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RESEARCH OF SOLID FUEL BRIQUETTES OBTAINING FROM BREWER'S SPENT GRAIN

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Abstract

The article describes the experimental studies results of the use of barley brewer's spent grain (BSG) for the production of alternative solid fuels. A method of obtaining briquettes by pressing is described. The calorific values of the raw material and the obtained samples are defined. According to the research results, the highest calorific value of the dried brewer's spent grain is 20005 kJ/kg, and that of the created solid fuel samples – briquettes – is in the range from 20173 to 20298 kJ/kg. The residual moisture content of the dried brewer's spent grain was ~ 6.5 % wt., the ash content of the dried brewer's spent grain was in the range of 1.6 ÷ 2.3 % wt. The residual moisture content of the briquettes was in the range of 0.5 ÷ 1.5% wt., and the ash content was in the range of 1.5 ÷ 1.6 % wt. The obtained alternative solid fuel, which contains barley brewer's spent grain, has a high calorific value, does not contain harmful impuritiesor require additional cleaning or auxiliaries to form a solid form, provides additional disposal of industrial beer industry wastes, increases environmental friendliness by replacing traditional fuel resources with absence of large amounts of harmful emissions. Created samples do not require binders and pre-cleaning before production.

Keywords: brewer's spent grain; secondary raw materials; briquettes; solid fuel.

ДОСЛІДЖЕННЯ ВИГОТОВЛЕННЯ ТВЕРДОГО ПАЛИВА З ПИВНОЇ ДРОБИНИ

Олександр С. Іващук, Володимир М. Атаманюк, Роман А. Чижович, Софія С. Кіяєва, Василь П. Дулеба, Ірина Б. Собечко

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Анотація

У статті описано результати експериментальних досліджень використання ячмінної пивної дробини для виготовлення альтернативного твердого палива. Описано спосіб виготовлення брикетів методом пресування. Досліджено теплотворні характеристики як підготованої вихідної сировини, так і отриманих зразків. За результатами досліджень визначено, що значення вищої теплотворної здатності осушеної пивної дробини становить 20005 кДж/кг, а виготовлених брикет – зразків твердого палива – у діапазоні від 20173 до 20298 кДж/кг. Вміст залишкової вологи осушеної пивної дробини становила ~6.5 % мас., зольність пивної дробини становила в межах 1.6 ÷ 2.3% мас. Вміст залишкової вологи брикет становив в межах в межах 0.5 ÷ 1.5% мас., а зольність становила в межах 1.5 ÷ 1.6% мас. Отримане альтернативне тверде паливо, яке містить ячмінну пивну дробину, володіє високою теплотворною здатністю, не містить шкідливих домішок, не вимагає додаткового очищення, не вимагає допоміжних речовин для формування ствердлої форми, забезпечує додаткову можливість утилізації промислових відходів пивного виробництва, підвищує екологічність шляхом можливості заміни традиційних паливних ресурсів та відсутності великої кількості шкідливих викидів. Створені зразки не вимагають в'яжучих і попереднього очищення перед виготовленням.

Ключові слова: пивна дробина; вторинна рослинна сировина; тверде паливо, брикети.

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Introduction

Unfortunately, the environmental situation around the world is constantly becoming worse. The increasing needs of the growing human population cause a number of problems that need to be permanently solved: the shortage of natural resources, the high quantity of secondary raw materials and industrial wastes, increasing pollutant emissions into the environment etc.

One of the growing needs is the accumulation of huge amounts of secondary raw materials, which very often cannot be stored for a long time and, when it spoiled, become a factor in environmental pollution. One of such by-products is brewer's spent grain (BSG), which are formed during the filtration of beer wort from solid grain particles in the brewery. By its nature, BSG is a solid residue in the beer production process with a characteristic smell, which consists of husks of barley malt in combination with parts of the pericarp and layers of the seed coat of barley. The composition of this waste may vary, depending on the type of barley used, the method of its cultivation and other factors [1].

About 15–20 kgs of BSG are formed on industrial production for every 100 liters of beer [2; 3], which is almost 31% of the initial mass of malt [3]. The amount of BSG is about 85 % of all by-products of industrial production [4; 5]. BSG has a high moisture content (± 70 %) [6; 7], which leads to rapid spoilage of the product. The shelf life of raw material is about 2–3 days, which complicates further use and limits the area of BSG application. Given the above, long-term storage and transportation of BSG is extremely uneconomical.

