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Utilization of Fine Coal Waste as a Fuel Briquettes

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This article presents the results of a pilot plant study on fine coal processing to produce alternative fuel. Fine-grained waste generated in the processing plant of a coal-processing plant in eastern Poland (Lublin Coal Basin) was used to obtain briquettes using the roll press briquetting method. The study included material homogenization, the selection of suitable parameters for the roll press unit, and an analysis of briquette quality. Strength and waterproof testing of briquettes and a study of the heat of combustion as well as ash and dust emissions were performed. Based on the results, the production processes were developed for three types of coal-based fuel briquettes with additional components, such as potato starch, molasses, and wood biomass. Briquettes made with starch met the minimum quality requirements, but use of a cheaper binder (molasses) did not provide good quality briquettes. The addition of biomass in an amount not exceeding 20% by weight did not significantly affect the pollution emissions in the combustion tests. The fuel obtained had a suitably high-energy value (22–24 $MJ \cdot kg^{-1}$) and may be used as an alternative fuel for combustion in industrial and domestic boilers.

Keywords Biomass; Briquettes; Fine coal; Fuel; Starch; Utilization

Introduction

To transport and utilize fine-grained waste coal, it is required to form larger-sized agglomerates. An important element of a fine coal briquetting process is mixture preparation (drying, homogenization, binder addition) and molding under pressure using a mechanical press. This article presents the results of the pilot-scale study of briquetting fine coal waste produced at the "Bogdanka" coal mine in eastern Poland (Lublin Coal Basin).

Coal is the primary raw material in the Polish energy sector and is used to produce more than 60% of the total electricity supply. Waste coal, as a by-product of the coal processing is cumbersome to manage. Significant amounts of fine coal waste are stored in landfills or underground. Damp and low-calorie coal sediment material is particularly difficult to load, to transport, and to combust. Physical and physicochemical methods can be used to obtain enriched fuel suitable for utilization [1, 2].

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Many researchers have indicated the possibility of using fine coal-based briquettes as a fuel in power plants [3–5]. Briquetting is a complex process that must deal with different types of fine-grained material. It is important to determine a range of factors that will affect the process, such as material hardness, moisture content, grain composition, internal and external friction, unit pressure, and type of forming punch [6]. Fine coal waste has a low susceptibility to bind during the briquetting process; therefore, it is desirable to change the properties of the material [7], which can be achieved by adding a binder compound. A typical binder may contain hydrolyzed flour, lime, starch, molasses, and some acids [8, 9]. The resulting compound is formed in a press to obtain briquettes, which are then dried and conditioned to produce a solid fuel for combustion in domestic and municipal building boilers. Fine coal can also be mixed with biomass prior to forming in a press to produce alternative fuels [7, 8].

Materials and Methods

The fine coal waste for the present study was a by-product of the mechanical coal processing used at the coal mine. Approximately 86% of the product from the processing plant is coal with a calorific value of 20–23 MJ/kg.

A fraction below 1.5 mm was concentrated in the radial thickener and dewatered on belt filter presses. The moisture of the dehydrated sludge and fines stored in the tanks was approximately 12%.

The preparation of the material for agglomeration was conditioned by the fineness of the structure, the addition of an organic binder, and thorough mixing. During mixing, the water content was adjusted in order to obtain particle agglomeration in the matrix-forming compound. Mixing was carried out with an electric vertical mixer, where the binder was added to the fine coal waste. The amount of binder was about 8 wt.% of the resulting mixture, and the moisture was experimentally established at 24%–25%. The following binders were tested (Table 1):

1. Molasses,
2. Potato starch,
3. Molasses and starch,
4. Shredded woody biomass,
5. Shredded woody biomass and molasses.

Table 1. Waste mixtures tested in trials

No.	Material	Binder	Binder share (%)	Moisture (%)
1	Fine coal	molasses	13	18.5
2	Fine coal	molasses & starch (1:1)	10	24.8
3	Fine coal	starch	8	24.0
4	Fine coal & 20% woody biomass	molasses	8	24.5
5	Fine coal & 20% woody biomass	–	–	25.0

The mixing time for each component was about 3 minutes, which was established experimentally. The required degree of mixing was assessed by calculating the share of indicators in the final product, using a microscope and MicroScan for Windows software. This enabled the measurement of geometrical quantities and the calculation of average fraction sizes, as well as the area and perimeter of the field particles.

