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Review paper

COAL RESERVES IN THE DEPOSIT AS A LIMITING FACTOR FOR THE INTRODUCING OF MECHANISED MINING TECHNOLOGY

REZERVE UGLJA U LEŽIŠTU KAO OGRANIČAVAJUĆI FAKTOR UVOĐENJU TEHNOLOGIJA MEHANIZOVANOG OTKOPAVANJA

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Abstract: In this paper are elaborated limiting factors and the need for methodological procedure at the time of the selectionand assessment of the underground production system (UPS) when exploiting coal deposits. The trends in the world production of mineral raw materials are going in the direction of mass production and large capacities in large deposits. Such orientation cannot completely eliminate certain role and importance of small deposits. The basic reasons that can contribute towards the preservation of small deposits exploitation are connected on one side with the genesis of these deposits, and on the other hand with exceptionally favorable technical, organizational and financial possibility when exploited. In the more and more complex conditions of deposit exploitation, modern and effective organization of work and production demands introducing and constant correction of technical-economic criteria that have been arrived at on the basis of the objective automatic processing of all data from the production process. In this paper the accent is on the recovery ratio of the deposit when applying the method of the longwall face mining, but principal assumptions the researches are based on are valid also for the application of the short width facemining method.

Key words: coal reserves, underground coal deposit exploitation, longwall face mining

Apstrakt: U radu su obrazloženi ograničavajući faktori i potreba za metodološkim postupkom prilikom izbora i ocene podzemnog proizvodnog (PPS) sistema pri eksploataciji ležišta uglja. Kretanja u svetskoj produkciji mineralnih sirovina idu u pravcu masovne proizvodnje i velikih kapaciteta u velikim ležištima. Ovakva orijentacija ne može u potpunosti da eliminiše određenu ulogu i značaj malih ležišta. Osnovni razlozi koji idu u prilog očuvanju eksploatacije malih ležišta vezani su sa jedne strane za samu genezu ovih ležišta, a sa druge strane za izuzetno povoljne tehničke, organizacione i finansijske mogućnosti prilikom njihove eksploatacije. U sve složenijim uslovima eksploatacije ležišta,

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moderna i efikasna organizacija rada i proizvodnje zahteva uvođenje i stalnu korekciju tehničko-ekonomskih kriterijuma dobijenih na osnovu objektivne automatske obrade svih podataka iz procesa proizvodnje. U radu je stavljen akcenat na iskorišćenje ležišta pri primeni metode širokočelnog otkopavanja, ali principijelne postavke na kojima se istraživanja baziraju važe i kod primene metoda kratkočelnog otkopavanja.

Ključne reči: rezerve uglja, podzemna eksploatacija ležišta uglja, širokočelno otkopavanje

1. INTRODUCTION

Basic trends in researching technical - technological solutions for all phases of the technological complex of the underground production system (UPS) when underground coal deposit exploitation is being done are directed, in modern mining science and practice, towards complex mechanization and automation of all processes and working phases. These efforts have, not only their technologic and technical-economic, but also deep social and humanitarian justification. Namely, in the underground technologic complex which has been projected and built on the basis of the contemporary scientific-research achievements, with full mechanization of all technologic operations, share of the manual human work becomes unavoidablya minimal part, and the basic role of the worker is to plan, manage, control and handle machines and equipment, to effect current repairs and servicing with maximal safety and favorable work environment. To this should be added that mechanized technological processes demand a smaller number of workers but on a higher skilled and educational level, and that also represents an important effect as it is easier to engage workers, to better organize the production, and in view of collective and personal safety etc. The truth is, in the real conditions of age and qualification level of workers in our coal mines the question of qualitatively new personnel, which may adequately answer the demands which are posed by new technological solutions, and may ask for long-term solutions in order to benefit from all advantages and technical-economic potential of the complex mechanization (Genčić, 1985).