The amount of BSG is growing constantly, as beer is considered the fifth most consumed beverage in the world. As of 2018, world beer production reached almost 182 million tons, while in Europe about 52 million tons were produced. It should be noted that the annual volume of BSG formed exceeds of 30 million tons [6]. At the same time, its production in Europe is about 3.4 million tons per year [8].

Even though BSG is a by-product, it is valuable for its chemical composition. This product contains the following components: protein (31 %), pentosans (19 %), lignin (16 %), starch and β-glucans (12 %), cellulose (9 %), lipids (9 %) and ash (4 %) [1]. Low cost, availability and valuable chemical composition allow the use of BSG as a feed additive to the diet of farm animals. It can be fed to cattle directly wet or after drying [3; 4].

Due to its high content of protein and fiber BSG can be added to human food [9; 10]. The raw products are dried, ground and sieved to form a powder. The resulting product has a high content of fiber and protein and reduces the caloric content of food. It is possible to replace flour with processed BSG by adding to bread [11], cookies [12] and other bakery products [3].

Studies have been carried out on the use of BSG for fertilization of agricultural land. The high protein content of this product provides the required amount of nitrogen in the soil, which is ideal for many crops such as beets, spinach, cabbage and onions. There is also a positive effect on the rate of plant germination when BSG is combined with compost [5].

One of the possible areas of BSG usage is also biogas production. As a result of anaerobic fermentation, a gas mixture consisting of methane 55–65 %, carbon dioxide 30–45 %, a small amount of hydrogen sulfide, and water vapor fraction is obtained [3; 4].

All mentioned application areas require partial or complete drying of BSG, which increases required time for storage, transportation, and its use as a secondary raw material [13].

Filtration drying is a promising and highly effective method of moister reducing in dispersed materials [14–17]. It is one of the intensive methods of drying dispersed materials, which allows to increase the intensity of drying, reduce the size and metal content of installations and improve the quality of test materials.

A promising possible way to use dried BSG is producing solid fuel briquettes, which would be used in industrial and domestic boilers in order to obtain a large amount of relatively cheap heat. It is known about the widespread use of secondary raw materials of plant origin such as sunflower stalks, energy willow, corn or miscanthus, as an alternative raw material for the production of solid fuels [18–20].

Previously, solid fuel briquettes were produced from corn alcohol distillery stillage, which is a by-product of ethyl alcohol production. The obtained samples were characterized by high calorific value (in the range from 22445 to 26594 kJ/kg) and low ash content (0.6 ÷ 1.6 %). Peculiarities of solid fuel production from by-products and recommendations on raw materials are described in the previous work [18].

The new area of BSG usage as a raw material for solid fuels can be an additional solution forthe problem of waste accumulation generated in industrial alcohol production. It will also reduce the negative impact on the environment by replacing the traditional slowly renewable resource (wood) and avoid the deforestation.

Experimental

The object of the research was barley BSG obtained on the production line of Kumpel brewery (Lviv, Ukraine). Drying of the experimental material was carried out by the energy saving method of filtration drying on a laboratory experimental installation. The method of experiments, measurements, as well as the scheme and operation principle of the laboratory installation are described in the previous work [13].

Three main indicators of the experimental material were determined by calorimetric combustion: moisture content, ash content and calorific value. All these measurements were done in accordance with the State Standards of Ukraine by the methods given in the previous work [18].

The formation of solid fuel briquettes from dried barley BSG was carried out with a P474A hydraulic press. Pressing of the experimental material was done at a pressure of 100 kgf/cm^2 for 60 s, 120 s and 180 s. The temperature in the mold was within 150 °C.

Results and discussion

The moisture content of the dried barley BSG (Fig. 1) used for solid fuel briquettes producing was ~ 6.5 % wt.

To determine the calorific value of the dried BSG, 3 parallel experiments were carried out according to the method [18]. As a result, we obtained theaverage value, that was 20005 kJ/kg or 4781 kcal/kg (Table 1).