In the next stage, the prepared mixture was sent to the roller press unit. A horizontal roller system with symmetric cavities (forming matrices) was used (Figure 1). The unit was characterized by the following parameters:

- Roller peripheral velocity, $v = 0.3\,\mathrm{m \cdot s^{-1}}$,
- Gap between the rollers, $a = 1.2\,\mathrm{mm}$,
- Stress force, $P_w = 400$ kN,
- Torque, $M_o = 19$ kNm,
- Capacity, $W_p = 800\,\mathrm{kg \cdot h^{-1}}$,
- Diameter of the rolls, $D = 500\,\mathrm{mm}$,
- Number of rows of forming cavities, $n = 7$,
- Number of cavities in a row, $k = 22$.

Figure 2 shows the line diagram used for the pilot-scale processing. Fine coal waste and binder from the tank was passed to the screw mixer. The mixture was transported to the central tank, where the screw conveyor fed the press roller. Separated briquettes were transported by a drying conveyor to the drying chamber. Any separated fines were recycled by reverse conveyor to the stacker of the briquetting unit. Dried and cooled samples were transported by container or big-bag. Axisymmetric, flattened, barrel-shape briquettes were obtained, each with a volume of about $50\,\mathrm{cm^3}$(Figure 3). The briquettes were then dried and cured.

The mechanical properties of the briquettes were determined using the drop test and an axial compression test to measure the force required to break a briquette [10]. The resistance of a briquette to a drop test was evaluated as the percentage loss of

Figure 1. Work rolls system in the briquetting press.

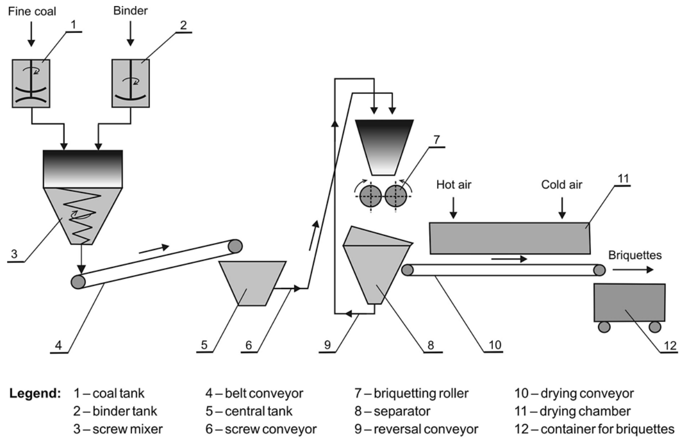

Figure 2. Schematic of briquettes process.

mass (it should be a maximum of 10%) after at least three drops of a briquette, from a height of 2.0 m onto a 20 mm steel plate. After each drop, samples were screened through a sieve size of 8 × 8 mm, which is an acceptable minimum size of agglomerates intended to be utilized [1].

The briquette compression strength method involved crushing a briquette placed between the flat surfaces of a compression tester until its structure failed. It was conducted using an automated test stand at constant speed of $2 \cdot 10^{-4}\,\mathrm{m} \cdot \mathrm{s}^{-1}$. This test used a Zwick 100 materials testing machine, which enabled a continuous measurement of compression force at any movement of the punch, with the data being recorded on a computer.

The required minimum resistance for the gravitational drop test should be at least 90% and the compression pressure in the axial compression test should be above 1.0 MPa [11].

Figure 3. Briquettes made of fine coal.

The water resistance was tested by submersing the briquettes in water and determining the percentage mass lost during the process. Initial moisture of briquettes was low (below 3%), and, during submersion, the briquettes degraded in the sequential process as the briquette swells and disintegrates. Briquettes are considered to be water resistant if they do not disintegrate or remain intact after at least 30 minutes to an hour in water.

The calorific value was assessed with a Parr 1341 calorimeter in accordance with the Polish standard procedure PN-EN 14918 2010.

