The use of fractionated fly ash of thermal power plants as binder for production of briquettes of coke breeze and dust

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Abstract. In this paper, we propose to use the slag and ash material of thermal power plants (TPP) operating on pulverized coal fuel. The elemental and chemical composition of fly ash of five Kuzbass thermal power plants differs insignificantly from the composition of the mineral part of coking coal because coke production uses a charge, whose composition defines the main task: obtaining coke with the required parameters for production of iron and steel. These indicators are as follows: CRI reactivity and strength of the coke residue after reaction with CO₂ – CSR. The chemical composition of fly ash of thermal power plants and microsilica with bulk density of 0.3-0.6 t/m³, generated at production of ferroalloys was compared. Fly ash and microsilica are the valuable raw material for production of mineral binder in manufacturing coke breeze briquettes (fraction of 2-10 mm) and dust (0-200 µm), generated in large quantities during coking (up to 40wt%). It is shown that this binder is necessary for production of smokeless briquettes with low reactivity, high strength and cost, demanded for production of cupola iron and melting the silicate materials, basaltic rocks in low-shaft furnaces. It is determined that microsilica contains up to 90% of silicon oxide, and fly ash contains up to 60% of silicon oxide and aluminum oxide of up to 20%. On average, the rest of fly ash composition consists of basic oxides. According to calculation by the VUKHIN formula, the basicity index of briquette changes significantly, when fly ash is introduced into briquette raw material component as a binder. The technology of coke briquette production on the basis of the non-magnetic fraction of TPP fly ash in the ratio from 3.5:1 to 4.5:1 (coke breeze : coke dust) with the addition of the binder component to 10% is proposed. The produced briquettes meet the requirements by CRI and require further study on CSR requirements.

1. Introduction

Usually, the power boilers of high capacity operate on pulverized-coal fuel. The boilers of Taganrog boiler plant (TBP) of steam boiler type TP-87 (E-420-140Zh) with steam capacity of 420 t/h, U-shaped configuration, natural circulation and liquid ash removal, and direct-flow symmetrical double-body boilers PK-40-1 with steam capacity of 640 t/h PK are the most common for the thermal power plants. At present, six stations of Kuzbass subsidiary of Siberian Generating Company located in Kuzbass have been converted from design fuel of grade SS to non-design fuel of grade D. Ash content of this coal Aₙ, supplied for generation, varies within 14-17%. On average, at actual thermal efficiency of about 92%, fuel consumption is approximately 0.12 kg of
coal at net calorific value per working mass of 21.9 MJ/kg per 1 kg of steam produced with enthalpy of 3459.2 kJ/kg. For example, consumption of coal of grade D on the TP-87 boiler at a nominal load is 14.2 kg/s or 51.12 t/h. This means that about one wagon of coal is burnt hourly in the TP-87 boiler, and about 78 tons of coal per hour are burnt in the PK-40-1 boiler. Recently, the ash content of coal supplied to the stations is close to 17%. In this regard, when burning 1 ton of coal, about 170 kg of mineral component is produced in the form of ash-and-slag materials (ASM). For boilers with liquid slag removal, it is assumed that the mineral component after coal combustion is divided by weight into fly ash and slag in proportion of 80% and 20%, respectively. According to data of Kuzbass branch of Siberian Generating Company, the annual output of ash and slag materials (wastes) that are sent to the storage tanks is about 1.5 million tons. Among the directions of ash fly processing, it is possible to distinguish well-known markets: cement and concrete; remediation of disturbed lands; road construction; and deoxidation of soils. According to the estimates of “Phoenix” consortium, this potential of sales market on the conditions that the product and service exist is about 35 million tons, and the current annual consumption does not exceed 4.2 million tons. Probably, there are no well-founded motivations for power engineers to bring fly ash to the product, which is in demand by the market, with involvement of service companies. In European countries, there is a charge for the coal-fired power plants on each ton of coal directed to the storage tank from 60 Euro (Finland) to 248 Euro (Czech Republic). In Russia, the plants pay up to 0.3 Euro per ton of ASM, sent to storage.

In this study, we solved the problem of developing an exclusively non-conservative approach to the use of fly ash as an inorganic binder (IB) in manufacturing the fuel briquettes without thermal drying, intended for the use in low-shaft furnaces for production of mineral wool and in foundry. Analytical studies of the mineral part of fly ash indicate a possibility of obtaining liquid aluminosilicate glue and preparation of a dry mixture, which, under specific conditions, can serve as a binder for making the fuel briquettes that meet the requirements of foundry and technology of mineral wool manufacturing. The work also compares the results of the study with the mineral component of microsilica.

