Coal Middlings Recycling – a Route for Increasing the Yield of Sellable Concentrate

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Abstract

Because of the low quality, middlings from the coal preparation often remain unused and are stored on the industrial site or simply landfilled. The authors offer a possible solution to this problem; its main idea is to upgrade the flowsheet of the coal processing plant by recycling the by-product that will turn it into valuable concentrate. Such approach would increase the efficiency of processing, allow comprehensive utilization of mineral raw materials, reduce the loss of combustible matter from coal with rejects, and would result in higher revenue from the sales of high-quality coal concentrate. This article represents outcomes of the studies of coarse coal middlings as potential raw material for producing sellable concentrate. The middlings are obtained from a coal preparation plant located in Kuznetsk coal basin, Russia. Samples have been crushed down to a size of 13 mm, and then a float-sink analysis has been completed from which the liberation degree is calculated. Performance of gravity separation and flotation of slimes has been evaluated with a laboratory scale equipment. It is shown that middlings of the coking coal have high potential to yield a high-quality concentrate. Forecasted mass balance of the proposed flowsheet for the middlings reprocessing shows that 50 to 80% of total middlings production might be transformed into low-ash coal concentrate.

Keywords: coal preparation, middlings, recycling, gravity separation, process simulation, Kuznetsk coal basin

Introduction

It is undeniable that in near future coal will retain its place among other important raw materials. However, related environmental issues have to be addressed and utilization of resources has to be done in sustainable manner. The Paris Agreement regarding climate changes (COP21, 2015) was signed by 195 countries from all over the world with aim to limit global warming. One of the major causes leading to temperature changes is the emission of so-called "greenhouse gases", which implicitly points to coal as unwanted energy source in the future. On the other hand, coal is widely used in metallurgy as a source of coke for blast furnaces. Acknowledging its significance for European economy, coking coal has been placed in the EU list of 20 critical raw materials with the second highest economic importance score after tungsten (European Commission, 2014).

The general trend in mineral industry for deteriorating quality of extracted ores is observed as well in coal mining. Deposits with lower seam thickness and higher ash content are getting involved into exploitation, coal washability becomes more difficult and market situation is not steady. These factors necessitate constant improvement of processing technologies and search of routes for increasing the efficiency of resource utilization. Conventional processing technology of coking coal with difficult washability includes two-stage gravity separation in heavy medium. In the first stage, initial material is separated into the concentrate of desired quality and mixed product which is treated further. The objective of the second stage of gravity separation process is to diminish losses of combustibles (organic matter) with tailings. Hence, three products are obtained as a result of coal processing: high-quality concentrate, low-carbon tailings and middlings of variable quality.

Because middlings are formed as a by-product and their quality is usually cannot be controlled, this product often remain unused and is stored on the industrial site or even landfilled. At the same time, coal middlings especially those of coarse size classes, are represented by non-liberated particles of coal and mineral matter. Depending on the composition of such particles, it is possible to achieve higher degree of liberation without very fine crushing or grinding. In this case, the flowsheet of coal processing plant can be upgraded to include the recycling of middlings that would positively affect the yield of sellable concentrate.

In order to demonstrate the potential of coarse middlings to be recycled into low-ash coking coal concentrate, samples have been taken at the "Mezhdurechenskaya" coal preparation plant located in Kuznetsk coal basin, Russia. The plant annually processes 3 million tons of two grades of medium volatile bituminous hard coal, namely KC and OC, according to GOST 25543-2013 classification. Current flowsheet of the preparation plant is designed for processing of coal with difficult washability characteristics and its main operations involve heavy medium separation in Wemco drums for 13–100 mm size class, dense medium hydrocyclones for 2–13 mm size class, spiral concen-

Tab. 1. Washability data of 13–100 mm coal middlings

Tab. 1. Wzbogacalność klasy 13-100 mm przerostów

Density fraction [g/cm^3]	KC grade		OC grade	
	Yield [%]	Ash content [%]	Yield [%]	Ash content [%]
< 1.3	9.4	4.9	6.9	3.9
1.3 – 1.5	18.5	9.4	42.4	7.8
1.5 – 1.8	31.9	15.8	49.7	25.8
> 1.8	40.2	52.1	1.0	46.3
Total	**100.0**	**28.2**	**100.0**	**16.9**

