TECHNICAL AND ECONOMIC OPTIMIZATION OF THE MECHANIZED LONGWALL FACES WITH TOP COAL CAVING MINING, IN HORIZONTAL SLICES

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Abstract
The mechanized longwall faces with top coal caving mining, in horizontal slices, of coal seam no.3 of the Jiu Valley hard coal basin could be efficient only if the sizes of the top coal height and the panel length determine o minimum cost of production. Therefore, the goal of this paper is the optimization of these parameters, from a technical and economic point of view, taking into account the general model of the cost function, at the panel level.

Key words: longwall face, horizontal slice, top coal caving, mining panel, production cost

1. Introduction

The Jiu Valley is the most important coal basin from Romania, both considering the balance reserves' value and of especial coke qualities of the western basin. From the 22 identified coal seams, the thick coal seams no.3 and 5 represent about 60% of the total reserves [6], [8].

The hard coal seams are intensively tectonized, with large variation of the quantitative and qualitative parameters, being a very complex coal deposit. The mining difficulties are amplified by the methane gas emanation, by the coal self ignition tendency and the low stability of the rocks [8].

Romania's accession to the European Union imposed compliance with the European rules and regulations, in the hard coal mining area as well. A correct assessment of the future evolution, concerning the coal mining in the Jiu Valley coal basin, must take into account the imposed constraints by the economic efficiency of the mining and the environmental ones [4].

Among others, a taken measure for increasing the economic efficiency of the coal mining in this basin is the introduction of the top coal caving mining methods, first for the medium and gentle inclined seams of the coal seam no. 3, and later for the thick and dip coal seams.

In that direction, in the following, the technical and economic optimization of the main parameters of the top coal caving mining method, in horizontal slices, used for the thick and dip coal seams, will be presented.

The goal of this study is the determination of the optimum interval in which, the parameters taken into calculus (mainly, the top coal height and the straight panel length), satisfy a minimum cost, at the panel level.

2. Establishment of the technological unit for optimization

Specifically for the mining industry, the operating process obeys the same economical laws as any industrial process. Their modelling respects the following scheme: $X\,\{\rightarrow[S]\rightarrow\}\,Y$; where: $Y=(y_i)$ is the system's outputs volume, $i=\overline{1,n}$; $X=(x_i)$ - the qualitative and quantitative factors that influence the system's outputs y_i, $i=\overline{1,m}$; *S*- system structure through the factors x_i that influence the outputs y_i.

A mining operating process could be represented, schematically, by a series of sets as of: the consumption factors that enter in the process $x=\{x_1,x_2,....,x_n\}$; the rules that the time development follows $L=\{l_1,l_2,.....,l_k\}$; the mining products (the production factors that are coming out of the process) $Y=\{y_1,y_2,....,y_m\}$ and the perturbation factors $U=\{u_1,u_2,.....,u_p\}$.

Analysing the mining method (Fig.1) and mining technology (Fig.2) for the thick coal seams, it is observed that they are characterized by a series of parameters classified into 3 importance groups, as in [1], [4], [5]:

a) Main parameters: represent the panel elements and those that are determined based on their interdependences, some auxiliary parameters and the technical and economical indicators;

b) *Auxiliary parameters*: determine or are determined from main parameters in function of the applied technological variant specificity and have a determined role in the mining method economy;

c) *Specific parameters*: are specifically only for a certain mining variant or method and have

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an influence, especially, on the labour productivity at the coal cutting, loading and exhaustion.

The main variable parameters that characterise this compound of the mining unit and which must be optimized are the panel length (l_{ca}) and the top coal caving height (h_b).

The criteria used in the optimization problem solving are the following: the cost of the unit product c $(c \to \min)$; the output capacity P $(P \to \max)$ and the labour consumption M $(M \to \min)$ [1], [4].

For solving the mathematical and economical models, resulted from the applied certain programming method, only one optimization criterion is taken into consideration, for the other ones being imposed restrictions, thus [4], [5]:

-if the used basis criterion is the cost of the product unit (lei/tonne) then the purpose function has the form: $C \to \min$, with the restrictions: $P \geq P_{plan}$ and $M \leq M_{admis}$ [11];

-if the output and the labour consumption are considered as a basis criterion, then: $P \to \max, M \to \min$, with the restriction: $c \leq c_{plan}$ (where: *plan* – targeted; *admis* – admissible).

The longwall face mining method, in horizontal slices (in conformity with the framework project) is shown in the fig.1 [3], [5], [7].

