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CALCULATION OF THE OVERBURDEN RATIO BY THE METHOD OF FINANCIAL AND MATHEMATICAL AVERAGED COSTS

Purpose. To calculate the parameters of the development of brown coal deposits, including the limiting overburden ratio, when involving coal clay into the development together with brown coal in the composition of the coal mass.

Methodology. To calculate the cost of mining a mineral, the method of financial and mathematical averaged costs was applied, considering the level of projected capital investments and the cost of investment funds.

Findings. The influence of the involvement of coal clays in the development together with brown coal as a part of coal mass on the limiting overburden ratio is investigated. It is determined that the limiting overburden ratio for a mining enterprise that extracts brown coal is 20 m³/t, and for the extraction of coal clay in a mixture with raw brown coal – 17 m³/t. The parameters of brown coal production in Novo-Dmytrivske deposit have been established, which have shown that with a coal production of 9 million tons/year, the overburden ratio is 4 m³/t. In the case of extraction of associated minerals in the form of coal clays, the opencast capacity can increase up to 20 million tons/year, and the overburden ratio will decrease down to 1 m³/t.

Originality. The dynamics of the change in the current overburden ratio over the years for the extraction of coal mass with the share of coal clays from 0 to 50 % for the conditions of Novo-Dmytrivske brown coal deposit has been established. The costs to produce raw coal have been determined in terms of both natural and conventional fuel. The modelling of the costs for the extraction of minerals and rock mass, depending on the overburden ratio, has been carried out. The change in the overburden ratio was determined when coal clay and off-quality brown coal were involved in the production in comparison with the production of raw brown coal.

Practical value. It has been established that those deposits and areas that were previously related to the development of the mine method or open-pit mines with large losses of coal during the complex mining of conditional seams of raw brown coal, off-quality seams, and coal clays, can potentially be mined with minimal losses of useful fossil and with low cost.

Keywords: *brown coal, coal clays, coal mass, limiting overburden ratio, mining cost*

Introduction. When designing and planning open pit development, the establishment of the final and current contours of the quarry is determined considering such efficiency indicators as the overburden ratio, the rock mass ratio, or the extraction ratio. Depending on the unit of measurement, there are coefficients of weight (t/t), volume (m³/m³) and mixed coefficients (m³/t; t/m³) [1, 2].

Now the problem of establishing the ultimate (final) contours of the quarry is solved by comparing the limiting overburden ratio with the contour, average and/or current overburden ratios [3]. This measure was introduced in the middle of the twentieth century due to the complexity of calculations related to the establishment of economically feasible depth of open pit mining by calculating the cost of mining.

The introduction of these coefficients was aimed at simplifying the calculations of the ultimate depth of open-pit mining. It was assumed that the value of the ultimate overburden ratio is constant. As an exception, different coefficients were taken for the development of capping mass and hard rocks. With this in mind, it should be noted that the value of the ultimate overburden ratio depends on the actual cost of extraction of minerals, overburden and the allowable cost of extraction of minerals (for example, the cost of underground extraction) [4, 5].

Literature review. Research by Rzhovsky V.V. proves that the increase in the cost of mining with increasing depth of development is influenced by the cost of transportation of rock mass. With the change in the depth of mining, the error in the calculation of the cost of development of the field is 3–15 %

and may not be considered. However, with the increase in the depth of open pit development to 500 m and more, the share of transportation in the cost of rock mass increases and now is 50–70 % [6, 7].

Therefore, the value of the ultimate overburden ratio can no longer be used to establish the final contours of the quarry. And the attempts to apply correction coefficients to this value contradict the idea of introducing an overburden coefficient – simplification of the procedure for setting the boundary quarry contours.

Therefore, with increasing accessibility and simplifying the electronic computing means, when setting the boundary position of the quarries' contours, it is more appropriate to comply with the conditions proposed by prof. Blyznyuk V.G. [8, 9] that the actual costs for the development of a deposit for a certain period of its operation (C_a , UAH) should not exceed the eligible costs (C_e , UAH)

$$C_e \geq C_a;$$

$$C_e = Pc_e A_p T,$$

where Pc_e is eligible production cost of 1 ton of a mineral, UAH; A_p is annual mineral productivity of a quarry, t; T is deposit exploitation period, years.

