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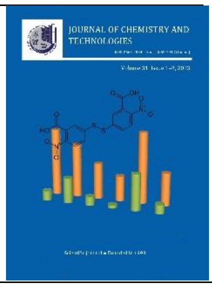

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USING OF BARLEY BRAN IN THE PRODUCTION OF ALTERNATIVE SOLID FUEL FROM COFFEE PRODUCTION WASTE

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Abstract

The article describes the results of experimental studies on the production of alternative solid fuels from coffee production waste – coffee production waste and barley bran. Briquetted samples of solid fuels with 0 : 100, 25 : 75, 50 : 50 and 75 : 25 % wt. of coffee production waste and barley bran, respectively, were made. The influence of the content of the initial components on the main parameters of the created solid fuel briquettes was researched. It was determined that the higher calorific value of the obtained samples is in the range of ~17329÷22147 kJ/kg, and their ash content is 0.6÷2.45 % by weight. It is shown that with an increase in the content of coffee production waste in solid fuel samples, the calorific value increases and at the same time the ash content of the samples decreases. The creation of composite solid fuel briquettes makes it possible to use coffee production waste more rationally and regulate the main indicators of solid fuel to meet existing standards by means of the content of the components of the initial mixture.

Keywords: biomass, coffee production waste, spent coffee grounds, barley bran, secondary raw materials, solid fuel, briquettes.

ВИКОРИСТАННЯ ЯЧМІННИХ ВИСІВОК У СТВОРЕННІ АЛЬТЕРНАТИВНОГО ТВЕРДОГО ПАЛИВА З ВІДХОДІВ КАВОВОГО ВИРОБНИЦТВА

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Анотація

Стаття містить результати експериментальних досліджень виготовлення альтернативного твердого палива з відходів виробництва кави – кавового шламу та висівок зерен ячменю. Створено брикетовані взірці твердого палива у складі 0 : 100, 25 : 75, 50 : 50, 75 : 25 % мас. кавового шламу та ячмінних висівок відповідно. Досліджено вплив вмісту вихідних компонентів на основні параметри створених твердопаливних брикет. Визначено, що вища теплотворна здатність отриманих взірців знаходиться в межах ~17329÷22147 кДж/кг, а їх зольність – 0.6÷2.45 % мас. Показано, що із збільшенням вмісту кавового шламу у твердопаливних взірцях відбувається підвищення показників теплотворної здатності та водночас знижується зольність взірців. Створення композиційних твердопаливних брикетів дозволяє більш раціонально використовувати відходи кавового виробництва та регулювати за допомогою вмісту компонентів вихідної суміші основні показники твердого палива для відповідності до існуючих стандартів.

Ключові слова: біомаса, відходи кавових виробництв, кавовий шлам, ячмінні висівки, вторинна рослинна сировина, тверде паливо, брикети.

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Introduction

Rational environmental management requires the reuse of industrial waste of plant origin [1], which accumulates in large quantities at food processing factories. Such waste includes alcohol distillery stillage [2], brewer's spent grain [3], coffee production waste [4], and others. Large volumes of secondary raw materials of plant origin cannot be reused due to their high residual moisture content (≥ 60 % wt.) [5], which leads to rapid product spoilage and makes it impossible to store and use them for a long time. Therefore, there is a need for a step of partial or complete drying [6–9].

One of the newest methods of reusing secondary biomass from food production is the creation of alternative solid fuels [10; 11]. The obtained samples are characterized by a higher calorific value compared to common plant analogs used for this purpose, such as miscanthus, energy willow, switchgrass [12] or crop waste (corn, sunflower) [13].

A previous paper [4] researched the process of solid fuel formation using coffee production waste, which is a mixture of spent coffee grounds, barley, and chicory waste obtained on the production line of JV "Galka LTD" (Lviv, Ukraine).

Another waste product of this production line is barley bran. This product can be reused in small quantities as a food ingredient in bakery products such as cookies, cakes and snack foods [14–17]. Also, β-glucan can be obtained from barley bran by extraction process [18–21]. The above-mentioned ways of the possible use of barley bran require small amounts of it, which leads to the accumulation of large volumes of this plant waste.

Since there is information on the formation of solid fuels from spent coffee grounds with the addition of other organic materials [22; 23], it was advisable to investigate the possibility of creating an alternative solid fuel from barley bran and its mixture with coffee production waste and determining the main parameters of the resulting solid fuel.

Experimental part

The research was carried out using coffee production waste, which was a mixture of spent coffee grounds, barley, and chicory waste [4], previously dried in a laboratory experimental installation [24] by filtration drying, obtained on the production line of "Galka LTD" (Lviv, Ukraine).

The barley bran did not require preliminary drying.

