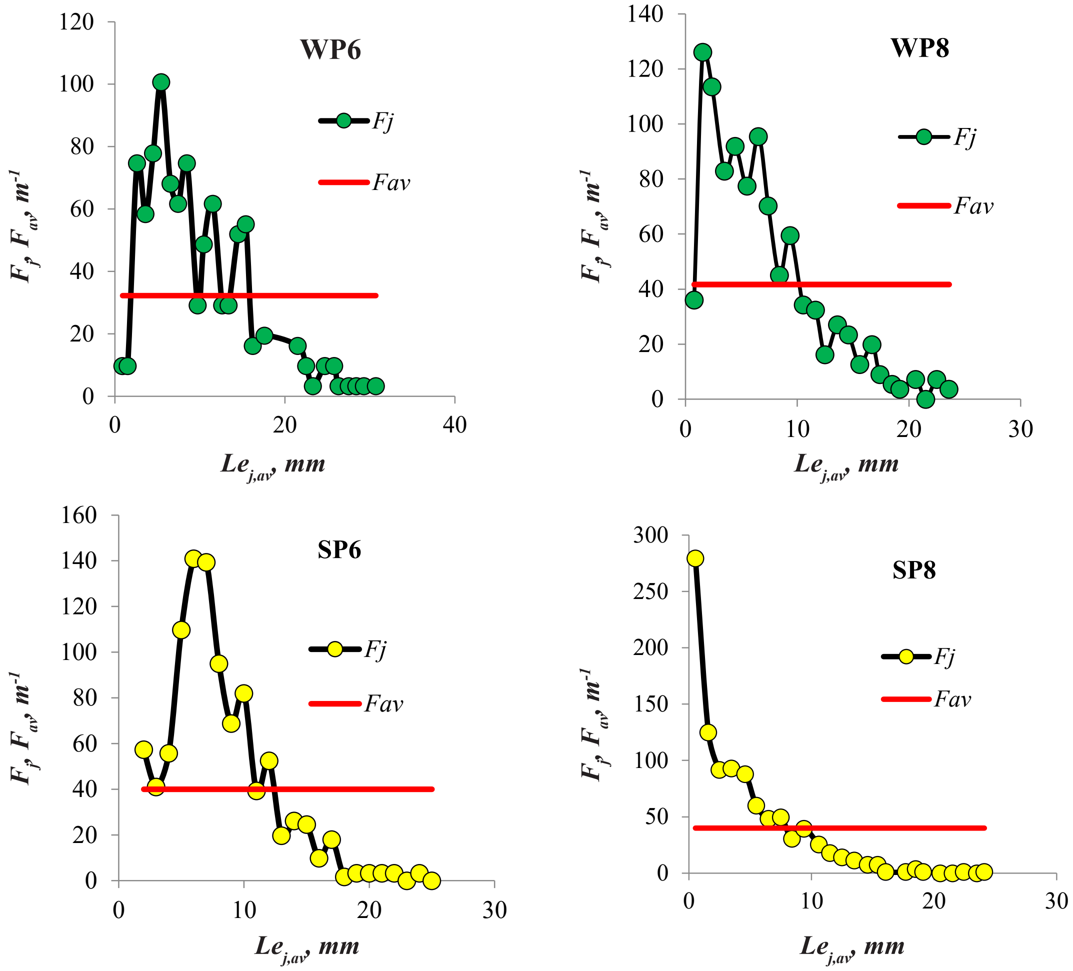

Figure 4. *Probability density F_j and the average equivalent length $Le_{j,av}$ of wood WP6, WP8 and straw SP6, SP8 pellets at intervals Δ=1 mm*

Figure 5, for example, shows graphs of the probability density distribution for WP6 wood pellets with increasing interval widths Δ from 2 to 15 mm. From the comparison of the data shown in Figure 4 and 5, it follows that as the interval width increased, the number of local maxima of probability density decreased: if at Δ=1 mm 8 local maxima were observed, then at Δ=2 mm there were 4 local maxima, and only one global maximum was shown on the graph for Δ=3 mm or more. As the width of the intervals Δ increased, the information about the content of pellets of short length and about the presence of local maxima of probability density was lost. In this regard, to apply the modal method of cluster analysis, it is necessary to determine the distribution of the probability density of pellets over lengths with an interval width of no more than 2 mm.