The value of eligible costs should be calculated considering the market situation and the rate of return from the deposit development. The actual costs should consider the cost of open-cast mining in certain career contours. Moreover, in view of the above, it is recommended that the cost of all processes except transportation be conditionally accepted as a constant value ($C_d = \text{const}$, UAH), while the rock mass transportation costs (C_t , UAH/t · km) be accepted as increasing value depending on mining depth [10]

$$C_a = C_d(V_p + P_K) + \sum_{i=1}^n C_i l_i (V_{pi} + P_{Ki});$$

$$l_i = f(H_i),$$

where n is the number of horizons inside a quarry space; V_{pi} , P_{Ki} are overburden rock and mineral volumes on the horizon number “ i ”, m^3 ; l_i is distance of transportation of rock mass from the i -horizon to the surface, km; H_i is i -horizon bedding depth, m.

In addition to transportation, the content of the useful component in the ore and the cost of its production are important in calculating the parameters of open field development, in particular the depth of development [11, 12].

Besides, the definition of design contours of opencast mining should consider the dynamics of the external competitive environment of the mining company, the risks associated with changes in market conditions, the cost of final products and demand for it [8, 13].

Unsolved aspects of problem. Determining the operational overburden ratio should be considered on the example of powerful Novo-Dmytrivske brown coal deposit with the involvement of coal clays. Studies have shown that coal clays overlap the Upper and Complex coal horizons [14]. Considering their high ash content and low calorific value, the use of their entire volume as a separate associated raw material is not possible. However, in a mixture with raw brown coal, rock mass (raw brown coal + coal clay) is an energy raw material that is suitable for further use.

It is projected that with the simultaneous commissioning of brown coal mining enterprises, Ukraine can annually produce at least 15 million tons of brown coal and much more taking into account the coal clays— 20 million tons/year. Per ton of conventional fuel, production may be more than 4.7 million tons of conventional fuel, which will fully cover the projected deficit in the gas group of coal in the amount of 4.4 million tons/year by 2030.

Involvement in the extraction and processing of coal clays not only expands the base of application of this technology, but also increases the efficiency of mining enterprises and, finally, reduces the impact on the environment during opencast mining.

In this regard, it is proposed to consider as a mineral not only coal separately from coal clay, but also coal mass, a mixture of coal and clay in certain proportions. Residues of coal mass that will not be used in the mixture are classified as overburden.

Purpose. Using the method of financial and mathematical average costs to calculate the parameters of the development of brown coal deposits, in particular the ultimate overburden ratio, with the involvement of coal clays in the development together with brown coal as part of the coal mass.

Calculation of the overburden ratio in the development of coal mass. During coal mining, its operational losses occur in the roof and sole of the productive stratum, as well as in the roof and sole of the interlayer seams. In this case, operating losses ($P_{b,e}$, m^3) are calculated as follows

$$P_{b,e} = \sum_{i=1}^n h_{b,e,i} S_{k,n,i},$$

where n is the number of contacts of rocks with minerals; $h_{b,e,i}$ is the zone thickness of the i -contact of rocks with minerals, m (0.1 m); $S_{k,n,i}$ is the area of the i -contact of rocks with a mineral, m^2 .

Since the seams of coal clay are in contact with the brown coal seams, and, taking into account the fact that coal mass is considered as a mineral, not coal separately, and in order to ensure the most efficient use of the deposit, the volume of coal clay per contact with brown coal is considered as the minimum required in the proportion of coal mass ($P_{b,g,min}$)

$$P_{b,g,min} = \sum_{i=1}^{n_b} h_{k,b,i} S_{k,b,i},$$

where n_b is the number of contacts of coal with coal clay; $h_{k,b,i}$ is thickness of the zone of the i -contact of coal with coal clay, m (0.1 m); $S_{k,b,i}$ is the area of the i -contact of coal with coal clay, m^2 .

Then the operational reserves of brown coal should be calculated by the formula ($P_{e,b}$, m^3)

$$P_{e,b} = P_{n,b} - \sum_{i=1}^{n'_b} h'_{k,b,i} S'_{k,b,i},$$

where $P_{n,b}$ is industrial coal reserves, m^3 ; n'_b is the number of contacts of coal with rocks, except for coal clays; $h'_{k,b,i}$ is thickness of the zone of the i -contact of coal with rocks, except for coal clays, m (0.1 m); $S'_{k,b,i}$ is the area of the i -contact of coal with rocks, except for coal clays, m^2 .