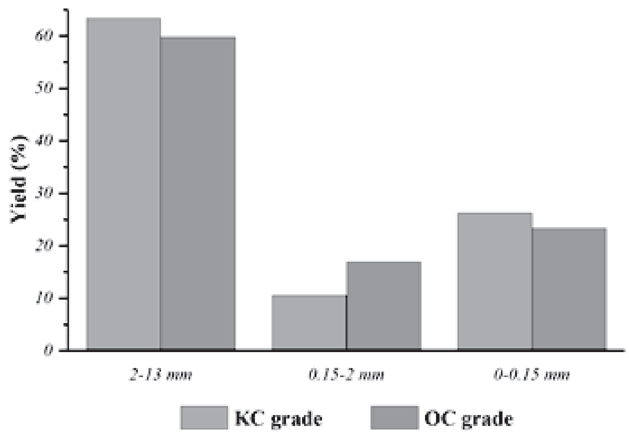

Fig. 1. Distribution of crushed coal middlings by size classes

Rys. 1. Rozkład przerostów w klasach ziarnowych

trator for 0.15–2 mm size class and flotation of 0–0.15 mm fines. The primary product of the plant is coking coal concentrate with ash content in range between 9.0 and 10.5%, coal middlings with ash content of 20 to 35% are produced as by-product and tailings which contain at least 75% of mineral matter are landfilled.

Materials and methods

Received samples of 13–100 mm size class middlings of both grades are approximately 400 kg in weight and their quality is representative for an average production of the plant. Middlings samples are subjected to float-and-sink analysis (ISO 7936–1992) in three solutions of zinc chloride with densities of 1.3, 1.5 and 1.8 g/cm³. After the separation, ash content of each density fraction has been assayed. Washability data of the coal samples is shown in Table 1.

Results of float-sink analysis is of utmost importance in forecasting the metallurgical performance of coal preparation plant. Liberation degree could be also identified from the washability data (Oki et al., 2004). Table 2 shows distribution of the material by density fractions and allows predicting the performance of gravity separation processes, which are predominantly employed at coal preparation plants.

Washability data indicates that yield of sellable concentrate with ash content of 10% from KC grade coal is about 35.1% of operation's input at separation density of 1.48 g/cm³, whereas processing of OC grade middlings would produce 62.8% of clean coal from cyclone feed at separation density of 1.56 g/cm³.

This implies more difficult washability behavior of KC grade coal middlings. Better performance of the OC grade coal in heavy medium separation is attributable to higher degree of liberation of complex coal-mineral particles during comminution which is reflected in increased yields of the lightest and heaviest density fractions as compared to data in Table 1.

Only 10 to 15% of crushed middlings report to 0.15–2 mm size class that makes feasibility of its processing questionable. On the other hand, this size class is typically concentrated on coal spiral, which does not require significant capital investments and is fairly easy to operate. Table 3 represents the results of tests with laboratory spiral concentrator. Its primary purpose is to diminish losses of combustibles with tailings while achieving acceptable quality of concentrate. For the assessment of viability of spiral concentration process, the recovery of combustibles ε_c, %, is used along with the ash content of concentrate A^d_c:

$$\varepsilon_c = \gamma \cdot \frac{100 - A_c^d}{100 - A^d}$$

where γ, %, is the yield of concentrate and A^d, %, is the ash content in feed of the operation.

Tab. 2. Washability data of 2–13 mm size class of crushed middlings

Tab. 2. Wzbogacalność klasy ziarnowej 2-13 mm dla prerostów skruszonych

Density fraction	KC grade		OC grade	
[g/cm^3]	Yield [%]	Ash content [%]	Yield [%]	Ash content [%]
< 1.3	14.6	6.1	26.5	5.7
1.3 – 1.4	7.3	11.0	8.6	7.3
1.4 – 1.5	13.8	14.3	17.6	12.6
1.5 – 1.6	15.9	25.7	16.3	22.0
1.6 – 1.8	19.2	31.5	16.5	30.2
> 1.8	29.2	58.7	14.5	40.6
Total	**100.0**	**31.0**	**100.0**	**18.8**