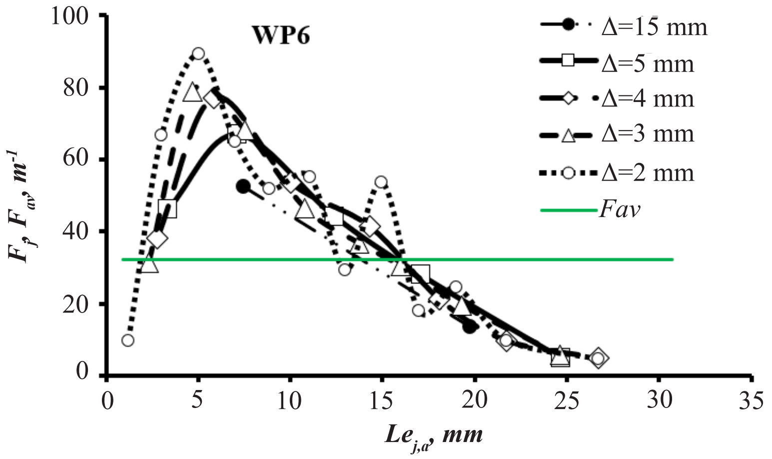

Figure 5. *Probability density distribution F_j of WP6 pellets at length intervals from Δ=2 mm to Δ=15 mm*

Distribution of pellets by clusters of their lengths

For each type of pellet according to the data in Figure 4, the presence of K=8 local probability density maxima were detected. For other pellets not described in this paper, 6 to 10 local probability density maxima were found. Figure 6 shows cluster histograms of the probability distribution P_k and the mass fraction of pellets M_k for K clusters with an average pellets length $Le_{k,av}$.

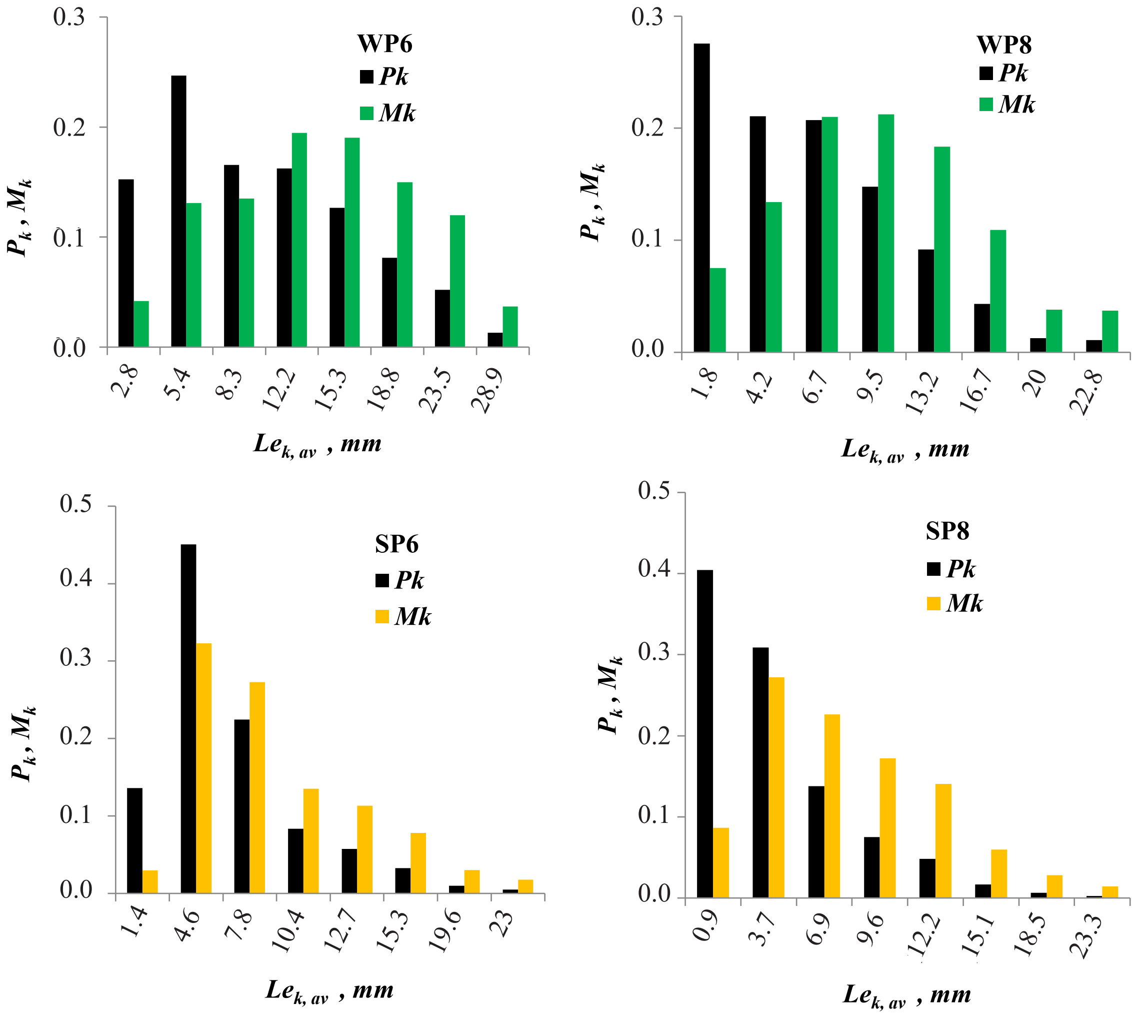

***Figure 6**. Probability distribution P_k, fractions by weight M_k and average length $Le_{k,av}$ of wood WP6, WP8 and straw SP6, SP8 pellets by clusters of lengths*