Minimum operating reserves of coal mass ($P_{m,e,min}$, m^3) is

$$P_{m,e,min} = P_{n,b} - \sum_{i=1}^{n'_b} h'_{k,b,i} S'_{k,b,i} + \sum_{i=1}^{n_b} h_{k,b,i} S_{k,b,i}.$$

Operating coal mass reserves of the required proportion of coal and coal clay ($P_{m,e}$, m^3) are

$$P_{m,e} = P_{e,b} \left(\frac{1}{1 - n_{b,m}} \right),$$

where $n_{b,m}$ is the proportion of coal clay in the coal mass, fractions of a unit.

Volume of coal clay in coal mass ($P_{b,g,m}$, m^3) is

$$P_{b,g,m} = P_{e,b} \left(\frac{n_{b,m}}{1 - n_{b,m}} \right).$$

Total operational reserves of coal clays ($P_{b,g,z}$, m^3) are

$$P_{b,g,z} = P_{n,b,g} - \sum_{i=1}^{n''_b} h''_{k,b,i} S''_{k,b,i},$$

where $P_{n,b,g}$ are industrial reserves of coal clays, m^3 ; n''_b is the number of contacts of coal clays with rocks, except coal; $h''_{k,b,i}$ is thickness of the zone of the i -contact of coal clays with rocks, except coal, m (0.1 m); $S''_{k,b,i}$ is the area of the i -contact of coal clays with rocks, except coal, m^2 .

Thus, when calculating the operational reserves of coal mass, the condition must be met

$$P_{n,b} - \sum_{i=1}^{n'_b} h'_{k,b,i} S'_{k,b,i} + \sum_{i=1}^{n_b} h_{k,b,i} S_{k,b,i} \leq P_{m,e} \leq P_{n,b,g} - \sum_{i=1}^{n''_b} h''_{k,b,i} S''_{k,b,i} + P_{n,b} - \sum_{i=1}^{n'_b} h'_{k,b,i} S'_{k,b,i}.$$

The volume of coal clays that will be classified as overburden ($V_{b,g,z}$, m^3) is

$$V_{b,g,z} = P_{n,b,g} - P_{b,g,m} = P_{n,b,g} - P_{e,b} \left(\frac{n_{b,m}}{1 - n_{b,m}} \right).$$

The operational overburden ratio at coal development ($K_{e,b}$) is

$$K_{e,b} = \frac{V_p + P_{b,e}}{P_{n,b} - P_{b,e}} = \frac{V_p + \sum_{i=1}^n h_{b,e,i} S_{k,n,i}}{P_{n,b} - \sum_{i=1}^n h_{b,e,i} S_{k,n,i}}.$$

The operational overburden ratio at development of coal mass ($K_{e,m}$) is

$$\begin{aligned}
K_{e.m} &= \frac{V_p - P_{b.g.m} + P_{n.b} - P_{e.b}}{P_{m.e}} = \\
&= \frac{V_p - P_{e.b} \frac{n_{b.m}}{1 - n_{b.m}} + \sum_{i=1}^{n'_k} h'_{k.b.i} S'_{k.b.i}}{P_{e.b} \frac{1}{1 - n_{b.m}}} = \\
&= \frac{\left(V_p + \sum_{i=1}^{n_b} h'_{k.b.i} S'_{k.b.i} \right) (1 - n_{b.m})}{P_{e.b}} - n_{b.m} = \\
&= \frac{\left(V_p + \sum_{i=1}^{n'_k} h'_{k.b.i} S'_{k.b.i} \right) (1 - n_{b.m})}{P_{n.b} - \sum_{i=1}^{n'_k} h'_{k.b.i} S'_{k.b.i}} - n_{b.m}.
\end{aligned}$$

Fig. 1 shows that the involvement of coal clays with brown coal as a mixture in the development will reduce the operational overburden ratio and increase the lifetime of the field.

Currently, in the market economy, these techniques can lead to incorrect assessment of both the choice of development method and determination of the quarry field boundaries and, consequently, to the loss of minerals.