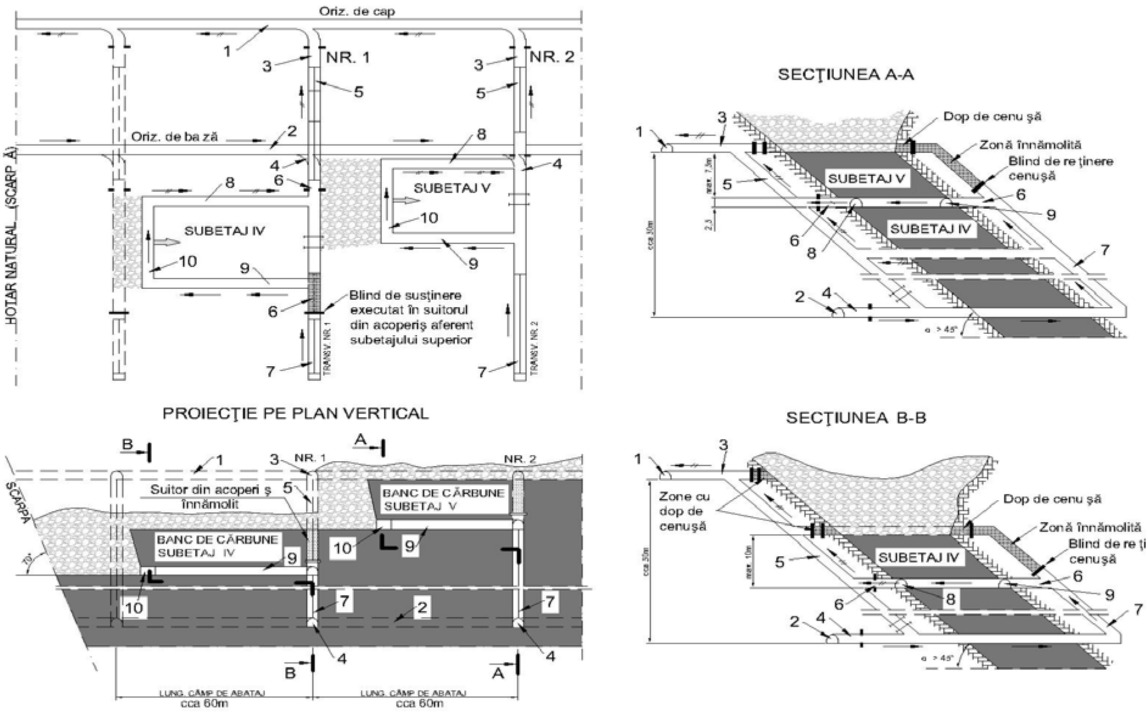

Fig. 1 *Longwall faces top coal caving mining method, in horizontal slices, applied at the coal seam no.3, for the dip of ≥ 45º (in conformity with framework method, elaborated by the ICPM SA Petroşani)*
1/2 –transport/ventilation directionally gallery; 3/4 – transport/ventilation panel cross-cut gallery; 5-transport rise; 6 – short cross-cut gallery; 7 – ventilation rise; 8/9 – transport /ventilation preparatory strike gallery; 10 – longwall face with top coal caving

The longwall face with top coal caving detain the following equipments: frame powered supports type BD-340 T (made by TAIM TFG – Spain) [7] or frame powered supports type GEROM GP 250/1200 of indigenous production (Fig.2); coal shearer type ESA 60 L; conveyor type TR-7A, on the coal face line and (in certain technological cases) a rear conveyor TR-3, for caved coal.

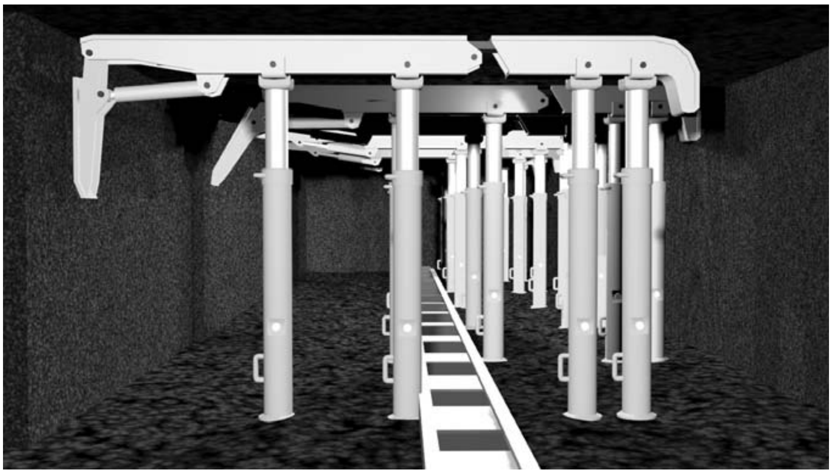

Fig.2 *Frame powered supports type GEROM GP 250/1200*

3. Establishment of the purpose function of the optimizing model

At the level of the *mining economical units,* the cost product on the primary cost elements has the following structure: 1) raw, basic and auxiliary materials; 2) fuel; 3) energy and water; 4) depreciation and fixed assets; 5) other material costs $(1 \to 15)$; 7)salaries; 8) insurances and social protection; 9) other labour costs (including the recovery of the geological researches); 10) total labour costs; 11) total costs (6+10).