Basic technical-economic principles and demands of the research process for the rational and optimal construction of the UPS, as well as the method and technology of mining are:

- increase of labor productivity;
- high level of production concentration and intensification;
- maximal coal reserve recovery;
- maximal simplification of technological production lines by transfer to technological processes with a smaller number of operations and by transfer of some operations to the surface;
- maximal simplification of the PPS construction and ventilation system, that, besides other things has decreased intensity of maintaining underground rooms;
- securing effective supplying of the mining field and working place for the preparation of necessary material and spare parts;
- transport of workers as near as possible to the working place;

- continual (chain) production system;
- scientifically organized work, managing and production planning;
- maximal reliability of all technological processes and the system as a whole;
- maximal safety and favorable work conditions for the employed.

To the given principles and demands mostly correspond longwall face mining methods based on the application of complex mechanization on the face i.e. mechanized hydraulic support units combined mining machines for disintegration and loading of coal in the face, systems of scraper transporters and additional machines and equipment. In somewell known world basins significant application have mining field ploughs of various construction and operating principles, as means for disintegration and loading of coal. However, the application of ploughs is very much limited to the coal seams of small and medium thickness, with low values of coal mechanical characteristics and of homogenous structure, as well as regular isometry. When geological characteristics of our deposits are known then it is justifiable that the problem of transfer to mechanized mining technology is basically regarded from the viewpoint of application of mining technology by way of cutting and supporting faces with MHP. Thus, the notion itself of transferring to mechanized mining technology will be treated in the context of technological connection between method of mining with longwall face and technology of mining with cutting. In the similar or the same manner are treated development scientific researches in all countries where these problems are studied as with the constant worsening of working conditions, which are caused in the first place by the mining depth, as the only alternative appear those technical technological solutions that can secure large production capacities and thus keep production costs within economically acceptable limits (Gagić and Gluščević, 2005), (Martin, 1986).

However, in the mines and deposits where application of longwall face mechanized mining is not rational, it is possible to apply short face mining methods together with application of continual and discontinued mining technologies under condition that they result in acceptable technical-economic and safety effects. On the contrary we think that in deposits which do not allow application of mechanized mining it is not rational to perform mining since satisfactory effects of production from any aspect whatsoever will not be possible.

In this paper the accent will be on the recovery of the deposit when applying longwall face mining method, but assumptions in principle upon which researches are based are also valid for short face mining methods.

2. GENERAL REVIEW

Studying the problem of transfer to mechanized mining technology from the viewpoint of the size of production plant, in case of small deposits, as the first limiting factor occurcoal reserves with their quantitative and qualitative characteristics (Gagić, 1986).

If we start from a given production and from known exploitation coal reserves then the time of the deposit exploitation or part of the deposit is directly proportional to the coal quantity and in an inverse proportion with the production height per time unit, i.e.:

$$V = \frac{R_e}{Q} \tag{1}$$

Where is:
V - exploitation time;
R_e - exploitation coal reserves in the deposit;
Q - coal production per time unit.

Exploitation time in a most direct manner connects technical and economic exploitation indexes as it is at the same time the period of reproduction of the invested means. In fact, exploitation time of a deposit or a part of the deposit must be such so as all invested means could be reproduced, and its connection and mutual conditioning with technical solutions must be specially considered during detailed research of the optimal construction of the pit and the choice of mining technology. Abandoning this principle demands various social privileges and compensation as is partially done in our country as well as in many countries that are big coal producers. In connection with production capacity and exploitation time of the deposit a basic question occurs which is the quantity of coal and of the given quality with which may be satisfied the exploitation costs in time T_e with capacity Q. That is, that is the problem of determining the minimum of reserves in the deposit demanded by modern technology.