In modern conditions, it is necessary to take into account the cost of invested capital when considering the efficiency of a mining enterprise. Therefore, to determine the economic feasibility of mining and processing of minerals, it is advisable to use the *method of financial and mathematical average costs (FMAC)*, which can be used to calculate the ultimate overburden ratio.

Calculation of the ultimate overburden ratio based on FMAC. In the early 1970s, the determination of the choice of working method and the boundaries of the quarry field (technical boundaries of the opencast field) was carried out based on the study of the following data:

1. Mining and geological conditions.
2. The accepted order of mining of the opencast field.
3. Technological features of mining equipment.
4. The ultimate overburden ratio.

In fact, analysing these data, including the capacity of the coal seam, its limits in 2.7-; 2- and 1-meter contours and a limit value of ash content of 40 %, in the implementation of development projects of the field and/or sites, a conclusion

Current overburden ratio

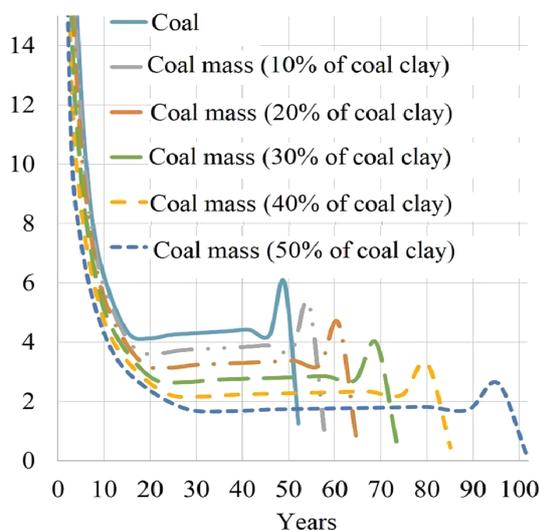


Fig. 1. Dynamics of change in the current overburden ratio over the years

was made about the suitability or unsuitability of open or underground mining. In this case, the main criterion of expediency was the ultimate overburden ratio, which was calculated based on the following equation

$$C_n = C_d + C_b \cdot K_p,$$

according to the following formula

$$K_p = (C_n - C_d) / C_b,$$

where C_n is costs per 1 ton of production during underground development, UAH/t; C_d is costs per 1 ton of minerals during open pit mining (excluding the cost of overburden mining), UAH/t; C_b is costs per 1 m³ of overburden, UAH/m³.

The second variant of this formula was the equation $C_n = C_{ws}$, where: C_{ws} is wholesale (price list) cost of raw coal.

In the prices in the middle of 70–80s the ultimate overburden ratio had the following value, m³/t

$$K_p = (6.23 - 1.74) / 0.4 \approx 11.0.$$

In the late 80s and early 90s of the last century, the ultimate overburden ratio already varied in the range of 12–16 and the value of $K_p = 15$ was considered acceptable.

It is important to note that when calculating the ultimate overburden ratio, the loss of coal in the extraction of minerals was considered, namely:

- losses in the roof of the seam;
- losses in the sole of the seam;
- losses of coal in the selective mining of rock layers;
- losses of coal attributed to outside-balance reserves.

In total, with opencast mining, coal losses could be 7–10 %, and in some cases more. For example, according to Kostiantynivsky open cut, only the first (lower) coal seam was mined, and the second, thinner and unsustainable coal seam, separated from the bottom seam by coal clays, was not taken into account when calculating industrial reserves. However, the losses of coal during opencast mining were significantly less than in underground mining.

A significant difference in the price indicators of production led to the fact that the ultimate overburden ratio, calculated by the formula of the cost correlation of opencast and underground mining was, m³/t

$$K_p = (17.04 - 4.27) / 0.44 \geq 30.0.$$

Obviously, the level of 30 m³/t cannot be considered reliable in practice. Thus, if instead of the cost of mine production to enter the value of the retail price for raw coal of 9.75 rubles/t in the formula, then ratio K_p will be 13.4 m³/t.

With the development of the technical level of mining equipment, areas of brown coal, which were previously considered suitable for operation by the mine method, are transferred to the category of suitable for opencast development.

The use of the method based on the cost of mining the field, in one way or another, has fully justified itself in the past in the planning and administrative system of the economy. However, with the development of market relations in the country, this algorithm has a significant disadvantage – it does not consider capital investment in the mining company and the cost of invested capital. Therefore, at present, this algorithm for determining the ultimate overburden ratio requires modernization.