Tab. 3. Experimental results of spiral separation of 0.15-2 mm size class

Tab. 3. Wyniki wzbogacania klasy 0,15 – 2 mm w klasyfikatorze spiralnym

Product	KC grade			OC grade		
	γ [%]	A^d [%]	ε_c [%]	γ [%]	A^d [%]	ε_c [%]
Concentrate	41.20	11.98	47.53	70.69	11.19	74.23
Middle product	33.60	27.97	31.72	19.54	21.83	18.06
Tailings	25.20	37.16	20.75	9.77	33.29	7.71
Total	**100.0**	**23.70**	**100.0**	**100.0**	**15.43**	**100.0**

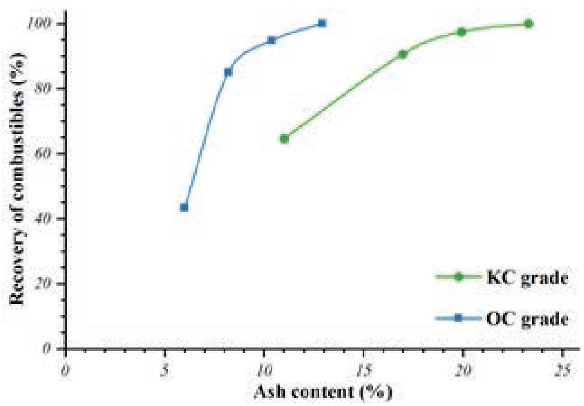

Fig. 2. Floatability curves of 0–0.15 mm coal fines

Rys. 2. Krzywe flotowalności klasy 0-0,15 mm

As it can be observed, recovery of combustibles to the concentrate of spiral from KC coal is 47.5%, whereas in case of OC grade coal 74.2% of organic matter is recovered. Quality of concentrates obtained with both feed materials is acceptable and can be improved slightly in full-scale plant operations that makes spiral separation of crushed middlings rational.

Modern coal preparation plants have a tendency to avoid treatment of coal fines with particle sizes smaller than 0.5 mm when possible in favor of discarding slimes with tailings. There are numerous reasons for that, such as difficulties in dewatering of fine coal concentrate, more complicated flowsheets of process water clarification, higher capital and operating costs required. Nonetheless, flotation of fine coal might be introduced into the plant's flowsheet for coal preparation if there is proven evidence of high efficiency and economic viability of the process. As shown in Fig. 1, particles of 0–0.15 mm size class make up to 25% of total crusher output, which indicates existing potential for increase of concentrate production in case of satisfactory floatability. Results of laboratory flotation tests in mechanical cell are represented in form of grade-recovery curves (Fig. 2) modified for the case of coal flotation.

As in the case of gravity separation, coal middlings of OC grade exhibit better floatability as well with recovery of combustibles close to 90% when ash content in concentrate reaches 10%. From slimes of KC grade it is difficult to obtain high recovery of organic matter to sellable concentrate by flotation, the highest recovery achieved in the tests is 64.6%. Some studies (Das, 2010) show that use of Jameson flotation cells helps to get higher recovery of combustibles from 0-150 µm coking coal fines with poor floatability.

Based on the empirical results from laboratory tests, the metallurgical performance of combined mid-