Fig. 1. The dried barley brewer's spent grain

Table 1

The results of experimental determination of higher calorific value of dried brewer's spent grain according to the calorimetry of combustion

Test No.	m, g	ΔT, V	$q_{ampoule}$, J	q_{thread}, J	q_{HNO3}, J	q_{soot}, J	Q	
							kJ/kg	kcal/kg
1	0.36107	0.82688	1337.6	82.0	9.4	77.1	19953	4769
2	0.30740	0.71715	1324.2	86.9	9.1	70.5	19751	4720
3	0.36788	0.86662	1500.7	67.6	8.6	82.0	20313	4855
The average value:							20005	4781

The ash content of the obtained samples of dried BSG is in the range of 1.6 ÷ 2.3 % wt.

It should be noted that the calorific value of dried BSG is almost the same as for alcohol corn distillery stillage, which we studied earlier [18]. In addition, the obtained data exceed the data for plant analogs [21], which are widely used in the industrial production of solid fuel briquettes (Table 2).

Table 2

The calorific value of dried brewer's spent grain and widely used plants for solid fuel production

	Dried barley brewer's spent grain	Dried corn distillery stillage	Energy willow	Miscanthus
Calorific value, kJ/kg	≈ 20005	≈ 19545	≈ 17600	≈ 17500

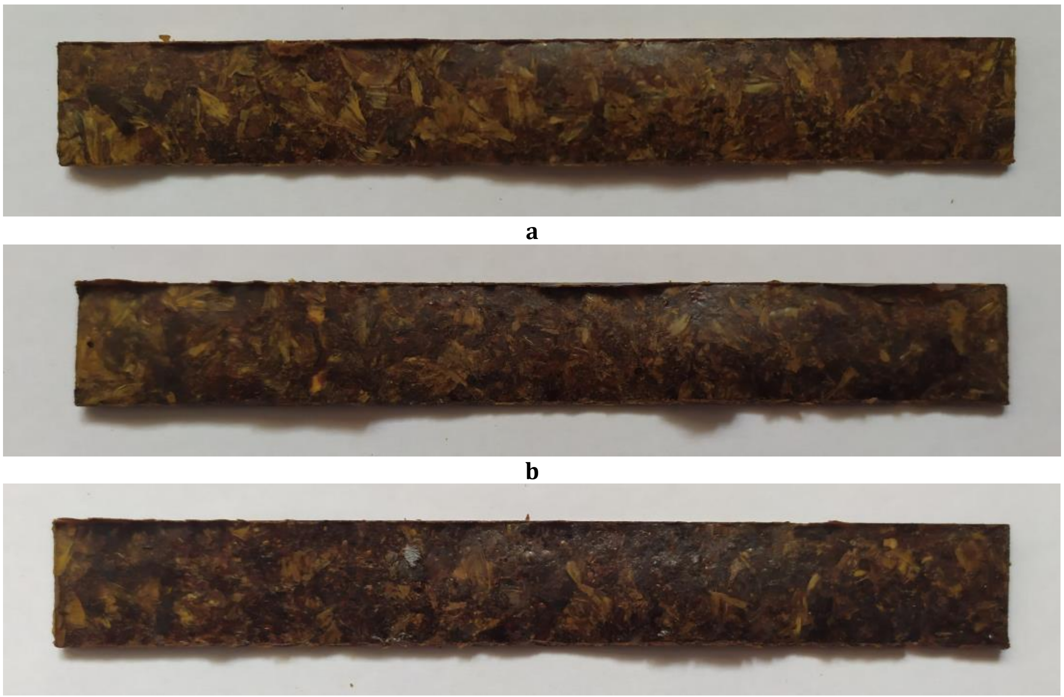
Slightly higher values of higher calorific value of dried BSG testified to the feasibility of further research of the material, namely the production of solid fuel briquettes.

The P474A hydraulic press was used to obtain briquetted solid fuel samples. The raw material was dried BSG with a moisture content of ~6.5% wt., which corresponds to the recommendations for the initial material [22; 23]. During the pressing, 3 samples of solid fuel briquettes were obtained. The difference between them was just in the formation time of the solid form, which was 60 s (Sample 1), 120 s (Sample 2) and 180 s (Sample 3). The temperature in the mold (150 °C) and the work pressure (100 kgf/cm^2) were without changes. Such pressing conditions have shown their efficiency in previous work [18]. The appearance of the formed solid fuel briquettes is given in Fig. 2.

An important feature of the obtained prototypes was that the formation of briquettes occurred without adding any binders. Let us note that the work pressure was lower than the recommended values [24] for the formation of pellets.

The residual moisture content of the obtained test samples is in the range of 2.5 ÷ 3.2 % wt., and the amount of ash is 1.5 ÷ 1.6 % wt.

