Geotechnical approaches to coal ash content control in mining of complex structure deposits

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Abstract. Coal deposits having complex structure and nonuniform quality coal reserves require improved processes of production quality control. The paper proposes a method to present coal ash content as components of natural and technological dilution. It is chosen to carry out studies on the western site of Elginsk coal deposit, composed of four coal beds of complex structure. The reported estimates of coal ash content in the beds with respect to five components point at the need to account for such data in confirmation exploration, mine planning and actual mining. Basic means of analysis and control of overall ash content and its components are discussed.

The Institute of Mining of the North, SB RAS, has proposed a new approach to estimating ore dilution based on continuous expansion and upgrading of the knowledge and understanding of the nature of a geological environment [1], considering mechanisms of technological conversion of a georesource into a finished product [2]. This has enabled enhanced extraction of mineral reserves with the improved efficiency of mining based on the rational ore pretreatment.

The research is continued in terms of coal reserves. The present-day situation forces to launch mining operations in coal fields with the increasingly complex structure of beds, and, by analogy with ore deposits, the new knowledge is required to maximize the effect of coal quality management based on the available and new synthesized information on the georesource. With this end in view, it has been proposed to assess coal ash content as a composition of natural and technology-induced impoverishment [3, 4]. Owing to more comprehensive analysis of structure and occurrence of a mineral substance in coal, this approach allows finding potential ways of auxiliary preparation of coal for dressing on-site, in an open pit mine, based on generation of coal flows with more uniform process properties for individual preparation of these flows for the purposes of enhancement of dressing efficiency. Ash content is proposed to be presented as a sum of at least five constituents: (1) dirt in roof, floor and damage zones (A^d_1); (2) extractable dirt bands and high-ash coal bands inside a bed (A^d_2); (3) unextractable thin dirt bands (A^d_3); (4) mineral particles of sand, clay and dust impregnated in coal and filling joints and pores (A^d_4); (5) matrix inorganic mineral admixtures (A^d_5).

As a test object to estimate the constituents of ash content and to study controllability of this quality index, the western site of Elginsk deposit has been selected; this site is composed of four beds of a complex structure, which is confirmed and refined by analyses of geometrical parameters of these coal beds and spatial variability of ash content in them [5]. For such high-ash and difficult-to-process coals, it is of high concern to find ways of enhancing utilization efficiency. The main coal beds are represented by two flat-dipping series 5–10 m thick. The design method is run-of-mine output, and coal, being highly mineralized

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per se, is additionally impoverished due to numerous intra-bed dirt bands (more than 0.05 m thick) and thinner (less than 0.05 m) intercalations and lenses neglected by geologists in the reserves appraisal.

Currently the deposit is under complementary exploration, advanced sampling of coal and first-stage mining in the site chosen as a test object. In 2015 Elgaugol company produced 3.95 Mt of coal [6]. The preparation plant of the company produces concentrate to manufacture standard charred coal and to be used in PCI technologies. The structure of the preparation products, as compared with the products of the other preparation plants, e.g. in Neryungri, is ineffective due to low yield of the concentrate and high yield of tailings.

On the test site, the above listed constituents of the ash content index were assessed using the available and permanently updated Database of Elginsk Coal Sampling. The studies involved various geological information systems, and the known and new-developed and adapted calculation methods [5]. As a result, in the four main beds (with the total ash content from 26 to 40%), A^d_1 makes 4.6–7.5%; A^d_2—7.2–21%; A^d_3—4.9–8.4%; A^d_4—55.5–77.4%; A^d_5—2.0–10.2%. Mapping of ash content contours for individual constituents with a view to studying their spatial variability shows that the structure and combinations of the constituents in areas with the same values of total ash content differ. This means that an area of coal beds with the uniform values of the total ash content can be additionally ranged into zones where this or that constituent prevails. As a consequence, though potential complication of mine planning processes, we have a potential to arrange quality control over coal forwarded to preparation.

Development and implementation of the ash content control with regard to effect of individual constituents should be based on assuming the deposit–open-pit mine–preparation plant chain as a unified process space where various processes are integrated for enhancement of end-to-end efficiency, such as: (1) operating exploration and advanced sampling of a deposit; (2) long-term and current mine planning; (3) coal extraction in face areas of different geometry and production output; (4) preparation of coal to dressing by technological and organizational influence of generated coal flows (separation and fusion of coal flows, use of ground-type or "wheeled" storages, etc.).

Coal flows appear when coal mass turns to a broken mass of coal and rocks after drilling and blasting or re-excavation, i.e. when georesource passes from static state to dynamic state connected with the motion of excavated or prepared coal. The existing mining technology at Elgaugol provides for differentiation, multiple separation and fusion of produced coal flows. In this case, in focus is, first of all, oxidation of coal (characterized by the plastic layer thickness, free bloating index, and American standard oxidation index) and ash content (concentrate produced by preparation of borehole and face samples under laboratory conditions at the partition density of 1350–1400 kg/m^3, overall for a bed, regardless dirt bands thicker than 0.05 m, the so-called "net").

