EXPERIMENTAL DETECTION OF THE PELLETS DRYING CHARACTERISTICS

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Abstract
The article is focused on the experimental detection of pellets drying characteristic. Experimentally were examined pellets made on pelletizing line MGL 200. The mass losses during the drying process were measured by Radwag MAC 210. Five pellet samples with different content of wheat straw and poppy capsules in initial material were investigated. The reference sample was pellet with natural moisture content and its characteristics were compared with pellets which have simulated moisture content. The measurements results were graphically processed and the time relations, regression equations for the mass loss were created. The results for mass losses of pellets with different moisture content were calculated and statistically processed. Presented drying curves declare nonlinear decreasing progresses. The biggest difference for drying curve shape was identified for samples with simulated moisture content, this sample has also the highest mass losses and finally, its structure was after drying process noncompact with visible destruction.

Key words: *simulated moisture content, mass losses, wheat straw, poppy capsules.*

INTRODUCTION

Green fuel sources have nowadays big attention (*Kažimírová, Kubik & Mihina, 2020; Nilsson, Bernesson & Hansson, 2010*). Nowadays, material of biological origin is largely processed into pellets, which have better physical properties and, above all, energy recovery in practice (*Pradhan, Arora & Mahajani, 2018*). Pellets are used for two primary sectors: industrial sector (substitute for coal in power plants), and residential sector for domestic heating. Usages of pellets have had significant growth in the past decade (*Pradhan et al., 2019*). Pellets have many advantages from the physical properties point of view, for example high bulk density, low moisture content and the high stability of energetic parameters (*Caroll & Finnan, 2012*). Next advantage is transport costs. Pellets have less volume to handle and facilitate less storage and transportation due to its high energy content than straw, chips etc. than other raw biomass (*Zamorano et al., 2011*). From the practical point of view is very important to know the influence of moisture changes on bio-based materials, especially on energetically usable products made from agricultural and food waste (*Vladut et al., 2010*). The way of processing, storage and pellets energetic characteristics is significantly affected by the moisture content of input material, this fact was presented by *Castellano et al., (2015); Ishii, & Furuichi, (2014)*. The moisture content is in relationship with pellet durability, which was discussed in detail by authors *Whittaker & Shield (2017)*. High moisture content of pellets has negative effect on the pellets performance by reducing the net energy output during combustion and generating high emissions of air pollutants (*Serrano et al., 2011; Unpinit et al., 2015*). The optimum moisture content of input material is important for palletization (*Golinski & Foltynowicz, 2012*). Storage conditions are affected and have effect on the material moisture content changes (*Graham et al., 2017*). Usage of non-adequate storage conditions leads to increase in the moisture content of the pellets and eventually deteriorating the physico-chemical properties of the pellets (*Bennamoun, Simo-Tagne, & Ndukwu, 2020*). For determining the ideal storage conditions, it is important to know the moisture adsorption behaviour of the pellets during storage at different conditions (*Lee et al., 2021*). Based on the presented facts from literature the next important aim of this research is determination of the original wheat and poppy capsules pellet's moisture content influence on its structure and drying characteristics. The originality of the research is declared by using of non-standard material to produce pellets. Pellets made from poppy capsules are one of the possibilities of energy recovery of agricultural waste.

MATERIALS AND METHODS

Measured samples were made from the agricultural waste, especially wheat straw and poppy capsules. The 1st sample was made from 100% wheat straw with moisture content 10.2% and the 5th sample was processed from poppy capsules with moisture content 12.8%. Next three samples (marked as Sample 2 – 4) had different fraction of poppy capsules and wheat straw in the input material (e.g., 25% poppy capsules and 75% wheat straw, 50% poppy capsules and 50% wheat straw, 75% poppy capsules and 25% wheat straw). The agricultural waste was mixed and then it was processed to the pellets by pelleting device MGL 200 (Kovo Novák Znojmo, Czech Republic). The final pellets had the moisture content in range (3.97 – 5.95) %. Before the experimental examination they were stabilized in the laboratory settings with the ambient temperature 21 °C and the relative air humidity 50%. The mass of the pellets was determined using laboratory scales Libra Axis AG100C (Libra Ltd., Podunajské Biskupice, Slovakia) with accuracy 1 mg. The moisture content of samples was identified by gravimetric method. The samples were dried by laboratory dryer at the temperature (103 ± 2) °C and then the relative moisture content was calculated from Eq. (1)

$$MC = \frac{m_{\omega} - m_0}{m_{\omega}} \cdot 100 = \frac{m_w}{m_{\omega}} \cdot 100 \qquad (1)$$

where: m_{ω} – is mass of the wet sample, m_0 – is the mass of dry sample and m_w– is the mass of water. The samples of pellets were before experimental identification of the dried curves exposed to humid environments for 5 days in laboratory settings. The moisturizing of pellets was used for the simulation of increasing ambient humidity. The humid weather can cause the destruction of the pellets compact structure during the storage.

