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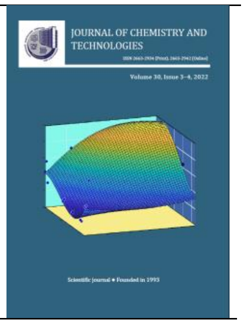

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USING COFFEE PRODUCTION WASTE AS A RAW MATERIAL FOR SOLID FUEL

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Abstract

The article describes the results of experimental studies of solid fuel production from coffee production waste, which by its nature is a mixture of coffee grounds, barley, and chicory. The formation of solid fuel briquetted samples was carried out by pressing under a pressure of 100 kgf/cm² for 60 seconds at different temperatures. The higher calorific value of the obtained solid fuel samples and dried initial mixture of spent coffee grounds was determined. The higher calorific value of the briquetted samples is in the range of ~22147÷23095 kJ/kg, and that of the dried initial spent coffee grounds mixture is ~21583 kJ/kg. The prospective use of the studied raw materials in comparison with existing analogues is shown. The use of a mixture of coffee production waste for the production of solid fuel will solve the problem of excessive production of industrial waste, rationalize their secondary use and avoid the negative impact of their accumulation on the environment.

Keywords: spent coffee grounds; barley; chicory; waste; secondary raw materials; solid fuel; briquettes.

ВИКОРИСТАННЯ ВІДХОДІВ ВИРОБНИЦТВА КАВИ ЯК СИРОВИНИ ДЛЯ ТВЕРДОГО ПАЛИВА

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Анотація

У роботі описані результати проведених експериментальних досліджень виготовлення твердого палива з відходів виробництва кави, що за своєю природою є сумішшю шламів кави, ячменю та цикорію. Формування взірців твердопаливних брикетів здійснювалося за допомогою пресування за тиску 100 кгс/см² протягом 60 с за різних температур. Визначено вищу теплотворну здатність отриманих взірців твердого палива та осушеної вихідної суміші кавового шламу. Вища теплотворна здатність брикетованих взірців знаходиться в межах ~22147 ÷ 23095 кДж/кг, а осушеної вихідної шламової суміші – ~21583 кДж/кг. Показано перспективність використання дослідженої сировини у порівнянні з існуючими аналогами. Використання суміші відходів виробництва кави для виготовлення твердого палива дозволить вирішити проблему надмірної кількості утворення даних промислових відходів, раціоналізувати їх вторинне використання та уникнути негативного впливу їх накопичення для довкілля.

Ключові слова: кавовий шлам, ячмінь, цикорій, відходи, вторинна рослинна сировина, тверде паливо, брикети.

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Introduction

Every year there is a steady increase in the demand for coffee all over the world – and Ukraine is no exception. Among European countries, one of the fastest growing rates of natural coffee bean consumption is observed in Ukraine. According to analytical data, more than 16 % new coffee shops were opened in 2019 in comparison to 2018 [1]. Also, despite the COVID-19 pandemic, there is a positive trend in the total number of coffee shops in 2020 compared to 2018.

Along with the increase in demand for coffee, the volume of coffee production and, accordingly, the share of generated industrial waste, namely spent coffee grounds, increases proportionally. On average, 1 ton of coffee product accounts for about 2 tons of coffee waste [2–4].

As of 2019, coffee consumption in Europe was about 34% of the world's, which is equal to 3356 thousand tons [1]. These data indicate that large volumes of spent coffee grounds are formed at productions throughout the world during the year.

Even though spent coffee grounds are a by-product of coffee production, this product has a valuable chemical composition. About 50.5 % of coffee grounds consist of polysaccharides in the form of cellulose (12.4 %) and hemicellulose (39.1 %). Coffee grounds also contain protein (17.44 %), fats (2.29 %), nitrogen (2.79 %), ash (1.3 %). It is also worth noting that this product contains a rather large amount of lignin – 23.9 % [5]. The lignin content of coffee grounds is higher than in other production lignocellulosic waste, such as alcohol distillery stillage, brewer's spent grain (16.0 %) [6] and sugarcane bagasse (18.93 %) [7].

Spent coffee grounds are a natural source of antioxidant insoluble fiber, contain essential amino acids, and are resistant to heat treatment, that's why it can be used in bakeries for making baked goods and cookies. The studied food products had high nutritional value and the potential to reduce chronic diseases, including obesity and diabetes [2].

Large volumes of spent coffee grounds formation allow it to be used for biofuel obtaining. Oil is obtained from this material by means of extraction [8], which is later converted into biodiesel [9; 10]. The oil-free residue is subjected to the fermentation process in order to produce bioethanol [11].

