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NATURE-ORIENTED OPEN COAL MINING TECHNOLOGIES USING MINED-OUT SPACE IN AN OPEN PIT. PART I: ANALYSIS OF THE CURRENT MINERAL MINING METHODS

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An analysis is performed into the currently applied coal mining methods using mined-out space in an open pit, with describing their basic advantages and disadvantages. The urgency of further development and wider application of the gritwise-and-capwise methods that involve differently directed advance of a mining front and mined-out space utilized to the limit for overburden storage is pointed out.

Coal production, mining method, open pit, mined-out space

The key point for the open-pit mineral mining to be effective is a rational sequencing. The sequencing means selecting a series of working area development operations such that the use environment be advantageous for the whole life of an open pit. The practice of design and operation of open pits located above stratal flat and inclined deposits extensively employs a girtwise mining method when an open-pit field is worked out by single-breasted quarries, with horizontal or inclined slicing (benches) for the whole length of the field. In this case, excavator breast advances on the strike, while mining front advance (MFA) is across the strike. This sequence allows long-term operation on upper levels, with small stripping ratios (above the average over the open-pit field) and ensures high productive capacity of the pit (when the working area is duly equipped with mining and hauling machinery). However, in the face of these benefits, the girtwise mining method has some serious drawbacks [1 – 3]:

— the overburden volume continuously grows for the whole period of main operations;

— the rock mass haulage distance increases as mining gets to lower levels, which entails large operating costs;

— the total length of MFA and, consequently, of transportation communications grows with deepening of the open pit;

— great areas are engaged in external dumping (external dumps of inclined and steep deposits hold up to 100 % of overburden, this index for flat deposits is from 20 to 65 %);

— the earth's surface is severely disturbed by mining operations which also deteriorate the natural environment;

— the disturbed surface reclamation is impossible during the open pit operation, and there is a large time gap between the earth's surface disturbance and redamation.

Today subsoil users are faced with more rigorous terms and have to pay for utilizing natural resources. In these conditions, the above listed drawbacks exert a high impact on the operating open pits and make the girtwise mining sequence low-promising for application to newly developed deposits.

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Searching for new updating solutions for mining systems (MS) and methods for worked-out open-pit reserves to be used more completely, researchers and design and mining enterprises' experts have proposed a series of earth-saving technologies based on various mining sequencings. As an example, the scheme in Fig. 1 gives a systematized review of the open mining technologies, with internal dumping on inclined and steeply dipping deposits; also the environmental level of the technologies is estimated in the form of an ecological cleanness factor (ECF) that involves the degree of mining practice impact on all natural resources [2].

Analysis of the technologies has shown that, as compared with the girtwise MS (taken as the reference), capwise and combined mining methods achieve the highest cost-performance ratios and ecological indices, as the mined-out space finds more efficient exploitation and mining scheduling is thereby optimized, overburden haulage distance is shortened by a factor of 1.2 – 1.4 and volumes of earth works are cut down by a factor of 1.5 – 1.7.

What unites these technologies is the presence of a primary open pit where internal dumping formation starts. Nevertheless all of the technologies can be divided into two groups.

The first group includes those variants where the primary open pit is mined to the total depth and the whole overburden volume (for inclined or steep dipping deposits), or a part of it (for flat deposits) is taken off to external dumps. The primary open pit has a cuneiform shape and is mined by the girtwise MS. This group has two subdivisions. The first subdivision is a family of the technologies where the primary open pit is created within a mining lease, in a bounded open-pit field area, with the downward girtwise MS applied. The secondary operation period of the deposit involves placing of overburden rocks in the new-created mined-out space. Here it is possible that MFA would turn over, and further mining would be capwise allwork or capwise slicing, as well as block mining with the girtwise system is also potential [4 – 7].

It is evident that the technologies of the discussed family resemble one another with respect to reserves extraction level, stripping costs, earth surface disturbance and reclamation indices, while their difference is the mining regime. The regime is more favorable in the capwise MS when the secondary mining adheres to keeping the open-pit working area parameters constant. However, the mining regime graph plotted for these technologies when applied to forming the primary open pit will have the saw-like shape as for the girtwise MS [1, 2].