The influence of barley bran content on the calorific value of the formed solid fuel samples were studied, for which the initial mixture of different percentage composition was used. The initial mixtures contained 0 : 100, 25 : 75, 50 : 50 and 75 : 25 % wt. of coffee production waste and barley bran, respectively.

The experimental mixtures of plant materials were pressed on a P474A press at an operating temperature of 150 °C, a pressure of 100 kgf/cm^2, and a duration of 60 s. As a result, samples of alternative solid fuel were obtained, which were analyzed for the highest calorific value by the combustion calorimetry method, as well as for ash content and moisture content in accordance with the methods of the State Standards of Ukraine [2].

Results and their discussion

Experimental mixtures for the formation of solid fuel samples were prepared from dried coffee production waste with a moisture content of ~5.52 % wt. and barley bran (Fig. 1) with a moisture content of ~6.8 % wt.

The initial raw materials and the obtained solid fuel samples were studied by the calorimetric combustion method to determine their main parameters – calorific value, ash content, and moisture content. Taking into account the heterogeneity of the secondary raw materials of plant origin, both individual and briquette mixtures, three parallel experiments were conducted to determine the average value of the research object parameters.

A previous study of unformed raw material (Fig. 1) showed the prospects for further research (Table 1).

Table 1

The higher calorific value and ash content of the individual components of the mixture

	Calorific value, kJ/kg	Ash content, % wt.
Dried coffee production waste	≈ 21583	< 1
Barley bran	≈ 16587	1.5÷2.1

Table 1 shows the higher calorific value and ash content of individual components of the mixture in the unformed state [4].

Fig. 1. Barley bran.

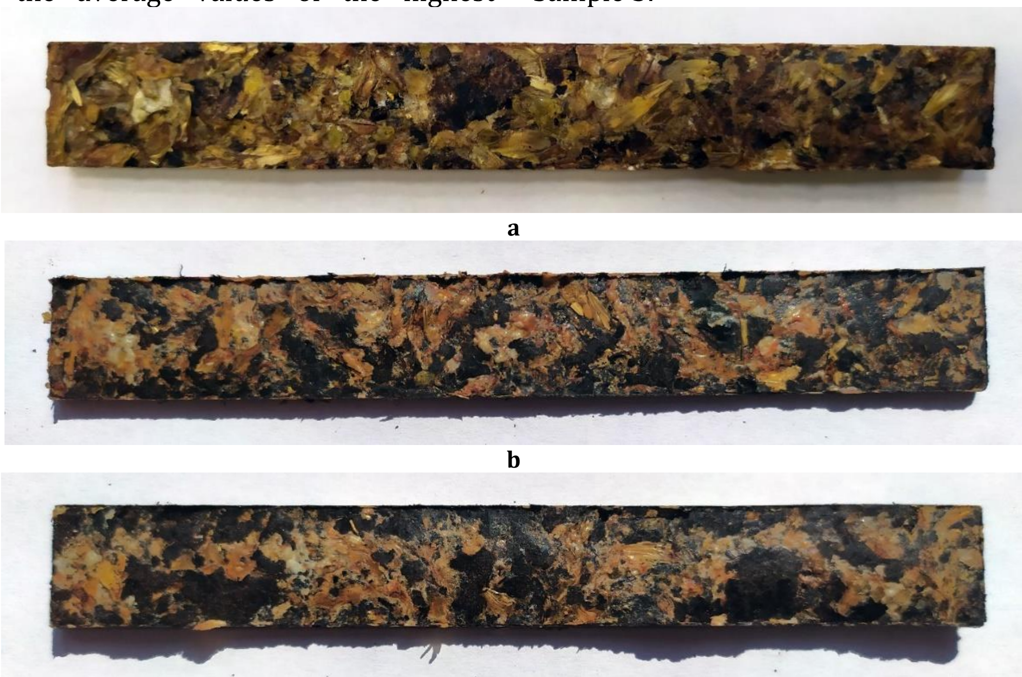
The obtained experimental higher calorific values of the research objects and analogs are given in Table 2 [2–4; 25].

Table 2

The higher calorific value of the research materials and their analogs

Raw materials of plant origin	Dried coffee production waste	Dried brewer's spent grain	Dried corn alcohol distillery stillage	Energy willow	Miscanthus	Barley bran
Calorific value, kJ/kg	≈ 21583	≈ 20005	≈ 19545	≈ 17600	≈ 17500	≈ 16587

The experimental mixtures of plant materials containing 0 : 100, 25 : 75, 50 : 50 and 75 : 25 % wt. (Samples 1–4, Fig. 2) of coffee production waste and barley bran, respectively, were pressed according to the parameters specified in the previous chapter, and briquette solid fuel samples were obtained. As in the case of unformed materials, the average values of the highest calorific value were determined and given in Table 3, along with the related values of calorimetric combustion [2]. The parameters of briquette coffee production waste (100 : 0 % wt. of coffee production waste and barley bran, respectively) were studied in previous work [4] and are presented for comparison in Table 3 as Sample 5.



