Fuel briquettes from sludge (cake) of concentrating mill

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Abstract. Briquettes made of cake (sludge) with addition of woody sawdust in a volume from 8 to 14% are studied here. Introduction of a moisture-removing agent in a ratio that is sufficient for initial stable shaping and hardening without thermal drying satisfies the requirement for mechanical strength at transportation. Briquettes have a mechanical strength of more than 97%, which does not change during freezing and thawing, underburning after combustion is no higher than 4%, and ash content is not higher than 36%. Stability of briquettes burning can be defined as steady and long-lasting. Such fuel briquettes for the purpose of their use in grate and other furnaces can be produced according to the scheme of pressing in extruders or roller press.

1. Introduction

A significant portion of coal mined is enriched with formation of high-ash waste, whose mass is currently estimated at millions of tons. Many coal preparation wastes in terms of calorific value are the potential fuels, albeit of low quality. Sludge pits and ponds occupy large areas, remove land from economic circulation, pollute the environment; at the same time, some of capital invested in extraction and processing of coal is deadened, and coal in sludge is oxidized [1]. Disposal of screenings, sludge, and coal preparation waste is one of priorities both for individual processing plants and coal-mining regions as a whole. This is especially true for Kuzbass as one of the largest exploited coal deposits in the world.

The problem of waste disposal of mines, pits and processing plants is acute in other coal-producing countries of the world community. For the coal mining industry in Australia, paper [2] describes a solution to the problem of recycling fine coal waste with sticky properties and moisture content of up to 30%, using a binder in the form of dry dispersed coal. Maturation of the strength of the briquettes is preferably carried out under a canopy. Waste coal industry in the United States [3] proposed briquetting using high-pressure polyethylene obtained from solid waste as a binder. Studies [4] are devoted to the utilization of fine (less than 100 microns) watered and sticky coals of South Africa. It is noted that if ultrafine coal contains clay minerals (kaolinite) and ash content does not exceed 15%, it is perfectly briquetted, having sufficient strength necessary for transshipment and transportation. In [5] it is noted that the Miocene lignite mined in Germany is a good binder, but if there is gelite in the formation, the strength properties of the briquette are reduced. A method of reducing the content of gelite in the extracted lignite is proposed. Binder additives in the form of magnesia, gypsum and sulfate liquor, as well as their mixtures were investigated during briquetting of fine high-sulfur coal of Turkey [6]. The most effective binder is a...
mixture of magnesite and sulfite liquor, which showed satisfactory strength properties of the obtained briquettes and the ability to capture (absorb) sulfur oxides in the combustion process. The ability of some ultrathin bituminous coals of the Witbank Deposit (South Africa) to briquetting without a binder is considered in [7]. It is established that the maturation of the required strength occurs mainly due to impurities in coal, in particular, kaolinite. It is obvious that in coal-producing countries a large amount of waste is stored in the form of ultra-thin, high-ash, wet and sticky coal (cake) formed mainly in the process of enrichment, which aggravates the environmental situation. In this regard, the paper adopted an attempt to transfer the cake, which has the ability to retain moisture firmly, in a state that allows obtaining a stable form when briquetting.

When a briquette is formed on a hydraulic press from cake without adding any components, the moisture from cake is not removed, and cake itself is squeezed out through the holes in the mould and the briquette is not formed. Thus, it is necessary to add binding and water-removing components to the cake, intended to perform the main function: shaping the briquette, which leaves the mould. The condition for moisture removal from the cake (sludge) is an excess of the capillary pressure in the draining component contacting with the cake moisture.

In this regard, identification of regularities of hardening the pliant watered coal mass of cake with introduction of a binding and moisture-removing agent in a ratio sufficient to initial stable shaping and further hardening without thermal drying is a relevant research avenue.

2. Problem statement
The goal of the work is an experimental substantiation of the processes of obtaining the briquettes of the required strength for transportation and burning in the grate and other furnaces.

At the processing plant mine named after S.M. Kirov, the samples of coal preparation (cake) were taken (figure 1). According to technical analysis, the cake has high humidity $\omega = 43.22\%$ and ash content $A_d = 36.54\%$, volatile output is $V_a = 26.41\%$. Fractional analysis showed that 80% of the total mass of the cake consist of particles of 80-250 µm. The heat of combustion was determined on the calorimeter IKA-2000 according to GOST 147-2013. The lowest heat of combustion is 3730 kcal/kg (15.6 MJ/kg).

When determining the moisture content of the cake (sludge), the analytical samples did not turn into a crumbly mass, but represented a porous solid structure. It can be assumed that the binding components are the flotation reagents and flocculants remaining on the surface of particles used at flotation and coagulation. The studies of composition of reagents used at flotation showed that they simultaneously served as a binder for the process of filter-cake briquetting. The main components in flotation are motor oils of up to 30-40% (mass.), kerosene-gas oil fractions of petroleum products of up to 40-50%, various mixtures of surfactants (oil X, KO 2-ethylhexanol, butane alcohol residue, KETGOL) of up to 20%. When deposited in horizontal thickeners, polyacrylamide is often used as a flocculant. It is these components that retain moisture in the mass of cake and do not allow its removal even when compressed in a press mould. Thus, it follows that the material, well-depleting moisture from the surface of particles, is required. Such materials can be sawdust or wood chips, which are wastes of the woodworking industry. The minimal size of the pore space of cake (sludge) is 80 µm, and the radius of pores in wood is on average 10 µm [8]. Thus, with introduction of wood into sludge (cake), whose capillary pressure exceeds the capillary pressure of cake (sludge) by almost an order of magnitude, the moisture from the cake (sludge) will be rejected to the wood structure. At that, the total moisture content decreases slightly, but the cake passes from the pliant sticky state into the state suitable for creating a non-deformable shape.