Inclusion of the ash content constituents in the coal product quality control can and should result in generation of new coal flows. The expediency of such differentiation ensues from the fact that processing of coal mass with more uniform quantitative characteristics, physical properties and grain-size composition will produce additional concentrate of higher value and marketability as compared with middlings. According to [7], simple reduction in size of Elginsk coal from -50 mm to -8 (-6) mm by re-milling to obtained better dissociation of highly mineralized coal and rock aggregates allow increment in the yield of the concentrate by 8–17% with the ash content of up to 10% at the concurrent reduction in the yield of middlings that are poorly merchantable. Based on the discussion and analyses of such notions as "limit potential" (maximum theoretically achievable value of mineral reserves) and "attainable potential" (recoverable value achievable using advanced technologies) in terms of Talda deposit in Kuzbass, it is clear that high technologies of mineral mining and processing as against the conventional run-of-mine output with overall coal preparation offer an increased potential of mine projects [8]. Application of the technology of thin blast-free slicing with Wirtgen surface miners at one of the Australian deposits, as compared with the common techniques, enabled high yield of the concentrate from 63 to 75% at the simultaneous decrease in the coal as content by 4% and the increase capacity of preparation plant [9].

In the conditions when it is necessary to enhance efficiency of utilization of coal reserves in each bed and each extraction area, a better insight into the nature and generating mechanisms of coal ash

content assists in adaptation of these processes and/or their elements (in planning or in operation) to the changed understanding of georesources. The processes (1)–(4) specified above in this paper are capable of including any analysis tools and control methods to deal with the overall ash content and its constituents. Engineering decisions, technologies and process flow charts, or organization, informational and economic methods to generate and control coal flows are the result of analyses of a sufficient body of information, patent search and approaches developed with the participation of the present article authors. They have no pretensions to omnitude but they are fruitfully used in mines in Russian and/or in the world and are proposed in scientific literature and design documentation.

At the stages of supplementary study of georesources and mine planning, it is possible to use various analysis approaches or their combinations in order to enrich the knowledge on a study object and to generate rational plans of mining (Table 1: gray color marks the analysis tools meant either for an ash content constituent or for the overall ash content). Individually, some decisions and methods in regard to complex-structure coal deposits are discussed, for instance, in [10–16].

Table 1. Analysis tools useful at stages of supplementary exploration and mine planning.

Supplementary exploration and mine planning	A^d_1	A^d_2	A^d_3	$A^d_{overall}$
Studies and mapping of damage zones and interfaces of roof and floor rocks and coal				
Detection of geologically and geotechnically uniform extraction zones and their mapping per beds and extraction sites				
Estimation of potential reduction in ash content and its constituents (natural impoverishment)				
Mapping of contours of overall thickness of beds				
Analysis of ash contents in boundary layers (floor–roof of beds)				
Analysis of structural complexity, spatial variability of ash content in beds, evaluation of reliability				
Additional analysis of physical properties of coal and intra-bed intercalations				
Improvement of exploration methods and means and supplementary study of the constituents of ash content				
Express-methods of ash content study in coal–rock mass, analysis of petrography of coal substance				
Rating of coal reserves in regard to their preparation to mining, considering spatial variability of coal quality				
Planning of concurrent operation of production faces, accumulating and/or blending coal storage yards				

The commonly used tools of analysis (Table 1) acquire specific value and find new application in the context of the proposed differentiation. For instance, mapping of uniform zones of the overall ash content and its constituents, for more comprehensive and appropriate assessment of which, it is required to upgrade and improve the available procedures and methods of mineral exploration and sampling. The cost of such modernization seems economically expedient when mining large complex-structure coal beds, panes or deposits.

Based on the evidence obtained with the proposed analysis tools, it is possible to implement coal quality control using different methods (Table 2) [5, 9–13, 16–20). The list in Table 2 is also incomplete, it should be continuously replenished, ranked and improved. At the same time, even these

actions, after the relevant technical-and-economic evaluation and proof, are sufficient to reach more complete extraction of mineral reserves per unit extraction volume.

Table 2. Measures to control coal quality at the stages of mining and preparation of coal in an open-pit mine.

Coal mining and preparation in an open pit mine	A^d_1	A^d_2	A^d_3
Ranking of coal in terms of its preparation to extraction and based on its ash content, considering number and output of production faces	■	■	■
Norming of geotechnical impoverishment	■		
Variation of production face parameters per beds and extraction panels		■	■
Scraping of coal–rock contacts, generation and control of separate coal flows	■	■	
Selective extraction of dirt bands and coal of different quality, and generation of coal flows with more uniform coal quality	■	■	■
Generation of sub-benches, considering coal quality in different layers		■	■
Preliminary cleaning of coal in face areas and intermediate storage yards	■	■	
Change of grain composition by loosening using drilling and blasting		■	■
Employment of surface miners, bulldozers and scrapers	■	■	■
Generation of storage yards to keep coal with the same characteristics	■	■	■
Blending in stationary and “wheeled” storages (various schemes)	■	■	■
Coal grinding in storage yards in an open pit mine	■	■	■
Integration and fusion of coal flows from face areas and from storage yards	■	■	■

Conclusion

The supplementary analyses of the data obtained in additional exploration at Elginsk deposit offered new information on structure of ash content of ill-dressable coal planned for extraction, considering natural and geotechnical impoverishment of coal.

The studies into geometry of coal beds and spatial variability of coal ash content divided into a few constituents have discovered advisability of adjustment of current approaches to coal ash content control within the single geotechnical space generated by Elginsk coal deposit–open pit mine–preparation plant.

The authors have proposed a package of the analysis tools and measures of technological and organizational control over coal flows generated in the course of mining in the framework of coal quality management system to be created and improved at Elginsk deposit.

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