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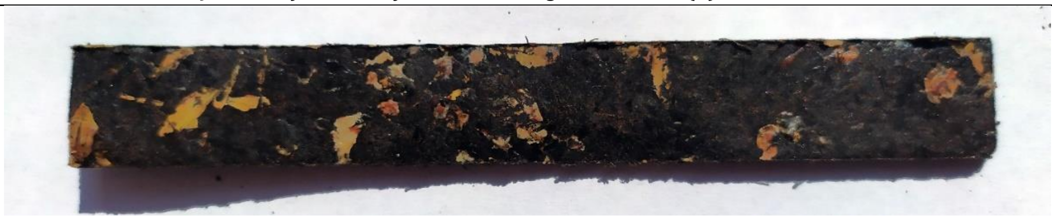

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Fig. 2. Briquetted solid fuel samples with different ratios of coffee production waste to barley bran, % wt.: a) 0:100 (Sample 1); b) 25:75 (Sample 2); c) 50:50 (Sample 3); d) 75:25 (Sample 4).

Table 3

Results of experimental determination of the highest calorific value based on combustion calorimetry of solid fuel briquettes from a mixture of coffee production waste and barley bran

Test No.	m, g	ΔT, V	$q_{ampoule}$, J	q_{thread}, J	q_{HNO3}, J	q_{soot}, J	Q, kJ/kg	Q, kcal/kg
Sample 1 (0:100 % wt.)								
1	1.30687	2.17990	-	75.7	29.5	187.0	17323	4141
2	1.23544	2.06273	-	83.0	23.6	134.5	17300	4135
3	1.09276	1.83106	-	70.2	29.5	126.3	17364	4151
					The average value:		17329	4142
Sample 2 (25:75 % wt.)								
1	0.82763	1.51861	-	77.2	13.0	88.6	18985	4537
2	0.83447	1.52436	-	92.3	21.2	150.9	18948	4529
3	0.75582	1.37629	-	81.5	13.6	146.0	18910	4520
					The average value:		18948	4529
Sample 3 (50:50 % wt.)								
1	1.26270	2.40992	-	75.7	22.4	88.6	19742	4718
2	1.17389	2.19702	-	78.6	30.1	403.4	19618	4689
3	1.24155	2.37583	-	79.3	26.6	83.6	19784	4728
					The average value:		19715	4712
Sample 4 (75:25 % wt.)								
1	1.24984	2.51940	-	87.6	16.5	116.4	20869	4988
2	1.04331	2.13867	-	86.0	21.2	170.6	21273	5084
3	1.30198	2.53209	-	92.1	23.6	137.8	20142	4814
					The average value:		20761	4962
Sample 5 (100:0 % wt.)								
1	1.24682	2.66923	-	79.3	24.5	97.6	22148	5294
2	1.56269	3.35161	-	89.6	23.6	65.1	22163	5297
3	1.30903	2.80358	-	86.9	18.6	64.8	22131	5289
					The average value:		22147	5293

Table 3 shows an increase in the higher calorific value of the obtained samples with an increase in the content of coffee production waste, which is absolutely fair due to its higher calorific value.

The obtained experimental values of calorimetric combustion are presented in the form of a graphical dependence of the influence of the mixture composition on the value of the higher calorific value and ash content of the obtained samples (Fig. 3). The results are presented for a two-component mixture whose composition varies along the abscissa axis (Fig. 3).

In Fig. 3, a clear dependence of the change in the average value of the higher calorific value of the formed solid fuel samples on the initial mixture composition is observed. The deviation of the experimental points from the averaging line (Fig. 3) is explained by the heterogeneity of biomass, both the individual components and their mixtures. Theoretically, by using the obtained dependence, it is possible to determine the optimal composition of the initial mixture to produce briquettes for which the calorific value will correspond to the standards for solid fuels [26]. The obtained experimental data are close to the Swedish standard SS 187120, according to which the main parameters of biofuels are within the following limits: calorific value (> 4039 kcal/kg), ash content (< 1.5 %), residual moisture (< 10 %) [27]. The indicators of the German standard DIN 51731 (calorific value (3705÷4661 kcal/kg), ash content (< 1.5 %), residual moisture (< 12 %)) can be reached by additionally adjusting the initial moisture content of the initial mixture, in accordance with the preliminary conclusions in work [3].