The second family technologies of this group also presuppose the two-stage mining. During the first-stage mining until the total depth, in order to improve the mining regime, seams are extracted at the same time as they basset under detrital deposits on the whole open-pit field [2, 5]. The second stage is either longwall capwise MS, or extraction by strips on the dip and MFA along the strike, with complete internal dumping. The over-field mining of the seams considerably enlargers the area of the extracted earth and aggravates the second-stage mining regime.

As compared to the downward MS, the first group technologies offer overburden rock storage in the created mined-out space and thereby allow highly elevated indices of the open-pit mining along the strike: earth works volume, rock mass haulage distance, mining regime. The application sphere of the technologies captures also horizontally extended stratified deposits (less than 4 – 5 km along the strike) where it is economically sound to build and operate the long-term serviceable open pits. Once the stratified deposits mostly get deeper than the estimated open-pit boundaries, selecting the technology must follow after sufficiently exact determination of the total depth and expediency of storing rock masses in the mined-out space. According to [8], for such technologies with simple reproduction of the mined-out space, an open pit must have the depth of 110 – 250 m maximum. The main drawback of these technologies is a long period the first-stage open pit construction takes.

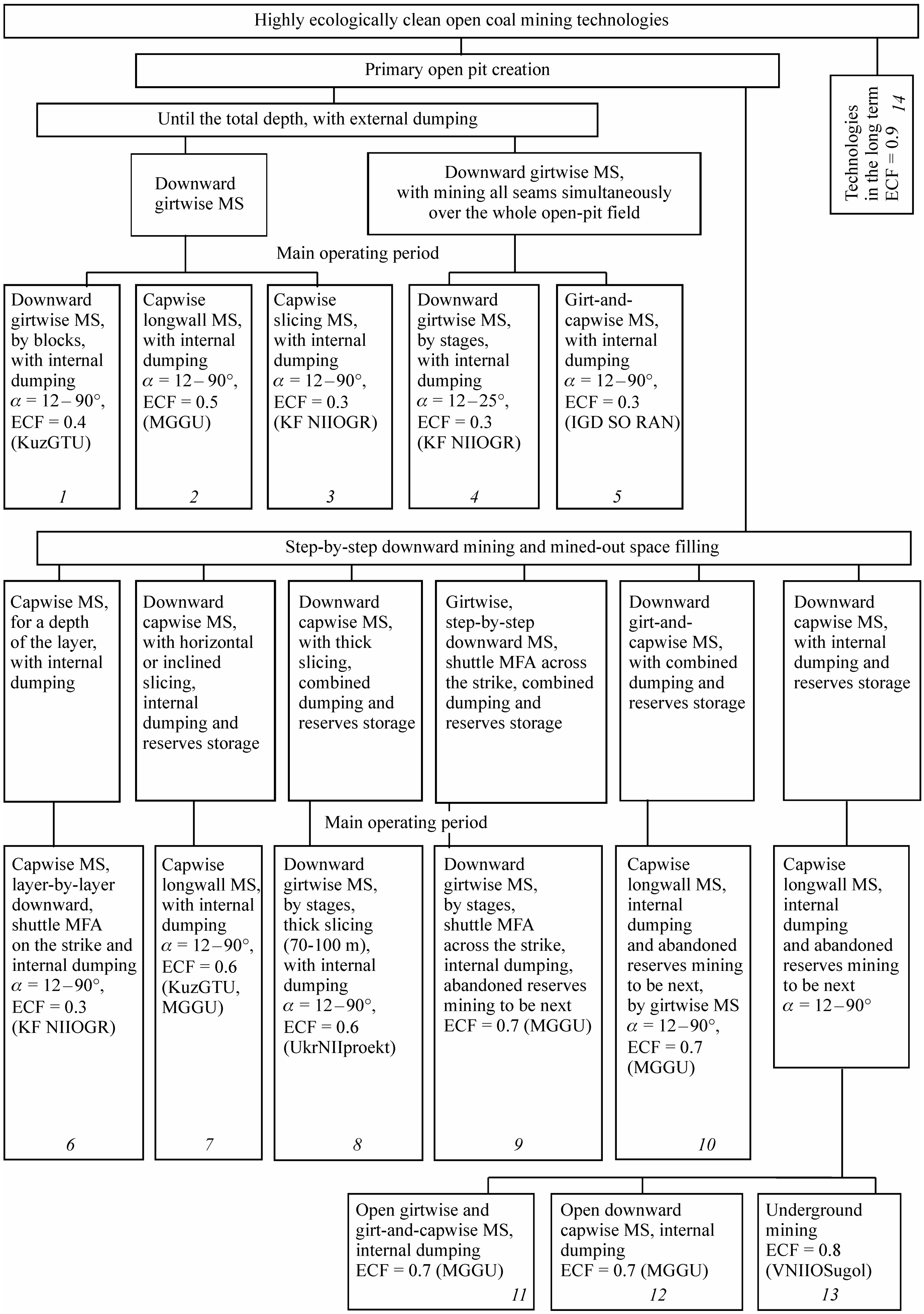

Fig. 1. Classification of open coal mining technologies: α — stratification dip angle; given in brackets is the designer of the technology; *1*, *2*, ... *14* — number of the technology

A feature of the second group technologies is that the first-stage open pit is constructed by step-by-step mining getting deeper along the strike of the seams with filling at the same time the mined-out space with overburden rocks. The downward girtwise, capwise or girt-and-capwise MS allows the external dumps volume to be cut down partially or in full already in the beginning of the open pit operation and the disturbed land reclamation to be drawn nearer. This group has three subdivisions of the downward technologies.

The first family includes the technologies where downward mining is performed layer-by-layer, overburden rocks are placed on the mined-out layer surface, MFA is shuttle, along the strike of the productive thickness, within the boundaries of the open pit. The absence of the external dumping, as a good factor, is worsened by large volume of current earth works (particularly in the beginning of the open pit operation).