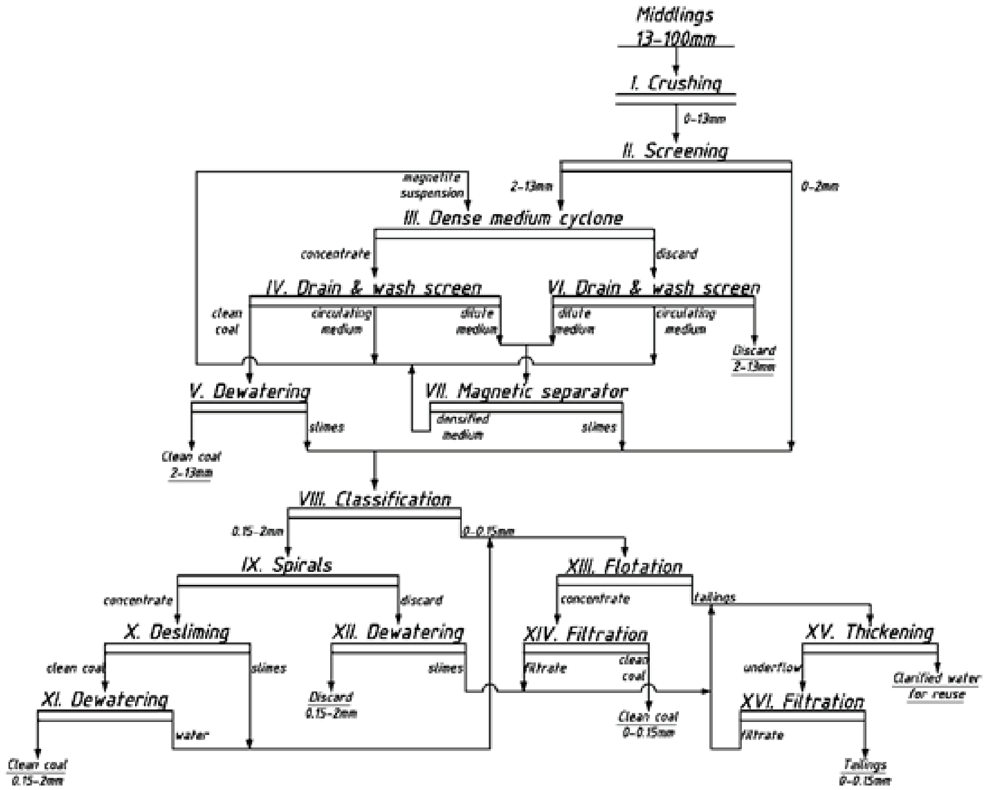

Fig. 3. Proposed flowsheet for coarse middlings recycling

Rys. 3. Propozycja schematu wzbogacania przerostów

Tab. 4. Summary product balance of coal preparation flowsheet (actual/simulated)

Tab. 4. Bilans schematu wzbogacania węgla (aktualny/symulacja)

Product	KC grade			OC grade		
	γ [%]	A^d [%]	ε_c [%]	γ [%]	A^d [%]	ε_c [%]
Concentrate	49.48 / 60.16	10.21 /10.17	61.82 / 75.12	77.80 / 81.07	9.70 / 9.71	88.72 / 92.47
Middlings	31.53 / 18.28	27.55 / 32.96	31.78 / 17.03	6.65 / 2.87	21.22 / 27.19	6.62 / 2.64
Tailings	18.99 / 21.56	75.81 / 73.81	6.39 / 7.85	15.55 / 16.06	76.24 / 75.91	4.67 / 4.89
Plant feed	**100.00**	**28.10**	**100.00**	**100.00**	**20.83**	**100.00**

dlings recycling process has been evaluated including the auxiliary operations such as size classification, dewatering and regeneration of dense medium. Proposed flowsheet (Fig. 3) in general replicates the existing flowsheet of the plant providing opportunity for incorporation of middlings recycling operations into it with low capital expenditures. Only crushing of middlings and dense medium separation in cyclone would require installation of separate equipment units as the operation mode is differs from those of currently in use. Simultaneously, it is possible to join dense medium regeneration circuit with the existing one and combine concentrates for dewatering in centrifuges. Similar principle applies for spiral concentration and flotation of slimes. Processing of fine size classes in blend with raw coal using the same pieces of equipment will not compromise the quality of final products if process properly controlled.

For the estimation of economic potential of coal middlings recycling process, the integrated flowsheet has been simulated and outcomes of the computer modeling are compared to actual operating data from previous periods (Table 4). It shall be noted that low ash content of tailings obtained in middlings recycling is significantly lower than plant objective, therefore heavy fraction of recycling hydrocyclone cannot be joined with total plant waste stream. Instead, it is possible to combine this material with 2–13 mm middlings because of similar characteristics.