The higher calorific value of the obtained samples of solid fuel briquettes from dried barley BSG are given in Table 3.



a

b

c

Fig. 2. Test samples of solid fuel briquettes from barley brewer's spent grain after pressing for: a) 60 s (Sample 1); b) 120 s (Sample 2); c) 180 s (Sample 3).

Comparing the calorific value of dried BSG (Table 1) and the briquetted samples (Table 3), it is noticeable that this value is slightly higher in the form of compressed solid fuel. It can be explained by the increase in the density of the material due to pressing, as well as a significant reduction in the amount of moisture in the material, which additionally evaporates during the high temperature pressing. The effect of moisture on calorific value can be confirmed by the values obtained in Table 3 – with increasing in the pressing time, the higher calorific value of the sample also increases. In a shorter pressing time, less moisture is released from the material, and it reduces the calorific value because a part of the energy is used to release residual moisture during combustion.

It also should be noted that with increasing in the pressing time the briquette has traces of burning, it is noticeable in visual differences between the samples in Fig. 2. Therefore, in further research it is necessary to set a critical pressing time or a temperature to prevent charring of solid fuel briquettes.

Table 3

The results of experimental determination of higher calorific value according to the calorimetry of combustion of solid fuel briquettes from dried barley brewer's spent grain

m, g	Δ*T*, V	$q_{ampoule}$, J	q_{thread}, J	q_{HNO3}, J	q_{soot}, J	Q, kJ/kg	Q, kcal/kg
Sample 1 (150 °C, 60 s, 100 kgf/cm^2)							
0.50326	0.98698	-	64.2	18.6	45.8	20221	4833
0.36344	0.70996	-	69.8	7.7	70.5	20195	4826
0.46443	0.90688	-	86.1	11.2	49.2	20103	4804
The average value:						20173	4821
Sample 2 (150 °C, 120 s, 100 kgf/cm^2)							
0.81632	1.59860	-	78.2	23.0	123.0	20291	4850
0.71032	1.39261	-	92.6	26.3	64.0	20210	4830
0.47525	0.93379	-	87.7	13.9	29.5	20180	4823
The average value:						20227	4834
Sample 3 (150 °C, 180 s, 100 kgf/cm^2)							
0.42690	0.83547	-	75.5	6.8	54.1	20186	4825
0.77603	1.52280	-	87.1	19.8	80.4	20272	4845
0.91658	1.81498	-	89.3	26.0	65.6	20437	4885
The average value:						20298	4851

The obtained solid fuel briquettes parameters almost correspond to the German standard DIN 51731: moisture content (< 12 %), ash content (< 1.5 %), calorific value (3705 ÷ 4661 kcal/kg) [25]. While the moisture content and ash content are within the established limits, the calorific value of solid fuel made of the barley BSG is slightly higher than the upper limit of the standard. The use of raw materials with higher moisture content can slightly reduce the calorific value of the finish product, as well as the cost of BSG drying.

Conclusions

Thus, as a result of research, ready-to-use samples of solid fuel from secondary food raw materials were obtained. Barley BSG, a by-product of industrial beer production, was used for the solid fuel production. Due to the high moisture content of BSG, it was necessary to dry it previously. The calorific value of the dried barley BSG and the obtained prototypes of solid fuels was determined. On the average, the higher calorific value of unformed raw material is 20005 kJ/kg and that of the obtained briquettes – in range from 20173 to 20298 kJ/kg.

The ash content and residual moisture content of the alternative solid fuels test samples correspond to the requirements of the German standard DIN 51731 for solid fuel briquettes for industrial use. At the same time, the higher calorific value slightly exceeds the upper permissible limit of the standard, but this can be eliminated by increasing the moisture content of the raw material.

The described method of solid fuel production can provide additional use for large volumes of the beer industry waste – brewer's spent grain. This will improve the environmental situation by replacing traditional fuel resources with safer ones without harmful emissions – one of the main consequences may be the reduction of deforestation.

We will also note the cost-efficiency of this solution – the low price of raw materials in view of the fact that the source is a by-product. Also, BSG do not require any additional binders and technological cleaning procedures before use as raw materials for the solid fuel production.

To find the optimal conditions for the formation of solid fuels, it is important to continue current research for the production of solid fuel samples with full compliance to the parameters of existing European and world standards.

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