Minimal reserves are not a universally fixed quantity, however they, first of all depend on the complex of natural exploitation conditions which on the other hand condition technical solutions, and thus total investing, capacity and direct production costs. The influence of productive-technical characteristics of the existing production plant is significant, as well as of some external factors and from that standpoint should specially consider production capacity and determine possible surprises from any of domains which may be manifested as limitations. Here, before all other things, it is meant that there is a large investment scope for the equipment on the face, which demands transfer to the new technology (100,000 €/m - 200,000 €/m) from there immediately a logical conclusion occurs that bigger face lengths demand larger coal reserves with the similar quality, however the influence is more evident in the conditions of progressive negative action of external economic factors. In such a construction the tendency should be that ratio between the investments in basic face equipment, brought down to a ton of exploitation coal reserves which exclude possibility for a complete miss.

Quality of coal in active deposits represents the most reliable datum as it is continuously and systematically followed up, regarding its significance for the possible use and sales price.

All mentioned accents exploitation coefficient of balance reserves that is possible to achieve in the conditions when the method of longwall face mining and technology of mechanized mining are applied. Namely, due to regular shapes of production units, on one hand, and most often irregular geometrical shapes of the deposit, on the other hand, frequently considerable quantities of coal must remain in peripheral parts, i.e., it is not possible to systematically mine those parts of the deposit with the treated technical-technological system. This means that in certain cases transfer to mechanized mining technology gives as a result decreased exploitation coefficient of the deposit, i.e. industrial reserves and in the final consequence exploitation reserves. It is logical that with increase of the face length this factor appears with greater intensity.

In accordance with given explanations it is necessary, therefore, in the first phase of condition researches for transfer to mechanized mining technology to formulate several rational variants of the construction for the entire exploitation period and in that way determine industrial reserves of the coal that may be mined with the help of this technology, and on the basis of industrial reserves and exploitation coefficient in the process of mining of exploitation reserves in the deposit. This means that total exploitation reserves in deposit or in the part of the deposit where the new technology is projected representa total of exploitation reserves of every mining field, i.e.:

$$R_e = \sum_{i=1}^{n} R_i \tag{2}$$

Where is:

R_i - exploitation reserves of the *i* mining field:

$$R_i = P_{pi} \cdot d_{si} \cdot \gamma \cdot c_o \tag{3}$$

P_{pi} - surface of the *i* mining field [m^2];
d_{si} - average thickness seam in *i* mining field [m];
γ - coal unit weight (mass) [t/m^3];
c_o - seam recovery coefficient in the mining process:

$$P_{pi} = L_i \cdot l \tag{4}$$

L_i - length of the *i* mining field [m]
l - length of the mining field.

Seam recovery coefficient in the mining process mostly depends on the method and mining technology. In conditions when longwall face mining method is applied and where the working height of the face is equal to the seam thickness it has a very high value (0.95-0.99), and when the mining process is based on the caving of theoverlying coal strata a great number of factors has influence over technological recovery.

When exploitation reserves in the deposit are determined it is easy to calculate recovery coefficient of the coal balance reserves by induction, as:

$$K_b = \frac{R_e}{R_b} \tag{5}$$

This coefficient may be one of the criteria of the PPS construction and mining technology optimization however in any case economic losses connected with not mined reserves should be treated in the adequately in each optimization procedure.

3. COAL RESERVES RECOVERY DEPENDING ON THE SHAPE OF THE DEPOSIT AND LENGTH OF THE MINING FIELD

In any special case whatsoever exploitation limit of the face block (part of the deposit) in horizontal projection may be approximated by analytical function in relation to selected coordinate system connected to the location of underground rooms needed for basic preparations. In relation to the selected coordinate system XOY, the limit line (mining block limit) is given by equitation $y = f(x)$.