Thus, the general form of the optimization criterion is:

$$c_i = \frac{\sum C}{R_e}, \text{ lei/tonne} \qquad (1)$$

where: c- represents the unit cost of the coal mining at the longwall face level, in lei/tonne; $\sum C_i$ - the total costs, in lei; R_e- the industrial coal reserves of the mining panel, in tonnes.

The panel industrial coal reserves are calculated with the relation:

$$R_e = l_{ca} \cdot \frac{m}{\sin\alpha} \cdot (h_{ab} + h_b) \cdot \rho \cdot k_1, \text{ în tone} \qquad (2)$$

where: l_{ca} represents the panel length, in m; $l_{ab} = \frac{m}{\sin\alpha}$ - longwall face length, in m; m – normal thickness of the coal seam, in m; α - coal seam dip, in ^{o}; h_{ab} – face height, in m; h_b – top coal height, in m; ρ - coal apparent specific density, in tonne/m^3; $k_1 = \frac{\eta}{1-D}$ - coefficient that takes into consideration the recovery factor η and the dilution factor D.

4. Mathematical model of the unit cost, afferent to the longwall face with top coal caving

The mathematical model of the general costs, elaborated for the longwall face with top coal caving, in horizontal slices, as a basic technological unit, contain all of the cost categories effectuated for the coal mining at the panel level [4], [5]: in lei, (3)

$$\sum C = \sum P + \sum I + \sum U + \sum M + \sum E + \sum A$$

where: $\sum C$ represents the total costs effectuated at the panel level, in lei; $\sum P$ - preparatory workings costs, in lei; $\sum I$ - preparatory working maintenance costs, in lei; $\sum U$ - longwall equipments (drilling, support and transportation) costs in lei; $\sum M$ -labour costs, in lei; $\sum E$ - energy (electrical, pneumatic) costs, in lei; $\sum A$ - auxiliary costs (equipment maintenance, materials – wire mesh, wood, explosive material), in lei.

Finally, taking into account the previous equations and every element of the costs, the following mathematical model of the unit cost $c(l_{ca}, h_b)$ is obtained, in lei/tonne, as a dependent function – where: the panel length l_{ca} and the top coal height h_b are independent and variable parameters; coal seam thickness m and the dip α are the known data, but different in order to the geological conditions of the coal deposit. Also, the unit cost function contains a chain of constants X_1, X_2,…, X_{20} that results from the different fixed elements of calculation.

$$c_i = l_{ca}\cdot\left(\frac{X_8}{4\cdot\frac{m}{\sin\alpha}} + \frac{X_9}{4} + \frac{X_{10}}{1{,}6\cdot\frac{m}{\sin\alpha}} + \frac{X_{11}}{1{,}6} + \frac{X_{12}}{1{,}6\cdot\sin\alpha} + \frac{X_{13}}{4\cdot m} + \frac{X_{14}}{1{,}6\cdot m} + \frac{X_{15}}{4\cdot m}\right) + h_b\cdot\left(\frac{X_3}{4\cdot\frac{m}{\sin\alpha}} + \frac{X_4}{4} + \frac{X_5}{4\cdot m} + \frac{X_{19}\cdot\frac{m}{\sin\alpha}}{4}\right) +$$

$$+ \frac{1}{l_{ca}}\cdot\left(\frac{X_7}{4} + \frac{X_{20}}{4} + \frac{X_{21}}{4\cdot\frac{m}{\sin\alpha}}\right) + \frac{1}{h_b}\cdot\left(\frac{X_1}{1{,}6\cdot\frac{m}{\sin\alpha}} + \frac{X_2}{1{,}6} + \frac{X_6}{1{,}6\cdot m} + \frac{X_{18}\cdot\frac{m}{\sin\alpha}}{1{,}6}\right) + \frac{l_{ca}}{h_b}\cdot\left(\frac{X_8}{1{,}6\cdot\frac{m}{\sin\alpha}} + \frac{X_9}{1{,}6} + \frac{X_{13}}{1{,}6\cdot m} + \frac{X_{15}}{1{,}6\cdot\sin\alpha}\right) +$$