A common feature of wood and straw pellets with a diameter of 6 mm was the presence of clusters of short pellets with an average length of 2.8 mm and 1.4 mm with a probability (0.10...0.15), and for pellets with a diameter of 8 mm, the presence of clusters with an even smaller average length of pellets of 1.8 mm and 0.9 mm with a more considerable probability (0.28 ... 0.40). The detection of clusters with such short pellets was made possible by the experimentally – calculating determination of equivalent lengths for all particles in pellets, which was impossible when determining the pellet lengths using the standard method.

WP6 wood pellets had the highest mass content in clusters with an average length of 12.2 mm and 15.3 mm, and WP8 – in clusters with considerably shorter pellets of 6.7 mm and 9.5 mm. SP6 straw pellets had the highest mass content in clusters with an average length of 4.6 mm and 7.8 mm, and SP8 – in clusters with even shorter pellets of 3.7 mm and 6.9 mm.

CONCLUSIONS

The possibility of determining the equivalent length of pellets by an indirect experimental calculation method based on their individual weighing, identification of the average diameter and average density characteristic of the studied portion of pellets is substantiated. The method of indirect determination of the equivalent length of pellets is suitable for determining the length of all pellets, including irregular pellets and fragments. Replacing direct length measurement with pellet weighing reduces the impact of subjective factors.

The granulometric composition of pellets is proposed to be characterised by cluster histograms that reflect the distribution of probability, mass fraction, and average equivalent length across clusters. Cluster analysis is proposed to be conducted using the modal method, grouping pellets around objectively existing centres with an increased probability density, which can be identified on graphs of the probability density distribution at intervals of pellet lengths of no more than 2 mm. In the future, using the proposed approaches to determining the length of single pellets and cluster analysis of the distribution of pellets by length, the research can proceed to the formulation of a mathematical description of the burnout of polyfraction pellets. It is advisable to apply the proposed approaches to improve the standard for determining the length of pellets.

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Визначення довжини одиночних пелет та розподілу пелет за довжинами

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Анотація. Форма та розмір часток палива впливають на інтенсивність їх горіння та математичний опис процесу. Відомі методи не дозволяють коректно виміряти довжини всіх пелет в пробі та описати їх гранулометричний склад. Метою роботи було обґрунтування методу визначення довжини одиночних пелет і визначення статичних характеристик розподілу пелет за довжинами. Поставлена мета досягнута застосуванням запропонованого методу непрямого визначення довжини кожної пелети шляхом її зважування з наступним розрахунком еквівалентної довжини та модальним кластерним аналізом розподілу пелет за довжинами, що базується на розподілі густини ймовірності. Найбільш важливі результати полягають в тому, що експериментально-розрахункове визначення еквівалентної довжини дає результати, що збігаються з прямими вимірюваннями стосовно пелет правильної форми, але на відміну від прямих вимірювань також може застосовуватися для визначення еквівалентних довжин пелет неправильної форми та їх уламків. Кластеризація дозволила групувати пелети довкола об'єктивно існуючих локальних максимумів на розподілі густини ймовірності, які можна ідентифікувати при інтервалах довжин пелет не більше 2 мм. Значимість отриманих результатів полягає в тому, що непрямий метод визначення довжин пелет дозволяє замінити вимірювання довжин пелет їх зважуванням, що виключає суб'єктивні фактори при вимірюваннях довжин пелет неправильної форми та їх уламків. Кластеризація дозволила охарактеризувати гранулометричний склад пелет гістограмами розподілу ймовірності, масової частки та середньої довжини за кластерами. Із застосуванням запропонованих підходів визначено гранулометричний склад промислово вироблених деревних і солом'яних пелет та встановлено, що для пелет діаметром 8 мм характерна підвищена ймовірність у кластерах з меншими довжинами у порівнянні з пелетами діаметром 6 мм, для солом'яних пелет характерна вища ймовірність в кластерах з меншими довжинами у порівнянні з деревними пелетами

Ключові слова: пелети, вимірювання довжини, визначення довжини, розподіл густини ймовірності, кластерний аналіз, гістограма, гранулометричний склад