Dust emissions during the combustion of fuel were determined by the process of pyrolysis. This process was conducted under conditions similar to those in a conventional combustion furnace. The exhaust gas stream emerging from the furnace was examined using a Wöhler A 400 iHC gas analyzer. This analyzer was a multifunctional device with electrochemical gas sensors for: O_2, CO, NO, SO_2, and NO_2 with an infrared sensor to measure CO_2. The results of the gas analysis were collected throughout the test and processed by computer program.

The chemical composition of ash from the combustion of fuel briquettes was determined by X-Ray Fluorescence Spectroscopy (XRF).

Results

The strength of fuel briquettes sampled 30 minutes after leaving the dryer — green and after a 14-day period in storage — cured are listed in Table 2. The moisture content of green briquettes were approx. 4% but was not measured for the cured briquettes.

It was not possible to obtain durable fuel briquettes made with molasses alone. Increasing the mass fraction of molasses continuously improved the briquette combustion parameters, but the compressive strength remained below the required minimum while significantly increasing friction in the processing and transport equipment. Use of a two-component binder (molasses and starch) resulted in a stronger briquettes, but these were still inadequate to meet the minimum strength requirements. The samples with unmodified potato starch as a binder produced good results; the fuel briquettes met the required criteria for the axial compression and the drop tests (Table 3).

Positive results were also obtained for the briquette samples with a 20% addition of biomass from deciduous trees (bio-briquettes [BB]). The strength parameters were compared with and without the addition of molasses (Table 2). As a result, the use of molasses was not continued since the mechanical strength of the BB met the requirements without the addition of a binder.

Figure 4 shows the effect of seasoning on the strength properties of the different briquettes. Strength tests were carried out on the briquettes after 1, 4, 11, 28, 40, 60, and 90 days of seasoning. The results indicated that the seasoning of fuel briquettes is beneficial in terms of their mechanical strength, even after a period as short as 48 hours.

While being tested briquettes were mostly stored under constant temperature and humidity, but for a few days they were stored in open air and the strengths measured were very stable for 60 days but declined significantly after 90 days.

Table 3 shows the physical parameters of the fuel briquettes. The results indicate that the calorific value of the briquettes was $24\,MJ \cdot kg^{-1}$ and could be used as a fuel for combustion in industrial and other boilers. The waterproof limit of the samples

Table 2. The results of strength axial tests of fuel briquettes

	Briquette content			Maximum compression strength destroying briquettes (MPa)		Resistance to gravity drop (%)	
No.	material	binder	Binder share (%)	green (30 minutes)	cured (14 days)	green (30 minutes)	cured (14 days)
1	Fine coal	molasses	10%	0.52	0,62	69.8	73.3
2	Fine coal	molasses & starch (1:1)	10%	0.83	0,98	79.9	83.1
3	Fine coal	starch	8%	1.99	2,49	95.4	98.2
4	Fine coal & 20% woody biomass	molasses	8%	1.63	2,11	94.1	96.5
5	Fine coal & 20% woody biomass	–	–	1.42	1,85	92.3	95.1

Table 3. Characteristics of two types of fuel briquettes

Parameter	Units	Briquette with 8% starch	Briquette with 20% biomass
Specific density	$kg \cdot m^{-3}$	1220	1100
Calorific value	$kJ \cdot kg^{-1}$	23,675	21,520
Moisture content	%	3.8	4.3
Volatile matter content	%	27.3	42.5
Ash content	%	12.2	8.6
Sulfur content	%	0.6	0.5
Sintering point of ash	°C	970	960
Softening point of ash	°C	1390	1370
Water resistance	minutes	10.0	11.0

was 10 minutes, which is not enough for storage under natural conditions. It would be necessary to store the briquettes under cover or to transport them in closed containers.

BB fuels were combusted in a chamber furnace at a temperature of 900–930°C. The following exhaust gas emissions of the oven were measured:

- Nitrogen oxides–NO_x,
- Sulfur dioxide–SO_2,
- Carbon monoxide–CO,
- Carbon dioxide–CO_2,
- Hydrogen sulfide–H_2S.