Although it is promising for practical use, spent coffee grounds are usually not processed, but simply disposed of. Waste from coffee production, as a rule, has excess moisture, which is the reason for its rapid deterioration. Among the most common disposal methods is the concentration of waste in landfills [12], or incineration [1]. These methods are inefficient, cause significant damage to the environment and worsen the overall ecological situation – the effect in the places of waste concentration is gradually accumulating all over the world.

Considering the high content of lignin in spent coffee grounds, it is possible to assert the possibility and perspective of using this secondary raw material for the production of alternative solid fuel. Solid fuel briquettes are widely used not only at industrial productions, but also for heating private households. The main advantage of solid fuel is a relatively low energy requirement for the preparation of raw materials and the formation of a solid form in comparison with the amount of energy released during combustion [13]. The use of secondary plant materials, namely industrial waste, has already been considered on the example of the use of alcohol distillery stillage [14] and brewer's spent grain [6]. The results of the research showed the effectiveness of the use of such raw materials for the production of solid fuel briquettes, and the calorific values of the obtained samples exceeded this value for plants that are currently widely used for the industrial production of solid fuels [6; 14]. Thus, the use of spent coffee grounds to produce solid fuels will significantly expand the existing areas of its rational secondary use.

Today, there are already known cases of using spent coffee grounds for the production of solid fuels. Thus, in [3], the authors study the production of pellets from a mixture of spent coffee grounds and pine sawdust, changing the ratio of components in the initial mixture for parallel experiments. In [15], the authors, in order to process spent coffee grounds, use its mixture together with previously crushed chopsticks and polypropylene spoons. In both cases, the results of the studies showed the feasibility of using spent coffee grounds for the production of biofuel pellets.

Experimental

Spent coffee grounds, which were a mixture of coffee, barley, and chicory waste, were used for the research. This composition of the mixture is determined by the technological features of the industrial production of coffee at the production line of JV "Galca LTD" (Lviv, Ukraine). The quantitative composition of waste varies depending on the current technological processes in production.

The preparation of the initial material consisted in drying it to the recommended values, taking into account the high moisture content [16–18]. Preliminary drying of raw materials was carried out on a laboratory installation for filtration drying [19], according to advantages of using this drying method [20].

The dried mixture of spent coffee grounds was subjected to hydraulic pressing on a P474A press to form samples of solid fuel briquettes. The test material was pressed under a pressure of 100 kgf/cm^2. At the same time, the duration of the process was 60 s at temperatures of 20 °C and 150 °C in the mold.

To analyze the obtained samples of solid fuel, as well as the original dried raw materials, the highest calorific value, moisture content and ash content were determined. The measurement of these three main indicators was carried out by the method of calorimetric combustion in accordance with the State Standards of Ukraine according to the methods described in [14].

Results and discussion

The sample of the test material, which is a mixture of spent coffee grounds, was previously subjected to drying, considering the high relative moisture content, which was ~65.24 % wt. As a result of drying, the initial plant material (Fig. 1) was obtained, which was used for the production of solid fuel briquettes.

The residual moisture content of the dried spent coffee grounds was determined – 5.52 % wt.

Fig. 1. Dried test sample of the original spent coffee grounds mixture.

Considering the heterogeneity of the composition of plant raw materials, we obtained the calorific value of the studied material by conducting 3 parallel experiments to determine the average value. As a result, the average higher calorific value of dried spent coffee grounds is ~21583 kJ/kg or ~5159 kcal/kg (Table 1). The ash content of the samples was up to 1% wt.

Table 1

The results of experimental determination of higher calorific value of dried spent coffee grounds according to the calorimetry of combustion

Test No.	Q	
	kJ/kg	kcal/kg
1	21433	5123
2	21613	5166
3	21704	5187
The average value:	21583	5159

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The obtained experimental data of the calorific value of spent coffee grounds are slightly higher than these values for alcohol distillery stillage and brewer's spent grain, which were previously studied [6]. In turn, this confirms the possibility and especially the effectiveness of using coffee grounds for the production of solid fuel. Comparative values of the calorific value of the studied materials are given in Table 2 [7], where the calorific values of energy willow and miscanthus, as the alternative plant materials widely used in industry for the production of solid fuel briquettes, are also presented [21].

Table 2

The higher calorific value of the studied dried plant materials and their widely used analogues

	Dried spent coffee grounds	Dried barley brewer's spent grain	Dried corn distillery stillage	Energy willow	Miscanthus
Q, kJ/kg	≈ 21583	≈ 20005	≈ 19545	≈ 17600	≈ 17500

Production of solid fuel samples was carried out on a P474A hydraulic press. Pressing of the dried spent coffee grounds was carried out under a pressure of 100 kgf/cm^2 for 60 seconds. The temperature in the mold was 150 °C, in view of the positive results of previous studies [6; 14]. However, in view of the high level of lignin in the raw material, it was decided to additionally conduct the formation of the test sample under normal conditions (20 °C), without changing the other parameters of the experiment.