The pellets were moistened by spontaneous evaporation of water in an enclosed space. Distilled water was used as the humidifying liquid. The pellets were not in direct contact with the liquid. (Fig. 1A). The drying curves were experimentally detected by the moisture analyser Radwag MAC 210 (Fig. 1B) (Radwag Ltd., Radom, Poland). The temperature during continuous drying process was 150 °C ± 2 °C. The samples were measured until their mass changed by 1 milligram over 240 seconds. Then the moisture analyser automatically stopped the drying process. The final drying product can be considered as the dry matter of the pellets sample. The accuracy of mass measurement by MAC 200 was 1 mg. Experimentally were obtained parameters as: diameter of pellets, length of pellets, initial mass, final mass and the mass changes during the drying process, time, total time duration of the drying process. Calculated were parameters as: relative moisture content, the standard deviation, the probable error of arithmetic average in %, average mass loss per minute and the difference of relative moisture content of pellets. Experimental data were numerically processed and statistically evaluated by program Statistica® (TIBCO Software Inc., California, USA).

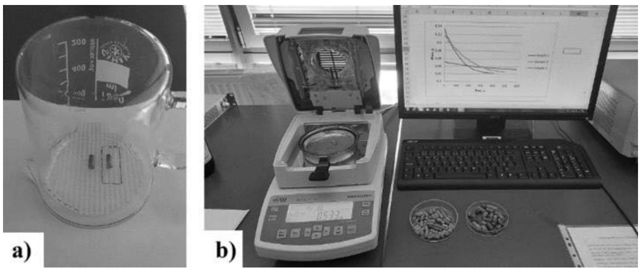

Fig. 1 a) Moistening of pellets samples, b) Detection of drying curves by moisture analyser MAC 210

RESULTS AND DISCUSSION

At the first were measured diameters of pellet samples, the length of pellets was in range (7.88 – 23.04) mm. The initial mass of samples was minimal 0.452 g for straw pellets with natural moisture content 6.4% and the maximal initial mass 0.698 had samples made from the poppy capsules with moisture content 5.014%. From initial and final mass of pellets were calculated total mass losses (Tab. 1). The other experimentally detected characteristics of pellet samples with different fraction of poppy capsules and wheat straw in the input material are summarised in the Tab. 1. From presented numerical values is clear that minimal experimentally detected mass loss was 0.029 g for wheat pellet and the maximal mass loss was obtained for pellet made from poppy capsules. The drying process for pellet sample made from 100% wheat straw – 1b (sample with natural moisture content and then moistened) taken longer time 398 s than the same process for sample 1a. This sample was completely dried with moisture analyser and then were selected samples laboratory moistened. The drying time depended on the type of sample. For pellets samples with natural moisture was the drying time 583 s (pellets from wheat straw), (627 – 715) s for the mix (wheat straw and poppy capsules) and 743 s for pellets made only from poppy capsules. For simulated moisture content, drying times of 399 s (pellets from 100% wheat straw), (421 - 486) s (mix) and 508 s (pellets from 100% poppy capsules) were achieved.

Tab. 1 Experimental results for pellet samples with the different content ratio of wheat straw and the poppy capsules in the input material

Pellet composition		Initial mass g			Final mass g			Total mass loss g			Initial relative moisture content of sample %		
Wheat straw	Poopy capsules										Natural MC	Simulated MC	
100%	0%	1	1a	1b	1	1a	1b	1	1a	1b	1	1a	1b
		0.452	0.532	0.517	0.423	0,423	0.426	0.029	0.109	0.091	6.416	20.489	17.602
75%	25%	2	2a	2b	2	2a	2b	2	2a	2b	2	2a	2b
		0.552	0.547	0.524	0.519	0.439	0.436	0.033	0.108	0.088	5.978	19.744	16.794
50%	50%	3	3a	3b	3	3a	3b	3	3a	3b	3	3a	3b
		0.601	0.596	0.573	0.567	0.483	0.481	0.034	0.113	0.092	5.657	18.961	16.056
25%	75%	4	4a	4b	4	4a	4b	4	4a	4b	4	4a	4b
		0.654	0.641	0.639	0.619	0.532	0.541	0.035	0.109	0.099	5.352	17.005	15.493
0%	100%	5	5a	5b	5	5a	5b	5	5a	5b	5	5a	5b
		0.698	0.683	0.668	0.663	0.569	0.568	0.035	0.114	0.100	5.014	16.569	14.971