The atmospheric emissions from the combustion in low-power boilers in terms of the percentage content of biomass in the BB are shown in Figures 5–9. The addition of biomass in a quantity not exceeding 20% of the mixture mass did not modify significantly the pollution indicators. The chemical composition of ash from the combustion of the briquettes is shown in Table 4. The elements of the ash pass

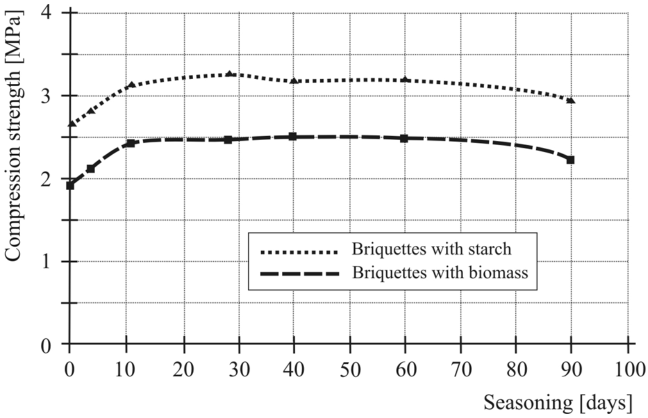

Figure 4. The compressive strength of cured briquettes.

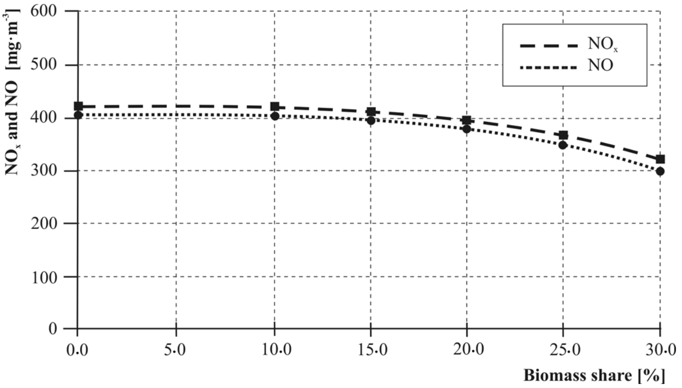

Figure 5. Effect of biomass share on NO and NOx emissions.

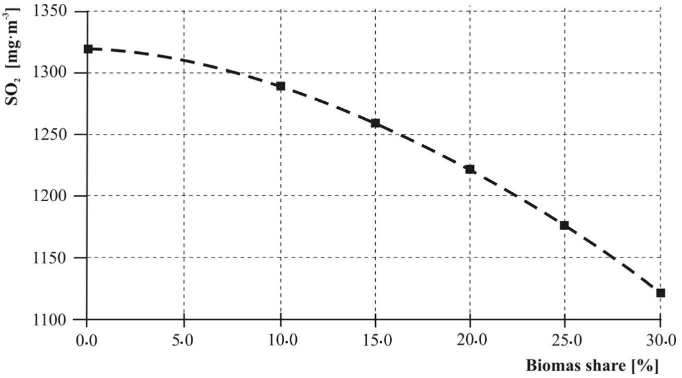

Figure 6. Effect of biomass share on sulfur dioxide emissions.

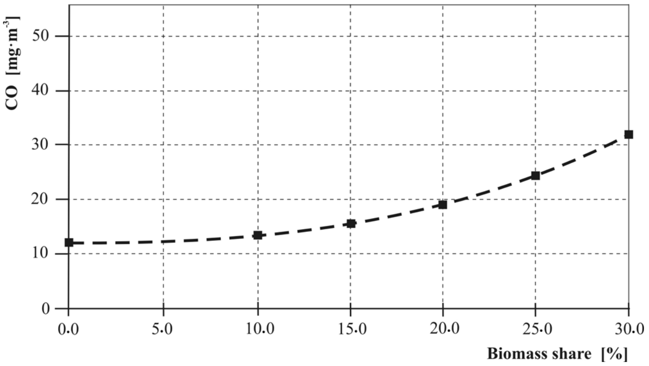

Figure 7. Effect of biomass share on carbon monoxide emission.