First, you need to determine the price parameters of the cost of brown coal production and the cost of mining operations. At present, there are no brown coal mining companies in Ukraine, so it is necessary to create an economic model of a conventional mining company. It is incorrect to accept economic indicators on brown coal open casts which existed recently for the following reasons:

1. Brown coal open casts, which were operated in the system of Alexandria coal until 2009 did not function on the project productivity.

Performance indicators of brown coal quarry

Name	Unit	Option with brown coal	Option with rock mass
Mining of minerals	million tons/year	2.30	4.03
Mining of brown coal	million tons/year	2.30	2.30
Mining of coal clays	million tons/year	–	1.73
Overburden ratio	m ³ /t	10.00	5.39
Volumes of overburden rocks	million m ³	23.00	21.72
Excavation costs per ton of useful product			
For overburden mining	UAH/year	142.59	76.89
For actual mining	UAH/year	31.16	31.16
Full operating costs	UAH/year	287.81	173.18
Calorific value of fuel	kcal/kg	2100.00	1685.39
Mining of minerals	million tons of conventional fuel	0.69	0.97
Full operating costs	UAH/tons of conventional fuel	959.38	410.70
Estimated capital investment	million UAH	4467.27	4404.31

2. The available mining equipment of Soviet design or German production of the 30s of the last century does not correspond to the modern development of mining engineering.

3. Price parameters of the late 90s and early 2000s do not reflect current values.

Therefore, the German data on economic parameters of the mining enterprise on an example were accepted as a basis:

Master plan for the development of the brown coal industry of Ukraine in relation to Kostiantynivsky opencast.

Economic and technologic aspects of Bucketwheel Excavator – and Crusher/Conveyor-Systems Dipl.-Ing. D. Schröder Krupp Fördertechnik GmbH, Essen, Germany.

Kostiantynivsky opencast was chosen as the object of study for the following reasons:

1. It is one of the youngest mining companies put into operation in 1987.

2. The average overburden ratio for the enterprise was 9–10 m³/t.

3. In the field of opencast, there are not only off-quality coal seams, but also significant reserves of coal clays.

4. Myronivske deposit was exploited by this opencast, which is promising for development.

Given that overburden and actual mining accounts for almost 60 % of the total costs of the enterprise and is conditionally variable, and the remaining 40 % – is conditionally fixed, the full cost of the mining enterprise was calculated.

Thus, with coal production in the amount of 2.3 million tons per year and an operational overburden ratio of 10 m³/t, the cost of brown coal production amounted to 287.8 UAH/t without VAT or, per ton of conventional fuel – 959.4 UAH/t of conventional fuel.

This means that the total cost, considering the spread of conditionally fixed costs for overburden and actual mining, are:

- overburden mining – 23.6 UAH/m³;
- actual mining – 51.6 UAH/t of brown coal.

Similarly, the cost of overburden and actual mining was calculated taking into account the simultaneous extraction of coal clays and off-quality layers/seams. It was assumed that the volume of production of raw brown coal is 2.3 million tons per year, and other coal mass – 1.73 million tons. In total, the volume of production of rock mass is 4.03 million tons per year with a calorific value of 1685.4 kcal/kg or 0.97 million tons of conventional fuel.

It is obvious that the involvement of coal clays in production proportionally reduces the amount of overburden mining and has a positive effect on the economy of the enterprise. Summary data on the options for consideration are shown in Table 1.

As can be seen from Table 1, the involvement of coal clays in marketable products by opencast reduces the overburden ratio from 10 to 5.4 m³/t (46 %), and production costs per ton of conventional fuel are reduced by more than two times with increasing production per conventional fuel by 41 %.

The next step is to assess the cost of fuel, which will be compared to the efficiency of the mining company.

As mentioned above, these can be the following values:

1. The cost of production of similar fuel by underground mining.

2. Wholesale, market, or price list for this fuel.

However, these values cannot be reliably determined in modern conditions due to the lack of information on the actual cost of brown coal extracted by the mine method and by open casts in Ukraine. Raw brown coal, which has significant differences from black coal, is not an energy fuel and does not participate in the energy market. Accordingly, there is no cost for this resource on the market.