2. Characteristics of raw material and results of its analytical examination

The choice of the raw material base for production of fuel briquettes was determined by both the low cost of production waste with the high cost of obtained product component, and predictive estimate of the product demand on the market. The base for briquetting was the raw materials of coke-chemical production of Kemerovo PJSC “Koks”: coke slag (0-10 mm), coke breeze (+10 mm) after wet coke quenching and coke dust (0-1 mm), formed in installations for dry coke quenching (IDCQ). The analysis shows that the mineral composition of charge for the coke production is slightly different from the mineral part of coals burnt in coal power engineering, which allows preservation of the important index of melting: reactivity of CRI briquette.

Technical analysis of coke-chemical raw materials for briquetting and requirements for table 1. Technical analysis of coke-chemical raw materials and CRI and CSR requirements.

| Table 1. Technical analysis of coke-chemical raw materials and CRI and CSR requirements. |
|---|
| Raw material | Ash content $A^d$, % | Volatiles $V^td$, % | Moisture $W$, % | CRI | CSR |
|---|---|---|---|---|---|
| Coke breeze CB (+10mm) | 10.5 | 0.63 | 18.3 |
| Coke slag CS (0-10mm) | 17.2 | 1.3 | 16.9 |
| Coke dust CD (0-1mm) | 16.7 | 0.35 | 0.3 |
| Indicators for metallurgical coke +25 mm | 11.2 | 0.4 | – | 30-35 | 55-60 |
It can be seen from the table that coke breeze corresponds to the requirement for metallurgical coke of +25 mm in terms of requirements for the coke ash content (not more than 11.2%), but does not correspond to the requirements for volatiles (no more than 0.4%). This shows that no matter what transformations are carried out over the raw material (unclaimed product for direct use), it cannot be brought to the corresponding parameters for metallurgical coke of +25 mm by the traditional technological methods.

The granulometric composition of coke slag and coke dust is presented in table 2.

| Raw material       | Granulometric composition in mm, % |
|--------------------|-----------------------------------|
|                    | 10-5.5   | 5.5-3   | 3-2   | 2-1   | 1-0.4  | 0.4-0.2 | 0.2-0 |
| Coke slag, CS      | 16.2     | 17.9    | 12.2  | 15.8  | 25.9   | 8.4     | 3.6   |
| Coke dust, CD      |          |         |       |       | 0.15   | 3.83    | 96.02 |

It should be noted that the strength of briquettes based on any binder is determined by the number and area of contacts of polydisperse particles participating in the pressing process, and hydrophilicity of the material surface relative to the binder component. It is known that the coke particles have significant hydrophobicity to most mineral binders and hydrophilicity to hydrocarbon binders. In this connection, we have considered coke charge briquetting, carried out in the following ratio: CB: CS; CD + IB + H₂O = 37.5: 37.5: 25 + 10 + (8-12) or 40:40:20 + 10 + (8-12) in mass percent. Briquettes were formed in a cylindrical mold with the diameter and height of 21 mm.

The requirements imposed on the binder include: 1) high adhesion in the areas of coke particle connection, when pressed into a briquette at minimal consumption and without thermal drying; 2) no destruction of the briquette at negative temperatures after wetting; 3) raw materials for the binder should be cheap, affordable and technologically convenient when introduced into coke charge.

The mineral binder was a mixture of fly ash with the fraction of less than 50 μm and crystalline sodium hydroxide (caustic) in the ratio of 3: 2, respectively.

Table 3 presents the chemical analysis of coke charge ash and fly ash of the Kemerovo SDPP used as a binder, as well as the basicity index of the coke batch Iᵦ calculated by equation (1), which plays a decisive role in calculating CRI by formula (2) [1].

The granulometric composition of a fly ash sample subjected to preliminary magnetic separation is shown in table 4.

According to table 4, the main part of fly ash is presented by a fraction of less than 80 μm. Additional screening was carried out to obtain the fraction of less than 50 μm in order to prepare the binder. The share of this fraction was about 70%.

The basicity index of coke charge, taking into account the data of table 1 and table 3 on the mixing ratio CB: CS; CD = 37.5: 37.5: 25, and basicity index of briquettes 1 and 2, taking into account the addition of 10% of the mineral part and chemical composition of fly ash and microsilica, were calculated by formula

$$Iᵦ = \frac{100A^0 (Fe₂O₃ + CaO + MgO + Na₂O + K₂O)}{(100 - V_{daf}^0) (SiO₂ + Al₂O₃)}$$  \hspace{1cm} (1)

where $A^0$ is the ash content of coke charge, %; $V_{daf}^0$ is the output of volatiles of coke charge, %; Fe₂O₃, CaO, MgO, Na₂O, K₂O, SiO₂, Al₂O₃ is the content of oxides in ash of coke charge, %.
The reactivity factor was determined by relationship

\[ \text{CRI} = 13.39 + 9.35 \cdot I_o - 0.45 \cdot I_o^2 \]  

(2)

According to table 3, the basicity index of coke charge exceeds value 4, which is the limiting value for coke sent to metallurgy. The optimal basicity index for metallurgical coke is 2.4-2.8. In addition, the reactivity of coke charge and briquettes on the mineral binder exceeds the value of +25 mm required for metallurgical coke by almost 10%. On the other hand, it is important to note that the reactivity and basicity indices of coke briquettes based on a mineral binder differ little from coke charge. In this regard, it is possible to use coke briquettes for production of cupola iron and melting silicate materials and basalt rocks in low-shaft furnaces.