$$+ \frac{1}{l_{ca}\cdot h_b}\cdot\left(\frac{X_7}{1{,}6} + \frac{X_{20}}{1{,}6} + \frac{X_{21}}{1{,}6\cdot\frac{m}{\sin\alpha}}\right) + l_{ca}\cdot h_b\cdot\left(\frac{X_{10}}{4\cdot\frac{m}{\sin\alpha}} + \frac{X_{11}}{4} + \frac{X_{12}}{4\cdot m} + \frac{X_{14}}{4\cdot m} + \frac{X_{16}}{1{,}6\cdot m} + \frac{X_{17}}{1{,}6\cdot m}\right) + l_{ca}\cdot h_b^2\cdot\left(\frac{X_{16}}{4\cdot m} + \frac{X_{17}}{4\cdot\sin\alpha}\right) +$$

$$+\left(\frac{X_1}{4\cdot\frac{m}{\sin\alpha}} + \frac{X_2}{4} + \frac{X_3}{1{,}6\cdot\frac{m}{\sin\alpha}} + \frac{X_4}{1{,}6} + \frac{X_5}{1{,}6\cdot m} + \frac{X_6}{4\cdot m} + \frac{X_{18}\cdot\frac{m}{\sin\alpha}}{4} + \frac{X_{19}\cdot\frac{m}{\sin\alpha}}{1{,}6}\right),$$

lei/tonne (4)

For this problem solving of the optimization of the mining method parameters, by this method, one must set the condition that the function $c_i \equiv C(l_{ca}, h_b)$ have a minimum value, that is the obtained coal tonne cost to be lowest, which means that the partial derivatives of this function, by report to the variables l_{ca} and h_b must be zero [2], [4]:

$$\frac{\delta \sum C(l_{ca}, h_b)}{\delta\, l_{ca}} = 0 \qquad (5)$$

$$\frac{\delta \sum C(l_{ca}, h_b)}{\delta\, h_b} = 0 \qquad (6)$$

The expressions (5) and (6) compose a system of two equations, with the unknowns l_{ca} and h_b. Because of the fact that this system is very complex and is not to be solved by the analytical way, it is preferred to make a sensibility analysis of the function by report to the optimization variables (the variants' method).

5. Data analysis to establish the optimum values of the panel length and the top coal height in function of the unit cost

The optimum values of the panel length and of the top coal height could be obtained by two methods: a) analytical method (by finding the minimum of the unit cost function); b) variants' method (analyzing the sensitivity of the unit cost function to the optimizing parameters variation) – used in the condition of the technical and economic model (4) [2], [4].

In our case, the input values, in the unit cost function (4) are the following: m={17, 20, 25, 30, 35, 40, 45, 50, 55}m; α={46, 50, 55, 60, 65, 70, 75}°; l_{ca}={100, 200, 300, 400, 500, 600}m; h_b={1,2,…,15}m. Also, a set of number of workers per shift was taken into consideration, so that: n= {6, 8, 10, 12, 15}. In the basis of obtained data, there was provided a series of graphical representations of unit cost variation in function of the studied parameters (Fig.3-6).

The top coal height value for which are obtained the minimum costs is $h_{b\ optim}$=4m, regardless of the coal face length and the workers number. The optimum interval for the application of the mechanized top coal caving mining method, is between the following limits:
for l_{ab}=(20 - 40)m, $h_{b\ optim}$=(3 - 6)m; for l_{ab}=(51 - 56)m, $h_{b\ optim}$=(3 - 5)m; for l_{ab}=(60 - 78)m, $h_{b\ optim}$=(2 - 5)m.

The optimum domain, for the panel length l_{ca}, fits in the natural limits of the geological blocks in which the mining method is applied, respectively of (100 – 600)m; the unit costs varying in this case with the values ranging between 21 lei (for l_{ab}=20m) and 11 lei (for l_{ab}=78m). In percents, these are situated in the interval of 2.23% and 2.83%.

The increase of the coal face length has a major influence on the cost value obtained at the panel level. Thus, increasing the coal face length from 20m to 78m determine a unit cost reduction with 471 lei/tonne, that is with ≈200%.

Also, increasing of number of the working team, from 6 to 15 workers/shift, does not have a significant impact on the cost reduction. The percentage of cost reduction, when 15workers/shift exist in the face, by report to 6workers/shift, is a maximum of 2%, for all analyzed coal face lengths. Although the coal face operations are mechanized, the appropriate number of workers placed at the face ends for special operations is very important, to maintain a constant advancement speed of the coal face.