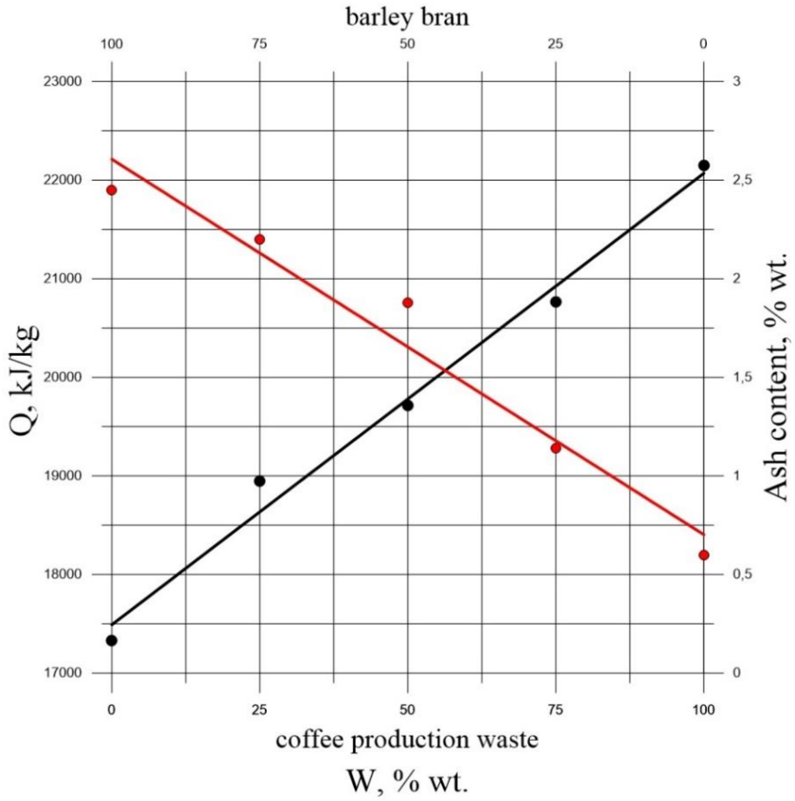

Fig. 3. Graphical dependence of the effect of the component mixture composition on the averaged values of the higher calorific value (– black line) and ash content (– red line) of solid fuel briquettes from coffee production waste and barley bran.

The results of determining the ash content of the obtained experimental solid fuel samples are given in Table 4 and compared with this value for the formed coffee production waste obtained in our previous work [4]. The residual moisture content for all samples is ≤ 1% wt.

Table 4

The average ash content of solid fuel samples obtained from a two-component mixture of coffee production waste and barley bran

Test samples of solid fuel	Ash content, % wt.
Sample 1 (0 : 100 % wt.)	≈ 2.45
Sample 2 (25 : 75 % wt.)	≈ 2.2
Sample 3 (50 : 50 % wt.)	≈ 1.88
Sample 4 (75 : 25 % wt.)	≈ 1.14
Sample 5 (100 : 0 % wt.)	≈ 0.6

The data show that with an increase in the content of coffee production waste in the test sample of solid fuel, its ash content decreases (Table 4, Fig. 3). However, it should be noted that the averaged values of several measurements are given, as in the case of higher calorific value studies. The ash content indicators are not stable, which is due to the heterogeneity of the composition of the initial biomass.

We will also note that, as in the case of alcohol distillery stillage [2] and brewer's spent grain [3], the nature of which is similar to the materials under studying, a great advantage of using these components for briquettes obtaining is that no additional binders are required, as is usually necessary for the solid fuel formation process [10; 28].

Conclusions

As a result of the experimental studies, briquette solid fuel samples were obtained in the composition of 0 : 100, 25 : 75, 50 : 50 and 75 : 25 % wt. of coffee production waste and barley bran, respectively. The influence of the initial component content on the main parameters of the produced solid fuel briquettes was studied. It was determined that the higher calorific value of the obtained samples is in the range of ~17329÷22147 kJ/kg, and this value for the initial components is ~21583 kJ/kg for coffee production waste and ~16587 kJ/kg for barley bran.

Thus, the creation of composite solid fuel briquettes makes it possible to use all the coffee production waste more rationally. Use of barley bran together with other coffee production waste in a two-component initial mixture to create an alternative solid fuel allows adjusting the values of the main parameters – higher calorific value, ash content and moisture content – to meet existing standards. It has been determined that with an increase in the content of coffee production waste in the initial mixture, there is an increase in the higher calorific value of the samples and, at the same time, a decrease in the ash content of the samples.

It is shown that the main parameters of the obtained solid fuel samples are close to the existing European standards. By changing the composition of the initial mixture components, it is possible to reach full correspondence in terms of the ash content of the samples; as for the calorific value, an additional way to adjust it is to change the moisture content of the mixture components.

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