Table 3. Chemical composition of a sample of coke charge ash, fly ash (mass %) and I_0 and CRI indicators of coke charge and charge with binder mixture.

| Sample                                     | SiO_2  | SO_3 | Al_2O_3 | Fe_2O_3 | CaO/MgO | K_2O | Na_2O | MnO/P_2O_5 | TiO_2 | CRI |
|--------------------------------------------|--------|------|---------|---------|---------|------|-------|------------|-------|-----|
| Coke charge (ash)                          | 48.64  | 2.25 | 24.11   | 9.53    | 5.2/ 2.26 | 1.82 | 1.75  | 0.13/ 1.13 | 0.78  | 4.15| 44.4 |
| Briquette 1 of coke charge with 10% of fly ash of Kemerovo SDPP | 58.11  | 0.6  | 16.11   | 5.14    | 5.58/0.68 | 2.47 | 0.58  | –/–        | 0.63  | 4.43| 46.0 |
| Briquette 2 of coke charge with 10% of microsilica MKU-85      | 90.0   | 0.83 | –       | –       | 0.28/ –   | 1.95 | 1.69  | –/–        | 4.1   | 44.2|

Table 4. Granulometric composition of fly ash sample.

| Title                         | Mesh sieve aperture, mm |
|-------------------------------|-------------------------|
| Passed through mesh sieve of 0.08 | 0.08 | 0.2 | 0.5 | 1.0 |
| Fractional residue, %         | 80.91 | 1.66 | 2.90 | 4.67 | 9.85 |
| Average size of particles, mm | 0.06 | 0.05 | 0.3 | 0.75 | 2.00 |

3. Investigation methods and results. Discussion

Coke charge, made of coke breeze, coke slag and coke dust at the ratio of 37.5: 37.5: 25 by weight, was brought to the moisture content of 12-14% by humidification or drying. The binder had the following composition: three parts of dry fly ash and two parts of crystalline caustic. A sample of the binder was 10% per a dry mass of coke charge. After mixing coke charge and binder, the resulting mixture was put into the molds and pressed by a hydraulic press at the load from 1 to 3.5 tons. The weight of a briquette did not exceed 12.8 g for the dimensions of a cylindrical briquette with the diameter and height of 20-22 mm. The time for briquette holding under the maximal load was not more than 15 s. The briquette was taken from the mandrel by the same press. Not less than seven obtained briquettes were kept on the laboratory table for more than 24 hours at the
temperature of about 20°C and humidity of about 60% for a one-time test on mechanical strength by compressing the samples.

The mechanical strength of a batch of briquettes was tested every 24 hours after manufacturing for 5 days. The test results showed no dependence of mechanical strength of briquettes on holding time; it was almost the same and equaled 31.5 kgf/cm² as the arithmetic mean of the maximal pressure, destroying the briquettes. Data of other authors on the study of mechanical strength of microsilica briquettes against compression showed that the maximal pressure of destruction is 34.9 kgf/cm², and the minimal pressure is 15 kgf/cm². In our experiments, the pressure range that destroys the briquettes is 28.8-43.7 kgf/cm².

A change in the mass of briquettes with time was measured in the laboratory. The mass of briquettes reduced during 5 days, then the briquette mass was constant. The average value of mass loss was about 25% relative to its initial mass.

The results of experiments on post-reaction strength index of CSR showed practically zero hot strength, which coincides with the data of other authors who obtained the result using an inorganic binder based on microsilica with various additives. Perhaps, this is due to insufficient adhesiveness of the binder components to the surface of coke particles and high cohesion of the binder, which makes it possible to carry out carbon dioxide gasification in places, where the coke and binder surfaces are exposed. This leads to destruction of the briquette. We believe that it is necessary to consider the options for introducing additives to the binder that provide the dense and reliable contact between a binder and porous coke surface at the temperatures of up to 1100°C.

Conclusion
The technology for production of coke briquettes based on the non-magnetic fraction of fly ash of the thermal power plants is proposed in the ratio from 3.5: 1 to 4.5: 1 (coke breeze + coke slag: coke dust) with the addition of an inorganic binding component of up to 10% per a dry mass of coke charge. The produced briquettes meet the requirements for CRI, and for CSR, they require additional research aimed at finding the options for introducing additives to the binder, providing the dense and reliable contact between the binder and porous coke surface at the temperatures of up to 1100°C.

References
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