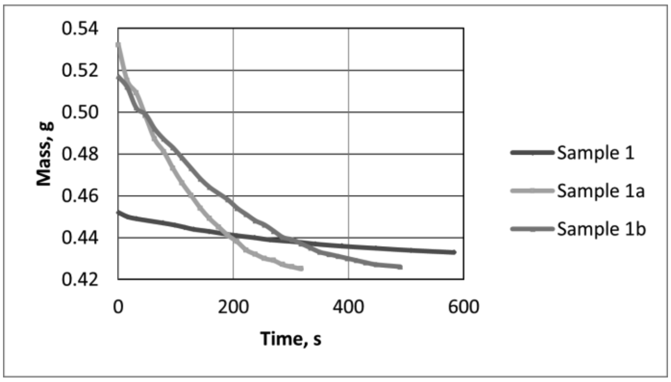

Fig. 2 Pellets drying curves: 1 – sample with natural moisture content, 1a – sample completely dried with moisture analyser before the moistened, 1b – pellet with natural moisture content and then moistened

From Fig.2 is evident, that the mass losses of the straw pellet sample 1b was more moderate during the drying process. The drying curves had nonlinear shape, which can be described by polynomial function of the second degree – Eq. (2), but the regression coefficient of quadratic term is too small. The regression coefficients for all measured pellet samples are presented on Tab. 2. The coefficients of determination for all detected graphical dependencies were in range (0.9662 – 0.9987).

$$m = A\,t^2 - Bt + C \qquad (2)$$

Measurement results for pellets drying curves agree with facts described in drying theory (*Selivanovs et al., 2012; Li et al., 2011*) and experimental results for bio-based materials presented by *Lambert et al.,* *(2018); Gebreegziabher, Oyedun & Hui (2013)*. In general, second and higher order polynomial functions are presented in the literature (*Azaka, Enibe & Achebe, 2019*) for the description of drying curves. From the mathematical description point of view and the influence of the individual regression coefficients on the shape of the displayed model dependence, the polynomial function of the second degree, which is also presented by the authors *Wang et al., (2012)* in their works, can be considered optimal.

Tab. 2 Coefficients of regression equation for drying curves of pellets

Pellet composition		Sample with natural MC			Sample with simulated MC Type of pellet a			Sample with simulated MC Type of pellet b		
Wheat straw	Poopy capsules	A $g \cdot s^{-2}$	B $g \cdot s^{-1}$	C g	A $g \cdot s^{-2}$	B $g \cdot s^{-1}$	C g	A $g \cdot s^{-2}$	B $g \cdot s^{-1}$	C g
100%	0%	$5 \cdot 10^{-8}$	$6 \cdot 10^{-5}$	0.4511	$1 \cdot 10^{-6}$	0.0006	0.526	$4 \cdot 10^{-7}$	0.0004	0.5155
75%	25%	$6.1 \cdot 10,^{-8}$	$7.31 \cdot 10^{-5}$	0.5503	$1.02 \cdot 10^{-6}$	0.00061	0.537	$4 \cdot 10^{-7}$	0.0004	0.5206
50%	50%	$6.65 \cdot 10^{-8}$	$7.98 \cdot 10^{-5}$	0.5998	$1.12 \cdot 10^{-6}$	0.000672	0.589	$4.4 \cdot 10^{-7}$	0.00044	0.5722
25%	75%	$7.2 \cdot 10^{-8}$	$8.64 \cdot 10^{-5}$	0.6494	$1.21 \cdot 10^{-6}$	0.00072	0.6312	$4.94 \cdot 10^{-7}$	0.000492	0.6371
0%	100%	$7.7 \cdot 10^{-8}$	$9.24 \cdot 10^{-5}$	0.6931	$1.28 \cdot 10^{-6}$	0.000768	0.673	$5.16 \cdot 10^{-7}$	0.00051	0.666