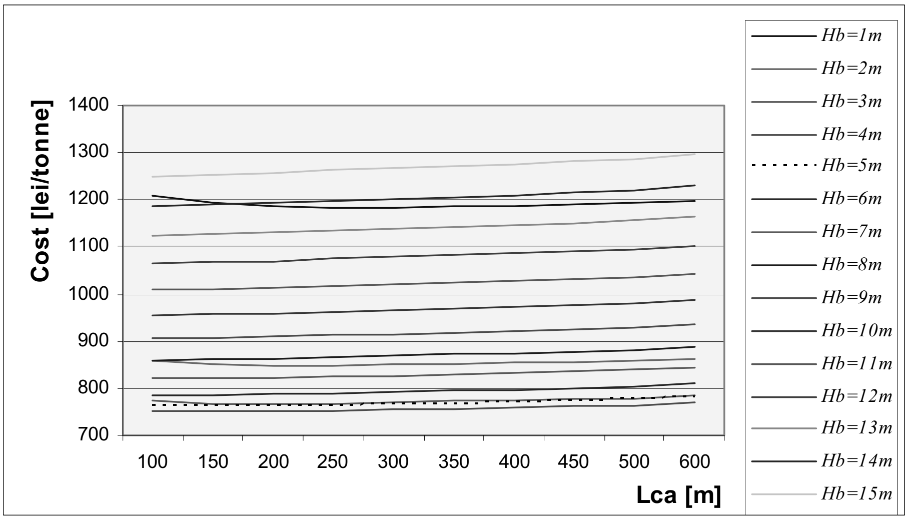

Fig.3 *Variation of the unit costs, for* l_{ab}*=30m and* N_{shift} *= 6 workers*

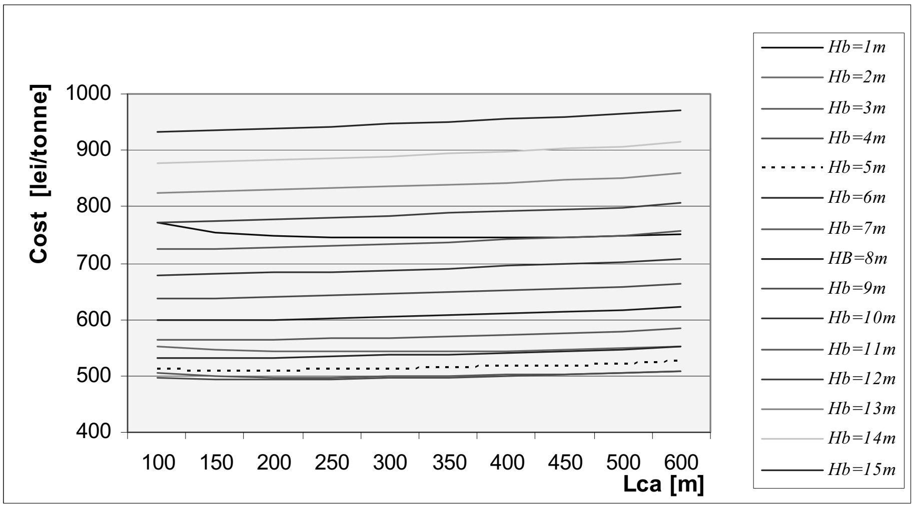

Fig.4 *Variation of the unit costs, for* l_{ab}*=60m and* N_{shift} *= 6 workers*

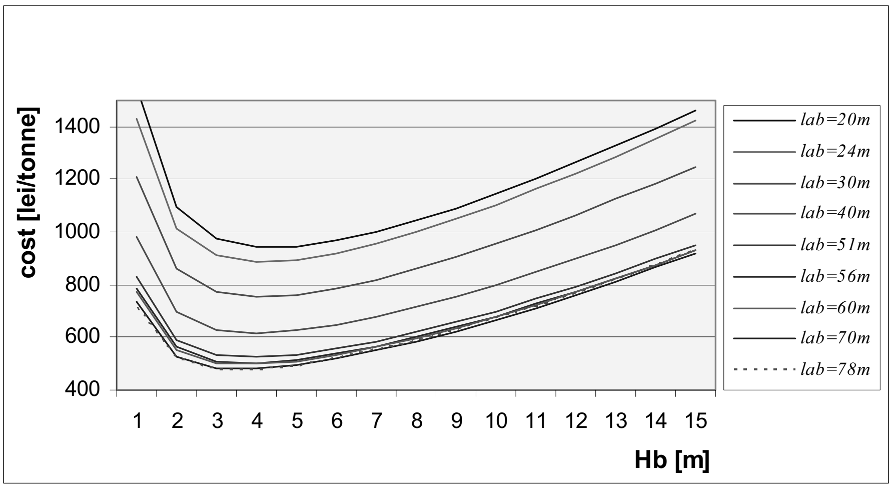

Fig.5 *Variation of the unit costs, for* l_{ca}*=100m and* N_{shift} *= 6 workers*