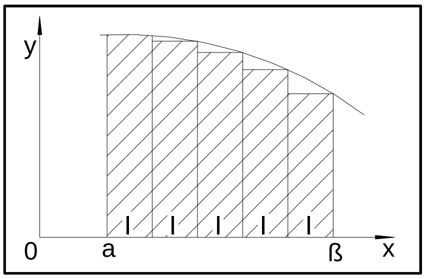

Figure 1 - Principal assumption of the problem dealing with deposit recovery investigation *f(x)* falling function

Area limited by part of x-axis between α and β, with lines $x = \alpha$, $x = \beta$ and by the arch of the curve $y = f(x)$ is given as:

$$P = \int_{\alpha}^{\beta} f(x) \tag{6}$$

Area that is formed by shaded rectangles (mining fields) has the value of:

$$P_1 = l\left[f(\beta) + f(\beta - l) + f(\beta - 2l) + ... + f(\alpha + l) \right] \tag{7}$$

where it is:

$$l = \frac{\beta - \alpha}{n} \tag{8}$$

respectively:

$$n = \frac{\beta - \alpha}{n} \qquad ....(9)$$

i.e. value:

$$P_1 = l\left[f(\alpha + l) + f(\alpha + 2l) + ... + f(\beta) \right] \tag{10}$$

when $f(x)$ is the falling function in the interval (α, β) then there is:

$$P_1 = l\left[f(x) + f(\alpha + l) + ... + f(\beta - l) \right] \tag{11}$$

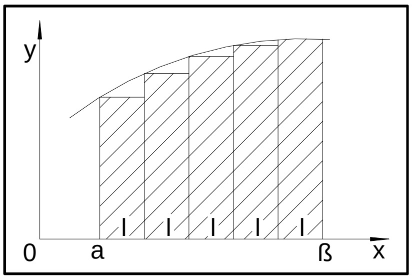

Figure 2 - Principal assumption of the problem dealing with deposit recovery investigation *f(x)* rising function

Area P_1 represents recovered part of the area P when mining longwall face length L. This area depends on the shape of the curve $y = f(x)$, i.e. of the shape of the deposit limits in the mining plane XOY and from the length of the face L for determined fixed values size α and β.

Relation P_1/P is given in percent, i.e. $k_i = (P_1/P) \cdot 100\%$ represents coefficient of encompassing of the area P when mining is done, i.e. coefficient of correction of the coal balance reserves as the consequence of geometrization of the deposit in order to apply methods for longwall face mining, under condition not to mine the parts of the deposit by some other technical solution offered by another mining method, and also that the average seam thickness in the entire treated area is the same. It is easy, before everything, to notice that mining of these peripheral parts of deposits represents a complex problem as regards spatial and time connection with basic production system. There, first of all, is the question of connection to the system of transport and ventilation as well as of the influence on the intensity of the underground pressure in the zone of the mechanized mining. Economic justification is to be necessarily examined in each determined case but, on the basis of some practical experience, as well as our researches we found out that most frequently these parts of deposits is not rational and economic justifiable to mine. A side from that, in the first phase of the research of the conditions for the replacement of technology, it is useful to define coverage of the seam area at different mining lengths in order to create a safe basis for the economic-mathematic optimization of the underground production system as a whole, i.e. to determine industrial reserves within the deposit that may be seized by mechanized mining of the longwall face.

In case that the average seam thickness in the entire treated part of the deposit is the same, the coefficient of the correction of balance reserves, as has already been said, will be equal to the coefficient K, thus the industrial coal reserves are:

$$R_i = R_b \cdot K_i \tag{12}$$

Losses of the coal substance in a general case may be also analytically determined as the function of the mining field length and the shape of the border curve. Namely, if $y = f(x) = y(x)$ is the equitation of the curve, then the area which is limited by the arch of the curve, part x-axis between points x_o and $x_o + l$ and lines $x = x_o$ and $x = x_o + l$ are given with:

$$\int_{x_o}^{x_o+l} y(x)\, dx$$

rectangle area is $l \cdot y(x_o + l)$ respectively $l \cdot y(x_o)$ depending of $y = y(x)$.

