RECOVERY OF FINE COAL GRAINS FROM POST-MINING WASTES WITH USE OF AUTOGENOUS SUSPENDING BED TECHNOLOGY

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Abstract:
In addition to rock waste post-mining waste dump sites also contain coal grains justifying treating the dump sites as secondary mineral deposits. The article presents the results of laboratory tests aimed at determining the possibility of using suspending bed technology to separate a combustible substance from post-mining waste of a 4-0 mm grain size. The test results showed the possibility of obtaining good quality coal concentrates from coal waste of a grain size of 4-1 mm. The need for de-sludging and densifying the feed for the classifier with an autogenic suspending bed in the case of coal waste beneficiation in a wide 4-0 mm grain size justifies the use of a two-chamber device or two separate classifiers for narrower grain size classes. Concepts of systems for the recovery of fine coal grains providing the use of the classifier with autogenous suspending bed for the density distribution of feeds with high ash content are presented. The concepts were developed for beneficiation of the material in a 4-0 mm grain class.

Key words: classification, fine grains, post-mining wastes dump sites, suspending bed

INTRODUCTION
Natural environment contamination is the side-effect of mines operation. This poses a threat resulting from deposition of post-mining wastes in heaps [15]. Recultivation and revitalization of heaps can make elimination of these hazards easier.
In addition to rock waste from mechanical coal treatment. post-mining waste dump sites also often contain coal grains justifying treating landfills as secondary deposits of raw materials that can be used for aggregate production and coal recovery. The recovery of coal from dumped material in heaps is usually carried out using technologies typical for mechanical processing in the hard coal mining industry.
This article presents the results of laboratory tests aimed at determining the possibility of using autogenic suspending bed technology to beneficiate coal waste in the 4-0 mm class. i.e. twice the grain size range of the feed compared to typical applications of TBS (Teeter Bed Separator) classifiers [11].

LITERATURE REVIEW
Cyclones with a dense liquids [1, 13, 21, 23] as well as pulsating classifiers [9, 10, 12, 15, 16, 17] developed at KO-MAG Institute of Mining Technology are used for beneficiation post-mining wastes of grain size > 2(3) mm. For recovery of combustible substance of smaller grain size (< 2 mm). the systems consisted of hydro-cyclones and spiral classifiers [18, 22] are often used.
TBS suspension classifiers using the autogenous suspending bed technology for material distribution by size or density are an alternative or complementary solution to the hydrocyclone – spiral classifiers system. High resistance to changes in material load and changes in feed quality parameters is their advantage and higher separation efficiency of the beneficiated material [4, 5].
The above advantageous features of the device ensure automatic control of the beneficiation process based on the stabilization of a given density of material separation in a suspending bed [4].
In order to ensure proper operation and obtain high quality products. the feed entering the suspension classifier should be de-sludged and concentrated. For the implementation of the above task. a pump-hydrocyclone system is most often used. in which the hydrocyclone product is a feed for the suspension classifier [2].
The classifiers with an autogenous suspending bed have been used. for example. in the production of aggregate for cleaning sand from organic substances [14, 25, 27]. in
the processing of metal ores [19, 20, 24, 29] and in the mechanical processing of hard coal for classification or beneficiation of feed in grain classes 2-0.5 mm and 1-0.2 mm [2, 3, 6, 7, 8, 22, 26]. Tests carried out at KOMAG also showed the possibility of using the abovementioned technologies for beneficiation of fine-grained coal waste in a grain size of 2-0.5 mm [9, 27, 28].

**TESTING METHODOLOGY**

The tests were conducted on the laboratory test stand equipped with the model of fluidal suspension classifier (Fig. 1).

![Fig. 1 Model of fluidal suspension classifier](Source: [9])

The material was separated in a working chamber of dimensions (length x width x height) 0.5 x 0.1-0.2 x 0.5 m. It was based on an autogenic suspending bed obtained as a result of the rising action of a water stream on the feed. Water was distributed in the separation part of the classifier using a flat diffusion plate equipped with holes of a diameter 2 mm being the bottom of the working chamber. The flow rate of fluidizing water was controlled using valves and rotameters in the water supply pump system. Water flowed from the working chamber through overflow of a width 0.2 m.

Process tests were preceded by a feed preparation including the dimensional classification of a material sample. Classified sludge from earth tanks obtained from mechanical processing of coal waste carried out by the wet method using vibrating screens with spraying and pulsating classifiers was the feed material.

The maximum size of the assumed feed grains was 4 mm and the ranges of material qualitative analyses were 4-1 mm and 1-0.2 (0) mm.