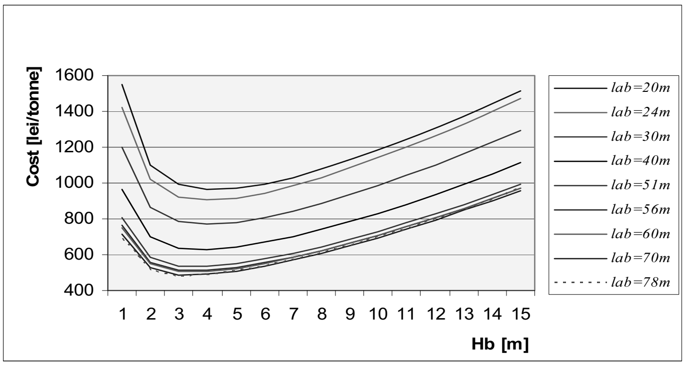

Fig.6 *Variation of the unit costs, for l_{ca} =600m and N_{shift} = 6 workers*

The top coal height increase, from 3m to 15m, in the case of workers team, with N_{shift}=6 workers, generates a *production cycle* (Fig.7 and 8) increasing with up to 265% (for l_{ab}=20m), respectively 311.94% (for l_{ab}=78m). The coal face cycle duration decreases when in the coal face exists a team of 15 workers/shift, with up to 54.5% (for h_b=3m and l_{ab}=20m), respectively with 15.34% (for h_b=3m and l_{ab}=20m), by report to a team with 6 workers/shift.

The *daily advancement speed* (Fig. 9) of the coal face decreases at the same time with the top coal height and the coal face length. For a top coal height variation between 3m and 10m, the advancement speed decreases with 265% (for l_{ab}=20m), respectively with 312.44% (for l_{ab}=78m). Increasing the coal face length, from 20m to 78m, leads to a face speed reduction with 266.143% (for h_b=3m), respectively with 313.77% (for h_b=15m). The coal face advancement speed increases when in the coal face exist a number of workers N_{shift}=15, by report to N_{shift}=6, with values ranging between 54.62%-39.4% (for h_b=3m and l_{ab}=20-78m), respectively 15.29%-10.22% (for h_b=3m and l_{ab}=20-78m).

Coal face *daily production* (Fig.10 and Fig.11) increases at the same time with the top coal height, from 3m to 15m, the obtained values belonging to the interval of 19.94% (for l_{ab}=20m), respectively 1.98% (for l_{ab}=78m). Increasing the coal face length from 20m to 78m implies a production increase with 46.6% (for h_b=3m), respectively 24.86% (for h_b=15m).

The workers' number growth in the coal face, from 6 to 15 workers/shift, in the conditions of the top coal height increase from 3m to 15m, determine a supplementary coal production of 54.36% - 15.40%, for l_{ab}=20m, respectively 34.8%-15.40%, for l_{ab}=78m (the biggest coal production increase are obtained for the smallest top coal heights).

Workforce productivity (Fig.12) has the same increasing tendency as the extracted production, for the same workers number placed in the coal face. Thus, the growing the top coal height from 3m to 15m has as impact the workforce productivity increasing with 20% (for l_{ab}=20m), respectively 1.95% (for l_{ab}=78m). Increasing the coal face length, from 20m to 78m, generates a workforce productivity increase with 46.54% (for h_b=3m), respectively 24.5% (for h_b=3m) and N_{shift}=6.

Supplementation of the number of workers in the coal face, from 6 to 25 workers/shift, in the conditions of top coal height increase, from 3m to 15m, does not have as effect the workforce productivity growth. Even if the coal production is bigger, the face workers number doubling has as consequence a productivity reduction with values ranging between 61.87% and 116% (for l_{ab}=20m), respectively 79.52% and 127.38% (for l_{ab}=78m).