It follows that to determine the marginal price of raw brown coal produced, it is advisable to apply the equivalent value to another product. This can be both thermal coal of the gas group and the product obtained after processing raw coal

to obtain high-calorie fuel. The second option is the most promising, as it allows considering the costs of extraction and processing of brown coal to obtain liquid final products.

Thus, according to the experimental work, to obtain 1 ton of high-calorie fuel, you need to process about 4.8 tons of rock mass with an ash content of about 40 % by dry weight.

With the calorific value of high-calorie coal at the level of the gas group of thermal coal (≈ 5200 kcal/kg), its market value will be about 2200 UAH/t, including VAT and transportation costs. Taking the error on the humidity of the final fuel, the real cost of high-calorie brown coal fuel can be about 1600–1650 UAH/t without VAT. This means that when attributed to one ton of production, its cost can be 343 UAH/t or 1425 UAH per ton of conventional fuel in the rock mass.

Therefore, the value of 1425 UAH per ton of conventional fuel is accepted as an opportunity cost of mining. Graphically, the definition of the production costs of raw coal in the calculation of both natural fuel and conventional, is shown in Fig. 2.

Similarly, calculations were performed to model the cost of rock mass production depending on the overburden ratio, as shown in Fig. 3.

The graph data indicate that the ultimate overburden ratio for a mining enterprise extracting brown coal is 20 m³/t, and for the extraction of coal clays mixed with raw brown coal – 17 m³/t.

At the same time, the involvement of coal clays in the extraction reduces the overburden ratio in comparison with a similar mining company, which produces only brown coal. The change in the overburden ratio compared to the base version is shown in Fig. 4.

As can be seen from the obtained data array, the involvement of coal clays and off-quality brown coal in the extraction leads to the fact that even at the maximum point at K_p for brown coal in 30 m³/t, the overburden ratio in the extraction of rock mass does not reach the previously obtained value of 17 m³/t.

However, the obtained dependencies do not determine whether this conditional mining enterprise is able to conduct a break-even and profitable economic activity at a given overburden ratio, taking into account the need to involve investment capital.

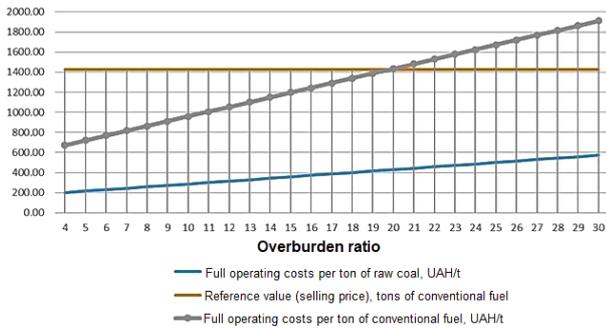


Fig. 2. Dependence of production profitability of raw brown coal on the overburden ratio of the mining enterprise

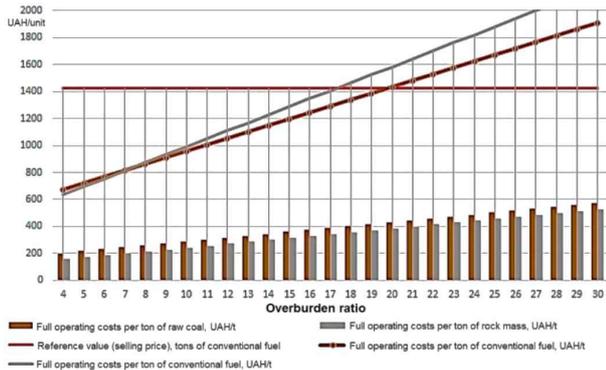


Fig. 3. Graph of the dependence of the cost of rock mass extraction on the overburden ratio

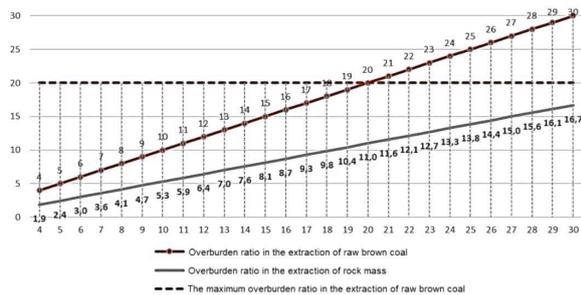


Fig. 4. Change in the overburden ratio with coal clays and off-quality brown coal involved in the extraction

Therefore, when calculating such indicators as the cost of production and overburden mining, it is necessary to enter both the level of projected capital investment and the cost of investment funds. For example, such an algorithm is quite clearly characterized by the so-called financial and mathematical average costs (FMAC) or spezifische Kosten (Grenzpreis) FMK, €/t.