As a result of the conducted research, experimental samples of solid fuel with strength and stable shape were obtained. The appearance of the obtained samples is shown in Fig. 2.

a

b

Fig. 2. Obtained test samples of solid fuel from dried spent coffee grounds after pressing at the following temperatures: a) 150 °C (Sample 1); b) 20 °C (Sample 2).

It is important to note that solid fuel was formed in the mold at a temperature of 20 °C, despite general recommendations regarding the required pressing temperature [22]. This fact shows the possibility of reducing the temperature of solid fuel formation, which in its turn significantly reduces potential energy costs in industrial scale production. In addition, in both cases no additional binders were used, which is also a positive feature of solid fuel production from spent coffee grounds.

As well as only dried spent coffee grounds, the solid fuel test samples obtained were subjected to complex studies to determine the calorific value. The obtained experimental data of the ash content of the samples were ~ 1 % wt. The residual moisture for Sample 1 (Fig. 2) was ~ 1 % wt. The higher calorific values of the studied samples are presented in Table 3.

The higher calorific value of the briquetted samples (Table 3) is slightly higher than of the unformed material (Table 1), which is generally quite logical considering the greater density of the briquettes and the lower moisture content. The experimental data confirm the previous conclusions [6] about the influence of moisture content on calorific value – with increasing in the amount of moisture in the initial material, the calorific value of the produced briquettes decreases.

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Table 3

The results of experimental determination of higher calorific value according to the calorimetry of combustion of solid fuel briquettes from spent coffee grounds

Test No.	Q	
	kJ/kg	kcal/kg
Sample 1 (150 °C, 60 s, 100 kgf/cm^2)		
1	22148	5294
2	22163	5297
3	22131	5289
The average value:	22147	5293
Sample 2 (20 °C, 60 s, 100 kgf/cm^2)		
1	23049	5509
2	23104	5522
3	23131	5528
The average value:	23095	5520

We also note that there is a difference in calorific value between two samples of solid fuel (Table 3), which were formed at different temperatures in a press mold. The difference between the values of the calorific value of the samples is about 1000 kJ/kg, which actually exceeds the effect of only the different residual moisture. This effect may be explained by the heterogeneity of the initial plant mixture and the presence of volatile organic compounds in the spent coffee grounds, which have a high calorific value and are released from the material at higher temperatures of pressing the test material.

The obtained experimental samples of solid fuel from dried spent coffee grounds were stored in the open air for several months to study the preservation of mechanical properties during storage. During this time, Sample 2, which was formed at a temperature of 20 ºC, experienced a partial loss of strength and integrity, which is undesirable for long-term storage. As for Sample 1, no visible changes were observed.

As in the case of solid fuel briquettes formed from alcohol distillery stillage [14] and brewer's spent grain [6], the formed samples have a slightly higher calorific value than provided in the European standard DIN 51731 (3705–4661 kcal/kg) [23]. However, this discrepancy theoretically may be adjusted by changing the pressing parameters and, as a result, the moisture content of the briquettes and their characteristics.

Considering the results of the conducted research, it can be argued about the advantages of using briquetted solid fuel from spent coffee grounds, which include higher calorific value and suitability of the finished product for long-term storage without changing mechanical properties. In the unformed dried mixture, the moisture content will be increasing over time, which will affect the calorific value and shelf life. However, it is important to research the energy costs of the solid fuel production process and make conclusions about the feasibility of using one or another of its forms.

Conclusions

Thus, the research results showed the possibility of using spent coffee grounds, which is a mixture of coffee waste, barley, and chicory, for the production of solid fuel. Due to the high moisture content, this material requires preliminary drying for long-term storage.

The results of the conducted research are samples of solid fuel made from a mixture of spent coffee grounds. The average higher calorific value of Sample 1 obtained at a temperature of 150℃ in the mold is ~22147 kJ/kg, of Sample 2 obtained at a temperature of 20 ℃ is ~23095 kJ/kg, and of the dried unformed spent coffee grounds is ~21583 kJ/kg.

The obtained experimental data indicate the promising and effective use of the spent coffee grounds mixture for the production of solid fuel. However, it is advisable to carry out in future studies the calculation of consumption coefficients and energy calculation of the production process of solid fuel briquettes. In addition, in order to reduce energy costs, it is important to research the effect of lower temperatures on the process of forming the solid form of the briquette without negative consequences on the mechanical properties of the object.

It should be noted that considering the possible quantitative variation of coffee, barley, and chicory in the industrial waste, it is necessary to research the samples taken at the production line at different times. Taking into account the obtained data, their calorific characteristics are predicted to remain high.

The production of solid fuel briquettes will allow expanding the scope of coffee production waste, and at the same time create an additional opportunity to replace traditional hard-to-renew fuel sources, such as coal and wood.

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