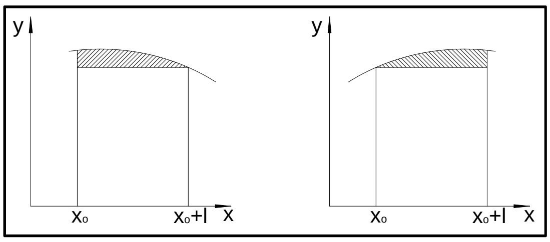

Figure 3 - Principal assumption of the problem dealing with coal loss research:
a - limit curve falling function, b - limit curve rising function

Shaded part which we have marked with $R(l)$ has the value:

$$R(l) = \int_{x_o}^{x_o+l} y(x)\,dx - l \cdot y(x_o + l) \tag{13}$$

respectively:

$$R(l) = \int_{x_o}^{x_o+l} y(x)\,dx - l \cdot y(x_o) \tag{14}$$

In the first case for $R(l)$ we get:

$$R(l) = \frac{l^2}{2} \cdot y'(c_1), \quad x_o < c_1 < x_o + l \tag{15}$$

In the second case:

$$R(l) = \frac{l^2}{2} \cdot y'(\overline{c}_1), \quad x_o < \overline{c}_1 < x_o + l \tag{16}$$

If we put $M_1 = \max\left|y'(x)\right|$, then for $R(l)$ in both cases is valid assessment: $x_o < x < x_o + l$

$$\left|R(l)\right| < \frac{l}{2} \cdot M_1 \tag{17}$$

In the case when in interval $[\alpha, \beta]$ we have n rectangle, then for $R(l)$ is valid assessment:

$$\left|R(l)\right| < \frac{l}{2} \cdot (M_1 + M_2 + ... + M_n) \tag{18}$$

where is: $M_i = \max\left|y'(x)\right|$

$$x_o + i \cdot l < x < x_o + (i + l) \cdot l$$

$$i = 1, 2, ..., n - 1$$

If we put $M = \max(M_1 + M_2 + ... + M_n) = \max\left|y(x)\right|$

$$\alpha < x < \beta \qquad (x_o = \alpha, x_o + n \cdot l = \beta)$$

then the assessment is:

$$\left|R(l)\right| \le \frac{l^2}{2} \cdot n \cdot M \tag{19}$$

Appraisal is valid for both cases, whether the function is rising or falling.

We have $l = \frac{\beta - \alpha}{n}$, than we have $n = \frac{\beta - \alpha}{l}$, so this can be written in the form of:

$$\left|R(l)\right| \le \frac{(\beta - \alpha) \cdot M}{2} \cdot l \tag{20}$$

Appraisal is valid also when the function $f(x)$ is in the interval (α, β) both rising and falling (Figure 4).

In the case shown in Figure 4 there is:

$$R(l) = R(l_1) + R(l_2), \qquad l = l_1 + l_2$$

from there follows:

$$\left|R(l)\right| \le \left|R(l_1)\right| + \left|R(l_2)\right| \tag{21}$$

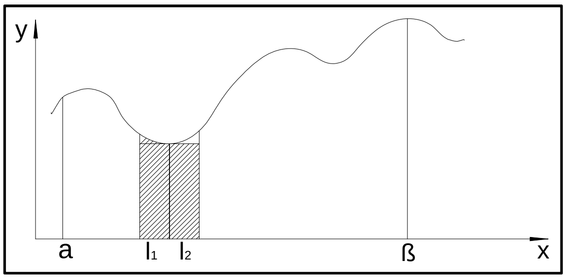

Figure 4 - Principal assumption of the problem dealing with coal loss when limit curve is both rising and falling function