It should be noted that today (after almost 20 years), the cost of electricity from TPPs in Ukraine is 1500–1600 UAH per MWh, i.e., even by 60 % higher than previously forecast. In other words, the discount rate, which acts as a return on capital, after 20 years, in fact, is higher than laid down in the calculations.

The general formula of FMAC is as follows

$$FMK = k_f = \frac{\sum_{i=0}^n A_i q^{-i}}{\sum_{i=0}^n M_i q^{-i}},$$

where A_i is payments for i -period, €; M_i is sales/production volume of i -period, t; q^{-i} is discount rate for i -period; k_f is unit costs (marginal price) = FMK, €/t.

Thus, instead of the values of the cost of overburden and open pit mining, the value of FMAC (k_f) should be entered, and instead of the values of the cost of underground mining – the cost of rock mass previously obtained or other alternative cost of minerals.

Accordingly, when determining k_f , according to the data and materials of the Master Plan, the costs of production and overburden mining are changed by the corresponding factor of addition of conditionally fixed costs. Data on the definition of the ultimate K_p are summarized in Table 2.

The data in Table 2 show that the application of the discount rate in the calculation of the cost of work significantly reduces the overburden ratios compared to the option when the values of ordinary (non-discounted) costs are used.

It is important to note that the accepted input values in these calculations are more conditional and are not project and actual data. However, considering the obtained values, it becomes clear that with the accepted data, the formula that was used earlier, leads to an incorrect decision about the method of development of the field or site. The introduction of the discount rate in the calculations allows one to determine the ultimate overburden ratios more accurately. Moreover, on the basis of this algorithm, it is possible to calculate more correctly the stress analysis on the considered projects on extraction and processing of brown coal.

Similarly, the value of 13.21 m³/t in joint production with coal clays, projecting onto the graph (Fig. 4), corresponds to the level of 24 m³/t in the extraction of raw coal only.

Based on the research, the formula for determining K_p may undergo the following modification

$$K_p = (C_n(p) - C_d(k_f) \cdot k) / (C_b(k_f) \cdot k),$$

where $C_n(p)$ is costs calculated by the method of FMAC per 1 ton of production in an alternative field development or market price for an alternative type of fuel, or price indicators of extracted raw materials that allow its cost-effective processing, monetary units/t; $C_d(k_f)$ is costs calculated by the method of FMAC per 1 ton of minerals in open pit mining (excluding the cost of overburden mining and conditionally fixed costs), monetary units/t; $C_b(k_f)$ is costs calculated according to the method of FMAC per 1 m³ of overburden (excluding the cost

Table 2

Comparison of calculated values of overburden ratios

Name	Unit	Option with brown coal	Option with rock mass
The cost of excavation per ton of useful product			
For overburden mining	UAH/m ³	14.26	14.26
For actual mining	UAH/t	31.16	31.16
Equivalent cost of the product	UAH/t	427.38	343.00
Ultimate $K_p = (C_n - C_d)/C_b$	m ³ /t	27.79	21.87
FMAC excluding conditionally fixed costs in production			
For overburden mining	UAH/m ³	19.89	19.89
For actual mining	UAH/t	46.88	46.88
Equivalent cost of the product	UAH/t	427.38	343.00
Ultimate K_p	m ³ /t	19.13	14.89
FMAC considering conditionally fixed costs in production			
For overburden mining	UAH/m ³	20.93	20.85
For actual mining	UAH/t	69.38	67.54
Equivalent cost of the product	UAH/t	427.38	343.00
Ultimate K_p	m ³ /t	17.10	13.21

of mining operations and conditionally fixed costs), monetary units/m³; k is coefficient that takes into account the increase in direct costs of extraction and deposit opening due to the presence of conditionally fixed costs of the enterprise.