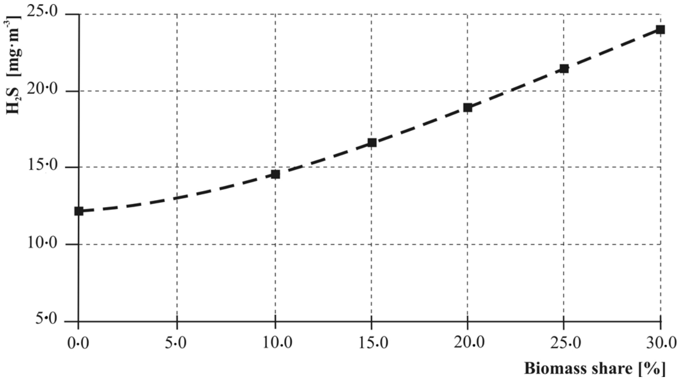

Figure 8. Effect of biomass share on hydrogen sulfide emissions.

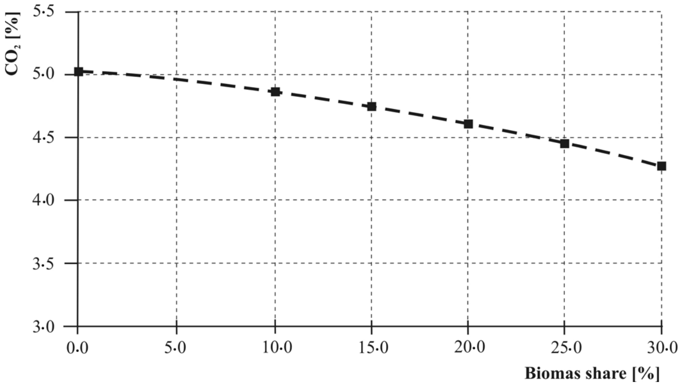

Figure 9. Effect of biomass share on carbon dioxide emissions.

Table 4. The chemical composition of ash from the combustion of fuel briquettes

	The composition of the ash (%) from the combustion of:	
Type of component	coal briquette	20% bio-briquette
SiO_2	55.22	49.97
Al_2O_3	30.04	28.52
Fe_2O_3	6.21	6.09
K_2O	2.98	3.51
CaO	1.66	2.50
MgO	1.46	1.93
P_2O_5	0.59	0.90
Others	1.84	5.58

into the slag to form oxides or silicates, and the silicate content in the ash was less when using bio-briquettes.

Emissions of nitrogen oxides, sulfur dioxide, and carbon dioxide decreased with increases in biomass in the briquettes, while emissions of carbon monoxide and hydrogen sulfide increased.

The results for NO_x and SO_2 are consistent with what one would expect with increasing biomass addition. However, the results of CO_2, CO, and SO_2 simply indicate an inadequate amount of air was not introduced to fully combust the fuel. Biomass burns more rapidly than coal so burning a blend of coal and biomass will initially require more air than burning coal alone.

The results demonstrated that the chemical composition of ash from the combustion of coal with starch was similar to the composition of the BB ash. The main chemical components in the ash were SiO_2 and Al_2O_3 (Table 4). The actual chemical composition is largely dependent on the source and type of biomass and the type of boiler.

Conclusion

Studies have shown that the quality of a fuel briquette is highly dependent on the choice of appropriate binders and the moisture content of the waste material. The quality is also affected by the merge process parameters for the roll press. To obtain suitable fuel briquettes from the roll press required the addition of about 8 wt.% of unmodified starch to achieve a moisture content of 24%–25%.

This high hydration fuel needs to be dried and then cured in containers or bags, so that it acquires a high mechanical resistance. The addition of woody biomass to fine coal produces briquettes without the use of any binder. Biomass content can be up to 20% by total mass. The use of unmodified starch binders for the production of briquettes from fine coal waste is suitable. Attempts to utilize molasses as a binder failed; it is not a very good binder for coal. Fine coal waste combined with woody biomass can be effectively used for the production of alternative fuels. The addition of biomass improves the combustion processes, particularly by the reduction of sulfur and ash content. These briquettes are acceptable as a commercial product for the power industry and for individual consumers.

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