In the case shown in Figure 4 there is:

$$R(l) = R(l_1) + R(l_2), \qquad l = l_1 + l_2$$

from there follows:

$$|R(l)| \le |R(l_1)| + |R(l_2)| \tag{22}$$

If it is:

$$M = \max |y'(x)|$$
$$\alpha \le x \le \beta$$

then we get:

$$|R(l_1)| \le \frac{(\beta - \alpha) \cdot M}{2} \cdot l_1 \tag{23}$$

and:

$$|R(l_2)| \le \frac{(\beta - \alpha) \cdot M}{2} \cdot l_2 \tag{24}$$

and now it can be written:

$$|R(l)| \le \frac{(\beta - \alpha) \cdot M}{2} \cdot l_1 + \frac{(\beta - \alpha) \cdot M}{2} \cdot l_2 = \frac{(\beta - \alpha) \cdot M}{2} \cdot (l_1 + l_2) = \frac{(\beta - \alpha)}{2} \cdot M \cdot l \tag{25}$$

It means that:

$$|R(l)| \le \frac{(\beta - \alpha)}{2} \cdot M \cdot l$$

The area of the entire field is:

$$P = \int_\alpha^\beta f(x)\, dx = k \qquad (k - \text{constant}) \tag{26}$$

Part which is not covered by faces length *l* is:

$$|R(l)| < k_1 \cdot l \qquad \left(k_1 = \frac{\beta - \alpha}{2} \cdot M \quad \text{is the constant} \right) \tag{27}$$

On the bases of these relations we conclude that for the part covered by faces is valid:

$$P_l \ge P - |R(h)|, \quad \text{i.e.} \quad P_l \ge K - k_1 \cdot l \tag{28}$$

Relation shows that the covered part P_l can not be smaller than $K - k_1 \cdot l$ thus this value may be used for calculation during the mining. If the length of the mining field is smaller, covering i.e. recovery will be bigger and vice versa.

If the interval (α, β) is divided to n subintervals of the length $l = \frac{\beta - \alpha}{2}$ i.e. to subintervals:

$$\left(x_o, x_1\right), \left(x_1, x_2\right), ..., \left(x_{n-1}, x_n\right)$$

where is:

$$x_o = \alpha, x_1 = \alpha + l, x_2 = \alpha + 2 \cdot l, ..., x_n = \alpha + n \cdot l = \beta \tag{29}$$

and if you put:

$$m_1 = \min f\left(x\right)$$
$$\left(i = 1, 2, ..., n\right)$$
$$x_{i-l} \leq x \leq x_i$$

Then the area of the covered part may be noted down in the form of:

$$P_l = l \cdot \sum_{i=l}^{n} m_i \tag{30}$$

Covering coefficient k_i is here the relation between the covered part of the area and the total part of the area:

$$k_i = \frac{P_l}{P} \tag{31}$$

If in we put $K = P$, then we have:

$$P_l \geq P - k_1 \cdot l \tag{32}$$

and for the coefficient of covering k_l now we get relation:

$$k_1 \geq l - \frac{k_1 \cdot l}{P} \tag{33}$$

Respectively:

$$k_1 > l - \frac{k_1}{k} \cdot l \tag{34}$$

Unit curve $y = f(x)$ may be determined on the basis of real data, and in the form of the polynome or some other function with which can be well approximated the location off the exploitation field limit in relation the object or preparation for each special case. The exact approximation may easily be calculated depending on the shape of the curve with which it has been performed. The fact is that the exactness of approximation will always be within the tolerant limits that allow corresponding normative regulation in connection with categorization and classification of the coal reserves.

4. CONCLUSION

Researches in connection with losses and recovery of the coal reserves, approximation of the deposit limit in the form of a curve $y = f(x)$ offer the possibility to analytically investigate also the influence of the changeable length of the mining fields on the total of technical-economic effects of exploitation, which is the basic result of this study.

Namely, to each length of the mining field l_i corresponds value y_i which is in fact the length of the mining field. Well known researches in the world are directed towards researches of optimal lengths of the mining fields and economically justified minimal lengths, while this aspect has not been considered.

Developed methodological procedure may be built into a complex algorithm intended for optimization of the mining filed parameters, and with help of modern computers analyze it from all aspects.

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