After separation of grains from the material > 4 mm, the feed was desludged to remove grains < 0.2 mm. The feed was desludged at a water flow rate to the classifier equal to Q = 2.1 m³/h and the speed of the rising water stream in the working chamber equal to v = 0.78 cm/s. Then, the process of density stratification of the feed was carried out at the rate of bottom water inflow Q = 3.6 m³/h and speed of the rising water stream v = 1.34 m/s. The height of the expanded suspending bed was 0.45 m and its surface was 0.05 m below the chamber overflow edge.

The approximate time of material beneficiation at a given speed of rising water stream was about 20 minutes. After turning off the water supply and slow emptying the working chamber from water, the remaining material of height 35 cm was divided into five layers of the following heights: 5, 5, 10, 10 and 5 cm (from the upper layer). Fig. 2 presents the method of separating stratified feed into beneficiation products.

![Fig. 2 The method of separating stratified feed into beneficiation products](Source: [9])

The material from layers was subjected to quantitative and qualitative analyses in grain sizes classes 4-1 mm and 1-0.2 (0) mm. To determine the quality parameters. The layer and the overflow product material was analysed for ash content and calorific value.

Based on the results of the analysis of the suspending bed layers and the overflow product sludge the outputs and quality parameters of concentrate and waste products in the 4-1 mm 1-0.2 (0) mm and 4-0.2 (0) mm grain size classes were determined.

**TEST RESULTS**

**Feed desludging**

The analysed sample of sludge classified on a 4 mm sieve contained 9.7% oversize grains above 4 mm and in the material with 4-0 mm grain size before desludging, the share of 4-1 mm and 1-0 mm grain sizes was 32.3% and 67.7% respectively.

The results of the analysis of the quality parameters of the 4-1 mm and 1-0 mm grain classes showed that the material contained therein had high ash content A and low calorific value Q.

In the class 4-1 mm and 1-0 mm ash content was 81.2% at gross calorific value 4130 kJ/kg but in the class 1-0 mm ash content was higher and was equal to 83.9% at lower gross calorific value equal to 3408 kJ/kg. The entire material in grain class 4-0 mm had ash content equal to 83.1% and gross calorific value equal to 3642 kJ/kg.

In a result of the process of desludging the material of 4-0 mm grain size 36.2% of material containing clay and dust particles mainly with grain size less than 0.1 mm and some light grains less than 0.2 mm were separated.

The results of the analysis of the desludging and stratification process are given in the Table 1.
In the product from desludging process (overflow) of grain size 0.2(0.1)-0 mm the ash content A<sub>a</sub> was 81.43% and calorific value Q<sub>sa</sub> was equal to 4130 kJ/kg. Average ash content in the grain size class 1-0 mm was equal to 83.94% and calorific value was equal to 3408 MJ/kg. Share of grain size classes 4-1 mm and 1-0.2(0) mm in the desludged feed was 50.7% and 49.3% respectively.

Parameters of the beneficiation products
The results of the analysis of the quality parameters of beneficiation products in the 4-1 mm and 1-0.2 (0) mm grain classes showed their significant differentiation for the assumed process parameters.

Grain class 4-1 mm
Results of analysis of parameters of the layers obtained during beneficiation of 4-1 mm grains size material presented in Table 2 and in Fig. 3 showed the possibility of obtaining the relatively high quality concentrate products from post-mining wastes od ash content A<sub>a</sub> = 81.2% and calorific value Q<sub>sa</sub> = 4130 kJ/kg.
was from 84.7% to 86.6% and calorific value $Q_a$ was from 2857 kJ/kg to 2158 kJ/kg.

Increase of concentrate output up to 31.18% (sum of layers I, II, III) caused significant reduce in the concentrate quality. Ash content increased to 65.74% and gross calorific value reduced to 9587 kJ/kg.

When considering the total amount of post-mining wastes of grain size 4-0 mm before desludging, the concentrate output in grain class 4-1 mm during tests was from 1.58% to 3.09% for the above qualitative parameters.

**Grain class 1-0.2(0) mm**

The results of the analysis of layer parameters obtained during the separation of grains class 1-0.2 (0) mm presented in Table 3 and Fig. 4 showed the inability to obtain high-quality concentrate products from desludged post-mining wastes of ash content $A_a = 86.8\%$ and calorific value $Q_a = 2611$ kJ/kg.