3. Investigation methods and results. Discussion
The briquette is produced as follows. After mixing the cake and binder, the mixture was put into the mould and pressed with a hydraulic press with a load from 1 to 3.5 tons. The mass of a cylindrical briquette did not exceed 12.8 g with a diameter and height of 20-22 mm (figure 2). The
time of briquette sample exposure under the maximal load was not longer than 15 s. The briquette was removed from the mould by the same press.

Figure 1. Initial cake picture.  
Figure 2. Typical view of produced briquettes.

Studies have shown that the fuel briquette should include 8-14% of sawdust; the rest volume is occupied by sludge with the moisture of 38-43%, which is enough to achieve mechanical strength of more than 97% within 24 hours after briquetting without thermal drying.

The produced briquettes were subjected to the freezing and thawing tests in a household refrigerator. Three newly-made briquettes were weighed on the analytical scales and placed on a waterproof surface in a chamber with the temperature of minus 40°C. In 30, 90, 150 minutes and 72 hours from the experiment beginning, they were taken out and weighted. The total weight loss was 1.1%. Then, the briquettes were placed for defrosting under the room conditions with a temperature of 24°C and relative humidity of 40%. The briquettes after defrosting retained their shape, no splits and cracking on the surface were observed. It can be concluded that briquettes can be stored and transported in the winter season.

When testing on water absorption, the briquettes were laid without touching each other on a metal mesh stand and placed for 24 hours in a vessel with room temperature condensate so that the level of condensate was 30-40 mm higher. After the first hour, the condensate began turning black gradually. After 24 hours of testing, the condensate had a pronounced black color and briquettes were destroyed. That is, briquettes are not recommended to be exposed to direct contact with water, but should be stored and transported under an artificial shed.

The last stage of research was the study of briquettes burning in an open space and in a household oven (muffle).

In a household oven (muffle), in 3 minutes after briquette introduction into the burning firewood, they were actively burning, which was characterized by a low ignition delay. In the first 3-5 minutes after the start of burning, smoke from the chimney was noted, which then was colored light gray. For half an hour, visible flames were seen (figure 3), in the next 30 minutes they decreased until disappearing. After cessation of visible burning (absence of flames), the oxidation process continued, indicated by a significant heat release (figure 4). When burning, the briquettes retained the original cylindrical shape. After 12 hours, the remnants of briquettes were removed from the muffle to analyze the unburned carbon residue. Being taken, the remnants of briquettes broke apart at a slight touch. Duration of briquette oxidation in a household oven (muffle) was at least 8 hours. The carbon-containing material of briquette burnt from the outer surface towards the briquette center. The loss of heat with flue gases is less than that with rapid burning of ordinary coal in a household oven.

Briquette burning (oxidation) was carried out in braziers in the open air. The delay of ignition until active burning was more than 10 minutes as compared with burning in a household oven, where the ignition delay did not exceed 3 minutes. The muffle of a household oven made it
possible to maintain a higher temperature in a volume in contrast to burning in the open air (only from the bottom of burning wood). The burning process with visible flames lasted no more than 45 minutes. Then, the carbon-containing part of briquettes was oxidized without a flame, but with the release of heat as at burning in a household oven, for at least 8 hours. The reddish tint between the briquettes (the evidence of high temperature) was visible even after 85 minutes of burning. Burning (oxidation of the carbon-containing material of briquette) occurred from the outer surface towards the briquette center.

After burning, the briquettes retained their initial shape, including burning with slight squeezing for the purpose of transporting to the underburning research basket, while the briquettes subjected to burning in a muffle (household oven) broke apart at a slight touch.

The resulting ash was studied in order to determine the residue of unburned carbon and screened to determine the particle-size distribution. The average value of carbon residue for briquette (in the muffle) is 4.0%; at open burning it is 4.7%. The most complete burning of carbon-containing material occurs in the muffle (household oven).

According to screening by the particle-size distribution, a large fraction predominates in the ash of briquettes subjected to burning in the muffle, in comparison with burning in open space. This pattern can be explained by the fact that the organic additive in the form of sawdust contains fusion elements of Na and K, which form druses at high temperatures, as it occurs in the muffle; i.e., sintering of ash particles into larger ones occurs. On the other hand, at open burning, 90% of ash contains the particles with a size of 0-80 µm.

Figure 3. Picture of briquette burning in a muffle in 12 min.  
Figure 4. Picture of briquette burning in a muffle in 60 min.

**Conclusion**

The briquettes obtained from the cake with addition of wood sawdust in a volume from 8 to 14% satisfy the requirement for mechanical strength sufficient for transportation by any kind of transport. They have the following characteristics: mechanical strength is more than 97%; underburning is not higher than 4%; ash content is not higher than 36%; volatile output is at least 26%; the lower heat of combustion of the briquette corresponds to the lower heat of combustion of the cake, since the wood filing has almost the same heat of combustion, i.e. about 15.6 MJ/kg; mechanical strength during freezing and defrosting does not change and is 97%; water absorption is almost 100%.

The advantages of obtained fuel briquettes include availability, low cost of the introduced component and mechanical strength of the briquette not lower than 97%. The industrial production of such briquettes can be carried out according to the scheme of pressing in extruders or roll press. Consumers of the briquettes can be utility boilers, long burning boilers and residential furnaces.
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