The second family encloses the technologies with step-by-step mining downward, by the capwise inclined (horizontal) slicing or girtwise thick horizontal slicing. These technologies presuppose that a part of the open-pit mineral reserves is abandoned under the internal dumps, which makes the indices of the earth works and mining profitability worse.

The third family technologies propose engineering solutions to extract the abandoned reserves under the internal dumps by applying an open or underground mining method.

The open mining of the abandoned minerals takes place after the open pit has reached the final contour of the deposit, by turning back to the zone of mining start, by stripping the abandoned reserves through the dumps and mining them up to the total depth, the overburden placed in the so-formed mined-out space (the second stage) [9]. These solutions require secondary mining of a greater part of the dump and disturbance of the already reclaimed surface. These circumstances, together with the mining zone loosing the height and the high stripping ratio, reduce efficiency of the reserves removal from storage whereupon some of the reserves is non-extracted.

The underground mining of the abandoned mineral reserves needs driving special-purpose workings on the bottom and in the walls of the pit, in trenches driven in rock mass, or directly in the dump body. While MFA goes on, the workings are extended and filled with overburden. Under-the-pit reserves are extracted at the same time as the open mining, or after it, by the underground method, with goaf stowing, which eliminates the reclaimed dump surface disturbance [10]. The fill is crushed overburden rocks. According to [8], the second group technologies, if classified by the mined-out space creation and utilization, relate to the technologies with continuous or discontinuous, expanded reproduction of the open pit area.

So, the most ecologically safe technology of the first group is the girt-and-capwise open-pit field mining: the first stage is the downward girtwise MS up to the total depth, with external dumping; the second stage is the capwise longwall MS, with stable parameters of the working area and overburden storage in the mined-out space (Fig. 1, technology *2*).

In the second group, the highest ecological cleanness is demonstrated by the technologies with stage-by-stage downward mining on the strike, internal dumping and open or underground mining of under-the-dump abandoned mineral reserves (Fig. 1, technologies *11*–*13*).