| Material layers | Feed (desludged) | Concentrate | Tailings |
|-----------------|------------------|-------------|----------|
|                 | $\gamma$ % | $A_a$ % | $Q_a$, kJ/kg | $\Sigma\gamma$ % | $A_a$ % | $Q_a$, kJ/kg | $\Sigma\gamma$ % |
| Layer I         | 16.65 | 70.33 | 8466 | 16.65 | 70.33 | 8466 | 100.00 | 86.81 | 2611 |
| Layer II        | 23.39 | 88.09 | 2061 | 40.04 | 80.77 | 4724 | 83.35 | 90.11 |
| Layer III       | 41.02 | 91.10 | 1183 | 81.06 | 85.97 | 2932 | 59.96 | 90.89 |
| Layer IV        | 14.84 | 91.08 | 1103 | 95.90 | 86.76 | 1103 | 41.84 | 90.39 |
| Layer V         | 4.10 | 90.17 | 2611 | 4.10 | 90.17 | 2611 | 95.90 | 86.76 |
| Total/Average*  | 100.00 | 86.81 | 2611 | 100.00 | 86.81 | 2611 | 100.00 | 86.81 |

*Source: [10].

At the concentrate output from 16.65% to 40.04% ash content $A_a$ was within the range from 70.3% to 80.7% and calorific value $Q_a$ from 8466 kJ/kg to 4724 kJ/kg. At the separation tailings output from 83.35% to 59.96% ash content $A_a$ was from 90.1% to 90.90% and calorific value $Q_a$ from 1441 kJ/kg to 1199 kJ/kg.

When considering the total amount of post-mining wastes of grain size 4-0 mm before desludging, the concentrate output in grain class 1-0.2(0) mm during tests was from 5.24% to 12.60% for the above qualitative parameters.

The quality parameters of the concentrate obtained during tests were significantly influenced by the low quality of the feed material in the grain class 1-0.2 (0) mm resulting with a low content of carbon grains.

Reduced class quality of the feed material in the class 1-0.2 (0) mm in relation to feed in the 4-1 mm class could have been caused by the loss in carbonaceous material during the desludging process.

**Grain class 4-0.2 (0) mm**

Results of analyses of coal layers parameters during classification of feed of grains class 4-0.2(0) mm presented in Table 4 and Fig. 5 showed, similar to the 1-0.2 (0) mm class lack of possibility to obtain the concentrate of high quality from the post-mining wastes of as content $A_a = 84.0\%$ and calorific value $Q_a = 3381$ kJ/kg.

Use of autogenic suspending bed technology for density separation of grain class 4-0.2(0) mm despite slightly better results in relation to class 1-0.2(0) mm did not allow for obtaining the concentrate product of expected high quality.

Quality of the concentrate product in the 4-0.2 (0) mm class reduced in relation to the concentrate product in the 4-1 mm class was due to both twice the grain size range and the low quality of the material in the 1-0.2 (0) mm class with a low content of carbonaceous substance.
Table 4
Qualitative parameters of density separation of grain class 4-0.2(0) mm

| Material layers | Feed (desludged) | Concentrate | Tailings |
|-----------------|------------------|-------------|-----------|
|                 |  |  |  |  |  |  |  |  |
|                  | γ | A  | Qₐ | δγ | δA | δQₐ |
| Layer I          | 10.69 | 56.81 | 13196 | 10.69 | 56.81 | 13196 |
| Layer II         | 13.90 | 81.25 | 4502 | 24.59 | 70.63 | 8282 |
| Layer III        | 31.19 | 87.81 | 2087 | 55.78 | 80.23 | 4818 |
| Layer IV         | 35.24 | 88.68 | 1637 | 91.02 | 83.50 | 3381 |
| Layer V          | 8.98 | 88.60 | 100.00 | 83.96 | 88.66 | 1637 |
| Total/Average*   | 100.00 | 83.96* | 3381* |

At the concentrate output from 10.69% to 24.59% ash content A² was within the range from 56.8% to 70.6% and calorific value Qₐ² from 13169 kJ/kg to 8282 kJ/kg. At the separation tailings output from 89.31% to 75.41% ash content A² was from 87.2% to 88.3% and calorific value Qₐ² from 2206 kJ/kg to 1782 kJ/kg.

When considering the total amount of post-mining wastes of grain size 4-0 mm the concentrate output in grain class 4-0.2(0) was from 6.82% to 15.69% for the above qualitative parameters.

Comparison of curves for ash content A² and calorific value Qₐ² in the concentrate for the analysed grains classes is presented in Fig. 6 and 7.

CONCEPTS OF SYSTEMS FOR RECOVERY OF FINE CARBONACEOUS GRAINS

Potential possibilities of using autogenous suspending bed technology separation of feeds of an increased grain size range from 2-0 mm to 4-0 mm are shown in Fig. 8 and 9.

Post-mining wastes of 4-0 mm class in the form of sludge deposited in earth tanks occurs e.g. during mechanical processing of 30-0 mm class using a pulsating classifier separating the material in 30-3 mm class.