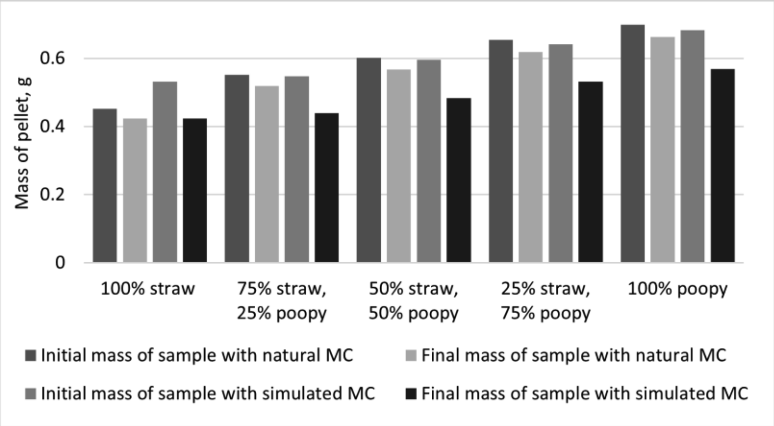

Fig. 3 Comparison of pellet´s initial and final mass for samples with natural and simulated MC

The similar graphical relations of the drying curves were obtained for pellet samples made from combination of initial material (wheat straw and poppy capsules), but the individual values differed. Based on presented facts were calculated the average differences between the mass values detected for points on the experimental curve. The differences were calculated with respect to the values obtained for sample of pellets made from 100% wheat straw.

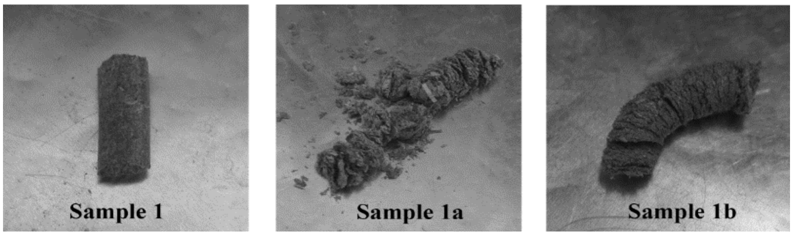

Fig. 4 Pellets samples after the drying process: 1 – sample with natural moisture content, 1a – sample dried with completely moisture analyser before the moistened, 1b – pellet with natural moisture content and then moistened

The graphical comparison of the initial and the final mass for selected pellets with poppy capsules content ratio are shown on the Fig. 3. From Fig. 3 is evident, that the pellets mass increases with increased percentage ratio of poppy capsules content. This fact was confirmed by repeating a series of 10 measurements for each pellet sample. The results were statistically processed by program Statistica®. The standard deviations were from ±0,00055 g to ±0,0034 g and the probable errors of arithmetic average were in range (0.693 – 2.184)%.
Furthermore, the constancy of the pellet samples compactness was monitored after processes that simulated the change in the moisture. As shown in Figure 4, sample 1a (dried to dryness and then moistened) disintegrated. Sample 1b, which originally had natural moisture content and was subsequently subjected to a simulated increase in moisture, did not disintegrate. Despite the relative preservation of the pellet compactness, changes in its structure are evident from Figure 4 – 1a. It follows from the mentioned facts that due to the repeated application of thermal processes (or changes in temperature), which result in repeated changes in moisture content, a permanent change in the pellet structure may occur. The presented results correspond to the results presented in the literature (*Graham et al., 2017; Cutz et al., 2021*), who also observed changes in the compactness of the pellet structure because of heat-moisture stress.

CONCLUSIONS

The research benefit was the identification of the moisture changes on the mass characteristics of pellets made from a non-standard combination of input raw materials, namely wheat straw and poppy capsules. The results obtained for poppy capsules can be considered original and innovative, as they have not been presented so far. The main result of the work was finding out the drying curves of pellet samples made from combination of wheat straw and poppy capsules. Results pointed to the relevant influence of the input material composition to drying process. Drying process can be described by nonlinear drying curves. Graphical course of curves depends on the ratio of input material. Drying curves can be mathematically described by polynomial function of the second degree. Furthermore, the influence of the method of moistening on the input mass of the pellets and its dry matter was confirmed. In general, it was confirmed that the input mass of the pellets increases with the increasing proportion of poppy capsules in the input raw material. On the contrary, the mass losses decrease with the increasing content of poppy capsules in the pellet. The presented differences are influenced by the chemical and physical properties of poppy capsules, which differ significantly from the composition of wheat straw. Research results confirmed, that both materials are well usable for the production of pellets. However, optimal moisture and temperature conditions must be ensured during the processing, handling and storage of the material. This fact was confirmed by observing visible structural changes after repeated simulation of moisture changes. The results of the research can be used in the optimization of the conditions of storage and handling of the pellets, to ensure its required quality.

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