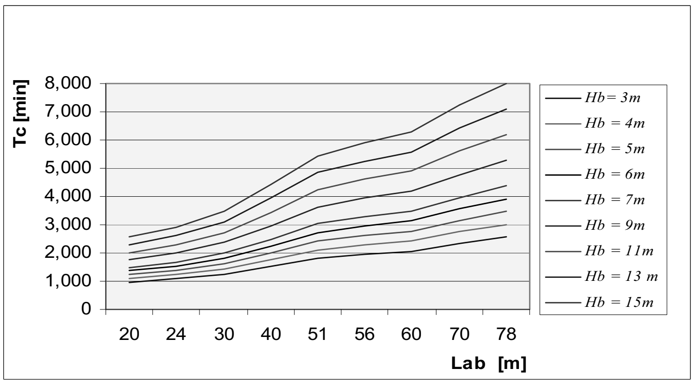

Fig.7 *Variation of the coal face cycle $T_c=f(l_{ab})$, in function of the coal face length, for N_{shift}=6 workers*

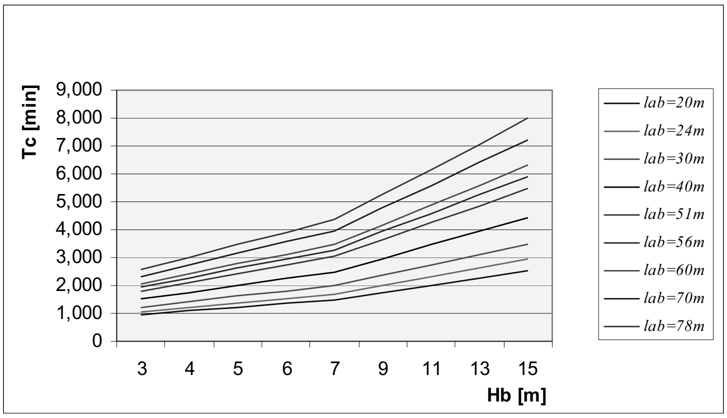

Fig.8 *Variation of the coal face cycle $T_c=f(h_b)$, in function of the coal face length, for N_{shift}=6 workers*

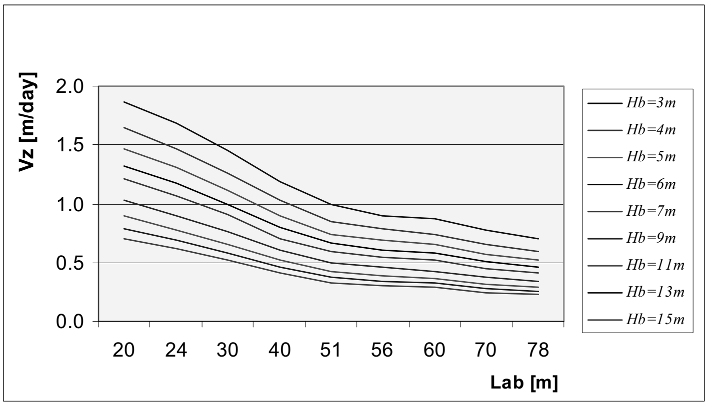

Fig.9 *Variation of the daily face advancement speed $V_z=f(l_{ab})$, in function of the coal face length, for N_{shift}=6 workers*

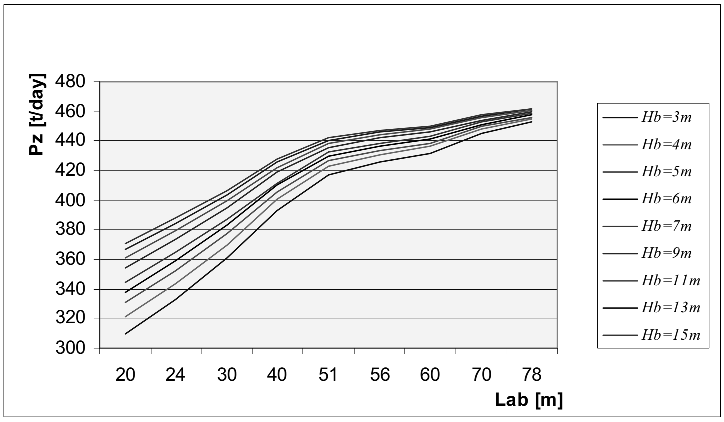

Fig.10 *Variation of the daily coal production $P_z=f(l_{ab})$, in function of the coal face length, for N_{shift}=6 workers*