In both cases, noticeable increase in concentrate yield is observed without compromising the quality of final concentrate. Even having more difficult washability characteristics, the KC grade coal produces 10.68% of additional sellable concentrate which correspond to 41.1% of coarse coal middlings. Due to high amount of this product recovery of organic matter is improved by 13.30%. Middlings of the OC grade are liberated more easily, which resulted in 3.75% increase in combustibles recovery up to 92.47% providing extra 3.27% of sellable concentrate corresponding to 72.8% of 13–100 mm size middlings.

Conclusion

Based on conducted laboratory tests and computer simulations, it is clear that recycling of coal middlings can provide additional value for processing plant. It also will help solving issues with huge stockpiles of middlings accumulated on mine site by reprocessing them into low-ash concentrate. However, this research has been focused only on coarse middlings, which are comparatively easier to liberate than finer size classes of coal. As for fine middlings, several possibilities might be considered – from similar approach to more sophisticated methods of valorization, such as reverse flotation or chemical leaching (Jaiswal, 2015; Sriramoju, 2016).

It has been shown on the example of one coal preparation plant that depending on the raw coal characteristics and grade 3 to 10% increase in concentrate yield can be achieved. For the implementation of process flowsheet adjustment and plant refurbishment thorough financial investigation has to be carried out in order to understand whether possible revenues from improved production would pay off the capital costs required for modernization.

Literatura – References

1. COP21. Paris Agreement. New York: United Nations, 2015. 25 p.
2. DAS, A. et al. Efficient recovery of combustibles from coking coal fines. In Mineral Processing and Extractive Metallurgy Review, 31 (4), 2010, p. 236-249. ISSN 0882-7508.
3. EUROPEAN COMMISSION. Report on critical raw materials for the EU. Brussels, 2014. 41 p.
4. ISO 7936. Hard coal – Determination and presentation of float and sink characteristics – General directions for apparatus and procedures. Geneva: International Organization for Standardization, 1992. 19 p.
5. JAISWAL, S. et al. An overview of reverse flotation process for coal. In International Journal of Mineral Processing, 134, 2015, p. 97–110. ISSN 0301-7516.
6. OKI, T. et al. Calculation of degree of mineral matter liberation in coal from sink-float separation data. In Minerals Engineering, 17 (1), 2004, p. 39–51. ISSN 0892-6875.
7. SRIRAMOJU, S.K. et al. Optimization of process conditions for leaching of middling coal. In International Journal of Coal Preparation and Utilization, 2016, in press. ISSN 1939-2699.

Recykling przerostów węglowych – droga do zwiększenia wydajności koncentratu handlowego

Ze względu na niską jakość, półprodukty z wzbogacania węgla często pozostają niewykorzystane i są przechowywane na terenach przemysłowym lub po prostu składowane na składowisku. Autorzy pro-ponują rozwiązanie problemu wykorzystania przerostów; główną ideą jest modernizacja schematu technologicznego zakładu przeróbki węgla poprzez wzbogacanie produktu pośredniego, który pozwoli uzyskać koncentrat handlowy. Takie podejście zwiększy wydajność przeróbki, pozwala na komplekso-we wykorzystanie surowców mineralnych, ograniczają straty substancji palnej z węgla i będą genero-wać wyższe przychody ze sprzedaży wysokiej jakości koncentratu węgla. W artykule przedstawiono wyniki badań półproduktów z wzbogacania węgla kamiennego jako potencjalnego surowca do produk-cji koncentratu handlowego. Zakład wzbogacania jest zlokalizowany w Zagłębiu Kuźnieckim w Rosji. Próbki zostały rozdrobnione do wielkości 13 mm, a następnie przeprowadzono analizę densymetryczną i poddano separacji grawitacyjnej i flotacji w warunkach laboratoryjnych. Wykazano, że półprodukty z przeróbki węgla koksowego mają duży potencjał do uzyskania wysokiej jakości koncentratu. Progno-zowany bilans masowy proponowanego schematu dla wtórnego wzbogacania półproduktów pokazuje, że 50 do 80% całkowitej ilości półproduktów można wzbogacić w celu uzyskania koncentratu węgla o niskiej zawartości popiołu.

Słowa kluczowe: wzbogacanie węgla, półprodukty, recykling, wzbogacanie grawitacyjne, symulacja procesu, Kuznieckie zagłębie węglowe