It is worth of noting that the technologies that are discussed above are applicable to steeply dipping or inclined stratal deposits. There are less innovation techniques developed for flat deposits (this is probably due to their reaching in practice the high indices of the mined-out space utilization and earth works volume).

Wide outspread of coal deposits (Kuznetsk Basin, KATEK, South Yakutia) has provided the basis for the Institute of Mining to update mining technologies for flat and inclined deposits where the technogenic resource of the mined-out pit areas is engaged to the highest extent. In particular, a method has been proposed [11 – 13] where some features of the first and second groups technologies are combined. This method presumes two-stage mining: the first stage is the capwise inclined, gradually-downward MS on the strike, simultaneous goaf stowing with overburden; the second stage is the capwise longwall MS, underground excavation of the temporarily abandoned reserves through an inclined shaft (gallery) which is sunk prior to starting internal dumping. This method differs from those discussed above by the shape of technological space of the primary open pit, its working wall structure, MFA direction in the working and dumping areas, inclined arrangement of the working wall in on-the-strike mining of the second open-pit stage. Together, these differences and similarities represent the sense of the proposed technology of the girtwise-inclined-capwise mining sequence.

The research data analysis for the strata dip angles $\alpha = 12 - 25°$ and the open pit depth of $90 - 255$ m [12, 13] indicates the proposed mining method for flat and inclined deposits to ensure a better cost-performance ratio already at the primary open pit creation stage even against the highest economically and ecologically safe girt-and-capwise mining system (Fig. 1, referent variant, technology *2*).

During this period, the stripping operations volume, the mineral production being the same as in the variant analyzed, may be lessened by a factor of 1.4 – 1.8; average stripping ratio, by a factor of 1.6 – 2.5; weighted mean haulage distance, by a factor of 1.6 – 1.9; stripping and production stream of supply, by a factor of 2.8 – 4.2; unit earth works volume, by a factor of 1.3 – 1.5. Overburden volume for the internal dumping is 25 – 30 % of the total overburden volume got in the primary open pit. In the second-stage open pit mining, the average stripping ratio is higher than in the reference variant by a factor of 1.1 – 1.3 while the weighted mean haulage distance is shorter by a factor of 1.1 – 1.3. The proposed technology substantiates this fact by an inclined position of the open-pit working wall, which favors the optimum development of the transportation network. Besides, load per 1 km of the mining front lowers by a factor of 1.4 – 1.8 due to the working wall being longer when in the inclined position, thus it becomes possible to intensify the second-stage mining. The rest indices of the second-stage mining are almost equivalent in the analyzed variants of the technologies.

The research carried out shows that the technology for the girtwise-inclined-capwise mining sequence ensures highly efficient production and ecological safety in flat and slightly inclined deposits.

In later publications the authors are going to develop the proposed technology and open-pit space formation methods such that the internal dumping be a maximum.

CONCLUSIONS

The widely applied downward girtwise mineral mining technologies are resource-hungry and have a great impact on the environment.

It is possible to improve the efficiency and ecological safety of the open mineral mining mainly by utilizing rationally the technogenic resource of the mined-out space formed in the open pits, by way of optimization of the mining sequencing.

The current ecologically friendly technologies are divided into two groups with respect to the formation and utilization of the mined-out space in the open pit:

— simple reproduction of the mined-out space; here, the best ecology and economy performance is demonstrated by the technologies of the girt-and capwise mining sequence for the open-pit working area;

— expanded reproduction of the mined-out space; in this group, the higher ecological and economical indices belong to the technologies of step-by-step deepening mining on the strike and then open or underground mining of mineral reserves abandoned under the internal dumps.

The researchers of the Institute of Mining, Siberian Branch of the Russian Academy of Sciences have developed two innovation technologies for mineral mining in flat and slightly inclined deposits:

— the technology with simple reproduction of the mined-out space, that presumes over-the-whole-pit field mining during the period when creating the primary open pit;

— the technology with expanded reproduction of the mined-out space and with the girtwise-and-inclined mining sequence for the working area of the primary open pit; this technology allows the stripping operations volume, instantaneous stripping ratio, average haulage distance, stream of supply and a unit earth works capacity to be largely decreased.

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