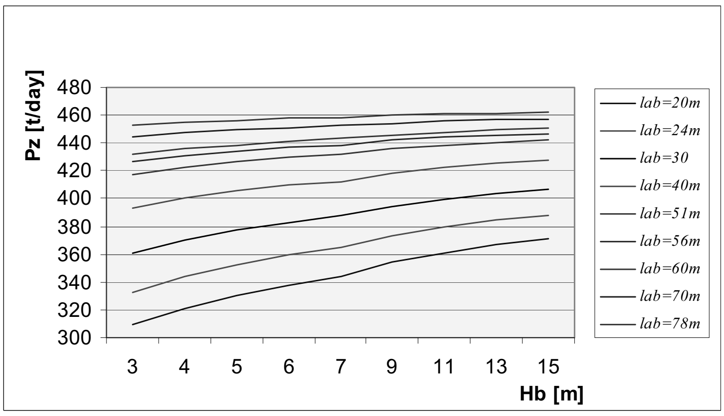

Fig.11 *Variation of the daily coal production $P_z=f(h_b)$, in function of the coal face length, for N_{shift}=6 workers*

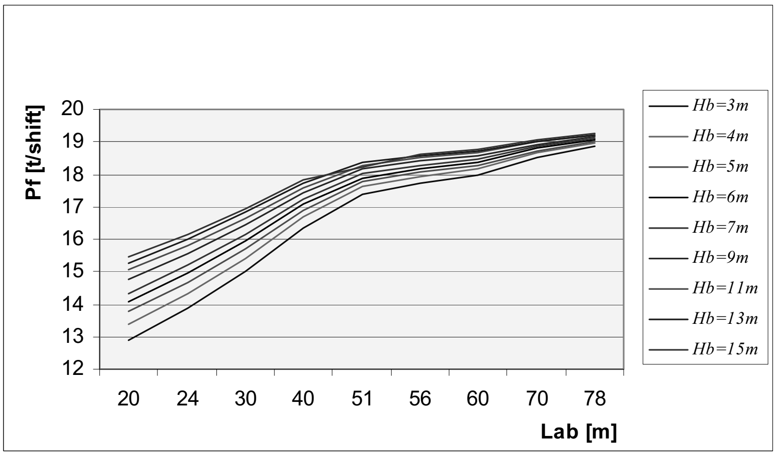

Fig.12 *Variation of the workforce productivity* $P_f=f(l_{ab})$, *in function of the coal face length, for* N_{shift}*=6 workers*

6. Conclusions

The main parameters optimization of the mechanized top coal caving face, in horizontal slices, has been achieved by analysing the general cost function, generated at the panel level.

The optimum value of the top coal height, for a minimum unit cost, is of $h_{b\ optim}$=4m (in the domain of 2-6m, for $\pm$ 5% cost deviation), regardless of the coal face length and the face workers' number.

The optimum domain of the panel length l_{ca} is framed in between the natural geological blocks limits, respectively of (100 - 600) m.

Increasing the coal face length has a major influence on the cost values obtained at the coal face level.

The growth of the workers' number of the face team, from 6 to 15workers/shift, does not have a significant impact on the cost reduction, but has as effect the production time cycle reduction (which increases at the same time with top coal caving height).

The daily advancement speed of the coal face diminishes at the same time with the top coal height and coal face length decrease.

The daily production and the workforce productivity, at the coal face level, grow with the top coal height increase.

References

1. Chiril,G.
Optimization of the main technological parameters of the top coal caving mining methods, applied in the thick and dip coal seams of Jiu Valley (in Romanian), Ph.D. Thesis, University of Petroşani, 2001.

2. Cozma,E.
Mining parameters optimization of the layered deposits (in Romanian), Focus Publishing House, Petroşani, 2002.

3. Cozma,E., Onica,I.
Improvement of the top coal caving mining methods applied at the great dip coal seams from Jiu Valley, Proceedings of International Symposium „Universitaria Ropet 2002", Petroşani, 2002.

4. Mihăilescu,V.
Improvement of the mining methods in the case of the thick and dip coal seams applied in the Jiu Valley mining basin (in Romanian), Ph.D.Thesis, Petroşani, 2013.

5. Mihăilescu,V., Onica,I., Cozma,E.
Parameters' optimization of the longwall faces with top coal caving mining, in horizontal slices and individual support technology, Annals of the University of Petroşani – Mining Engineering, 2012.

6. Onica,I.
Self-financing ways of the Jiu Valley coal basin mining (in Romanian), Mining Revue, vol.41, no.8, 1990.

7. Onica,I., Chiril,G.
Top coal mining in longwall faces (in Romanian), AGIR Publishing House, Bucureşti, 2005.

8. Onica,I., Cozma,E., Mihăilescu,V.
Improvement of economic efficiency of longwall mining in short panels in the case of Jiu Valley thick coal seams, Romania, Proceedings of the International Multidisciplinary Scientific Geoconference, SGEM 2011, 20-25 June, Sofia-Bulgaria, 2011, Published by STEF92 Technology Ltd. Sofia-Bulgaria, pag.801-808. DOI: 10.5593/sgem2011.