Material of class 3(4)-0 mm is obtained by classifying 30-0 mm feed on a vibrating screen using the wet method. by dewatering the concentrate and tailings from the pulsating classifier and discharge hydraulically of the flow through the sieves.

Due to the oversize grains in the sludge deposited in earth tanks, obtaining the proper grain size range of the 4-0 mm class feed for the node for separation of fine post-mining wastes requires the use of a vibrating screen with water spraying stream to classify sludge material.
Variant I – Fig. 8

After classification of the material on the screen, it is de-sluuged and densified in a hydrocyclone or a pack of hydrocyclones. The product of the hydrocyclone outflow is a feed for a two-chamber suspension classifier. In contrast to single-chamber structures classifying the 2-0 mm class materials at the same water stream rising speed, in a two-chamber classifiers it is possible to change this parameter depending on the differences in the speed of sedimentation of the material in two grain classes.

As a result of the two-stage classification process of the 4-0 mm class a coarse-grained and fine-grained tailings and a concentrated light product are obtained.

In the proposed solution, the light product collecting system consists of an arc sieve and a vibrating screen. Drained hydraulically, by overflow from a suspension classifier the light product is dewatered and classified on a fixed sieve and then on the screen, where the final separation of the smallest grain grades with a high ash content that can excessively reduce the quality parameters of the concentrated product occurs.

Waste products from suspension classifier are combined with the hydrocyclone overflow product and the bottom products from classification of the light product and then directed to the water and mud circulation.

Fig. 8 Diagram of the system for classification of fine grains in class 4-0 mm – Variant I
Source: [10].

The water-sludge circuit of tailings may include sedimentation earth tanks radial thickeners and filter presses. The partition size during classification of a light product from a suspension classifier is one of the important factors affecting the quality parameters of the coal concentrate. Excessive reduction of the partition size in the light product classification can significantly reduce the quality parameters of the coal concentrate.

Variant 2

In the solutions presented in Fig. 9 the collecting system of light product discharged hydraulically along with process water of suspension classifier overflow is more extensive than that shown in Fig. 7 and consists of an arch fixed sieve vibrating screen hydrocyclone and a spiral classifier.

As in Variant 1 dewatering and pre-classification of the light product is the task of the fixed sieve and classification and dewatering of 4-0.5 mm class coal concentrate is the task of the vibrating screen.

Contrary to the solutions presented in Variant 1 where the bottom product of the light product classification on the fixed sieve and the vibrating screen is a waste product, in the discussed solution it is the subject to secondary classification in the hydrocyclone – spiral classifier system.

The material of 0.5-0.15 mm class after densifying and desludging in the hydrocyclone undergoes density separation in the spiral classifier to reduce the ash content by destoning. A light product of the 0.5-0.15 mm class from the spiral classifier is combined with a 4-0.5 mm class coal concentrate from the suspension classifier which allows obtaining the final carbon concentrate with a relatively wide grain size range of 4-0.15 mm.

Fig. 9 Diagram of the system for classification of fine grains in class 4-0 mm – Variant II
Source: [10].

Tailings from the suspension classifier are combined with the hydrocyclones overflow product of desludging the feed for the suspension and spiral classifiers with the heavy product from the spiral classifier and then hydraulically directed and transported to the tailings water-mud circuit.

Possibility of coal recovery from the post-mining wastes in a broad grain class using the suspension and spiral classifiers which allows to increase the production output of coal concentrates compared to the solutions presented in Variant 1 is the advantage of the two-stage classification of the material of 4-0 mm class.

Complexity of the classification node arrangement in two different classifiers and the high investment and operating costs are disadvantages of two-stage material separation.
CONCLUSIONS
Analysis of the results of classification of sediments from earth tanks obtained during laboratory tests showed the possibility of using the technology of autogenic suspending bed for the density distribution of desludged post-mining wastes in the grain class 4-1 mm to recover carbonaceous substances.

The results of the comparative analysis of material classification in grain classes 4-1 mm and 1-0.2 (0) mm showed an adverse effect of the desludging process (requiring for the proper operation of the suspension classifier) on the quality parameters of coal concentrates of grain size less than 1 mm.

The need for desludging and densifying the feed for the classification with an autogenous suspending bed in the case of classifying the post-mining wastes with a low content of light fractions in a wide grain size e.g. 4-0.5 mm justifies the use of a two-chamber device or two separate classifiers for narrower grain grades.

In the suggested solutions, the feed for small grains classification node is previously classified by the wet method on a vibrating screen and densified and desludged in a hydrocyclone. Bottom overflow of which is directed to the suspension classifier.

Supply of fresh technological water from the water and sludge circuit is the condition for the proper operation of the fine grain classification node using the autogenous suspending bed.

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