Discussion. When considering the axial section of Myronivske deposit, it can be seen that with a low-capacity coal seam, there are significant reserves of coal clays on the site. Thus, in the borehole No. 39101 the thickness of the coal seam is 7 meters with an overburden capacity of 97 meters. Therefore, the linear K_p (ratio of the volume of the overburden to the mass of coal) is 12.05 m³/t. However, with the involvement of coal clays in the extraction and processing with a total capacity of 15 meters, the linear K_p is already reduced to the level of 3.58 m³/t. In the borehole No. 39086 the capacity of the coal seam is already reduced to 4 meters, and the linear overburden ratio is almost 25 m³/t. With coal clays in the borehole No. 39086, the linear overburden ratio is already about 5 m³/t.

It is expedient to determine the ultimate overburden ratio using the method of financial and mathematical average costs in the reconstruction of lignite open casts [15, 16], quarries for the development of ilmenite deposits [17, 18], as well as in the work of quarries for the extraction of construction raw materials [19, 20].

Conclusions.

1. The parameters of brown coal extraction of Novo-Dmytrivske deposit have been established, which have shown that at coal production with a volume of 9 million t/year, the overburden ratio is 4 m³/t. In the case of extraction of associated minerals in the form of coal clays, the opencast capacity can increase up to 20 million tons/year, and the overburden ratio – up to 1 m³/t.

2. When the ultimate overburden ratio is applied in the calculation, considering the discount rate during the development of coal clays, complex deposits such as Myronivske can be involved in the open-pit mining.

3. Based on the research, it has been established that those deposits and areas that were previously related to the development of the mine method or open casts with large coal losses in the complex extraction of conditioned seams of raw brown coal, off-quality seams, and coal clays, can potentially be worked with minimal losses of minerals and low cost.

4. To obtain more correct and reliable conclusions on a particular field or site in the future requires a reassessment of mineral reserves and associated rocks (coal clays). For example, based on Myronivske deposit of Kostiantynivska and Berzivska sections.

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Розрахунок коефіцієнту розкриття за методикою фінансово-математичних усереднених витрат

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Мета. Обчислити параметри розробки буровугільних родовищ, зокрема граничний коефіцієнт розкриття, при

залученні вуглистих глин у розробку разом із бурим вугіллям у складі вуглистої маси.

Методика. Для розрахунку собівартості видобутку корисної копалини застосовано метод фінансово-математичних усереднених витрат, що враховує рівень прогнозованих капітальних вкладень і вартість інвестиційних коштів.

Результати. Досліджено вплив залучення вуглистих глин у розробку разом із бурим вугіллям у складі вуглистої маси на граничний коефіцієнт розкриву. Визначено, що граничний коефіцієнт розкриву по гірничому підприємству, що видобуває буре вугілля, становить 20 м³/т, а з видобутку вуглистих глин у суміші з рядовим бурим вугіллям — 17 м³/т. Встановлені параметри добування бурого вугілля Ново-Дмитрівського родовища, які показали, що при видобутку вугілля об'ємом у 9 млн т/рік коефіцієнт розкриву складає 4 м³/т. У разі видобутку супутніх корисних копалин у вигляді вуглистих глин потужність розрізу може збільшитися до 20 млн т/рік, а коефіцієнт розкриву зменшиться — до 1 м³/т.

Наукова новизна. Встановлена динаміка зміни поточного коефіцієнту розкриву за роками при видобуванні вуглистої маси із часткою вуглистих глин від 0 до 50 %

для умов Ново-Дмитрівського родовища бурого вугілля. Визначені витрати на видобуток рядового вугілля в розрахунку як на натуральне, так і на умовне паливо. Виконано моделювання витрат на видобуток корисної копалини й гірничої маси в залежності від коефіцієнта розкриву. Обчислена зміна коефіцієнта розкриву при залученні у видобуток вуглистих глин і некондиційного бурого вугілля в порівнянні з видобуванням рядового бурого вугілля.

Практична значимість. Встановлено, що ті родовища й ділянки, які раніше відносилися до розробки шахтним способом або розрізами з великими втратами вугілля при комплексному видобутку кондиційних пластів рядового бурого вугілля, некондиційних пластів і вуглистих глин, потенційно можуть бути відпрацьовані з мінімальними втратами корисної копалини та низькою собівартістю.

Ключові слова: буре вугілля, вуглисті глини, вуглиста маса, граничний коефіцієнт розкриву, собівартість видобування

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