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Нови технологии и системи за открито и подводно разработване на находища на полезни изкопаеми

B. Drilling and blasting activities and blasting materials.
Пробивно-взривни работи и средства за взривяване

C. Innovatios and quality management. Cost effectiveness.
Иновации и управление на качеството. Икономическа ефективност

D. Electrification, automation, mechanization and repair.
Електрификация, автоматизация, механизация и ремонтна дейност

E. Information technology design, geological, mining and mine surveying.
Информационни технологии при проектиране, геологопроучвателни, маркшайдерски и минни дейности

F. Drainage, stability and consolidation of the slopes in open pits, quarries, dumps and tailings.
Отводняване, устойчивост и укрепване на откосите в открити рудници, кариери, насипища и хвостохранилища

G. Ecology, protection and reclamation of environment.
Екология, опазване и възстановяване на природната среда

H. Technical safety in open pit and underwater mining of minerals.
Техническа безопасност при открит и подводен добив на полезни изкопаеми

MULTICRITERIA MODEL FOR APPLICATION OF UNDERGROUND GASIFICATION IN COAL DEPOSITES IN MACEDONIA

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ABSTRACT
With the increasing need for energy, both in quantitative and qualitative terms increasingly demands that natural energy raw materials are used techno - economically and in environmentally optimal way. This should be especially popular in our country does not have sufficient and structurally favorable supplies of energy raw materials. In this paper the aim is to introduce and implement new unconventional method of coal exploitation in order to minimize the emission of harmful gases. Specifically it comes to underground gasification of coal which is still a new and developing technology.
Keywords: *underground coal gasification, multicriteria, coal deposits, ecology*

INTRODUCTION

Macedonia is relatively poor in quality forms of primary energy. Main energy potential is coal and it is mostly in the form of lignite with low calorific value. We will develop a profile of the state of exploitation on existing and future potential deposits of coal. Based on this profile and selected technology will form a mathematical model for the analysis and selection of potential deposits of unconventional coal exploitation. Then, from analyzed and selected alternative solutions of the potential deposits for the application of underground gasification of coal is defined multicriteria model that will make a ranking of potential deposits in order of priority and the possibility.

EXPERIMENTAL PART

Previous studies done in the field of underground gasification of coal showed that the large number of pilot projects and trials were conducted on almost all types of coal (lignite to anthracite), at different depths, layers with different litology, then various geological and hydrogeological conditions.
The success was a fully unsatisfactory to completely acceptable. As representative deposits are taken 3 coal deposits that provide an opportunity for analysing and making decisions about possible application of underground gasification of coal.
Based on modern research in this area for these deposits will be selected 4 main criteria (minimum depth of the coal seam is not greater than 12 meters, minimum power layer is not less than 2 meters, ash content not exceeding 35 % and a sulphur content of up to 5%) and 6 auxiliary criteria which are selected from conducted answers from questionnaires which mining engineers from Macedonia dealing with exploitation and projecting mines of coal.
For choosing coal deposit suitable for underground gasification of coal in the following table is given their sublimate that all three sites covering.

Tab.1 Parameters in order of their importance for the proper selection of location of underground coal gasification

No	Parameter	Requirement
1	Coal rank / type	Lignite and low-calorie coal
2	Seam thickness	Preferably >1 m, ideally 5 -10 m
3	Seam depth	> 12 m, ideally > 150 m
4	Seam dip / inclination	Any but steeper is preferred as it may be technically difficult to mine through conventional methods
5	Seam/strata structure	Avoid excessively fractured, faulted and broken rocks as they may cause water inrush or product gas and contaminant leakage
6	Moisture contents Coal quantity	Controlled inflow of water or high moisture contents are desirable especially after initiation of burning
7	Permeability and Porosity	More permeable the seam is, easy to link the injection and production well, more permeable the strata is more chance of gas leakage and contaminant movement
8	Groundwater	Avoid potable aquifer and large water bodies
9	Coal quantity	Dependent upon gas utilization and profitability
10	Infrastructure availability	Roads, electricity and power transmission lines
11	Socio - Economic	Structure of the population. Training of personnel

Defining the model of underground gasification of coal deposit No.1

Were used tabular data from borehole investigations, their elevations on the ground, the depth of matching coal layers, their power (thick), then the content of ash and sulfur.
Therefore, set a four (4 criteria) that are key to solving the model as follows:
CRITERIA K1 - depth layer $\geq$ 12 m,
CRITERIA K2 - THICKNESS (POWER) $\geq$ 2 m,
CRITERIA K3 – ASH CONTENT $\leq$ 15% (this criterion is an additional requirement for modeling, while it made 5 models with limiting values of the ash content of 15, 20, 25, 30 and 35%)
CRITERIA K4 – Sulfur content $\leq$ 5 %.
In total it is used 180 indexed data. According to the 5 surveys models of sub-variants of the model content of the ashes of 15, 20, 25, 30 and 35 percent the following is a table of met criteria.

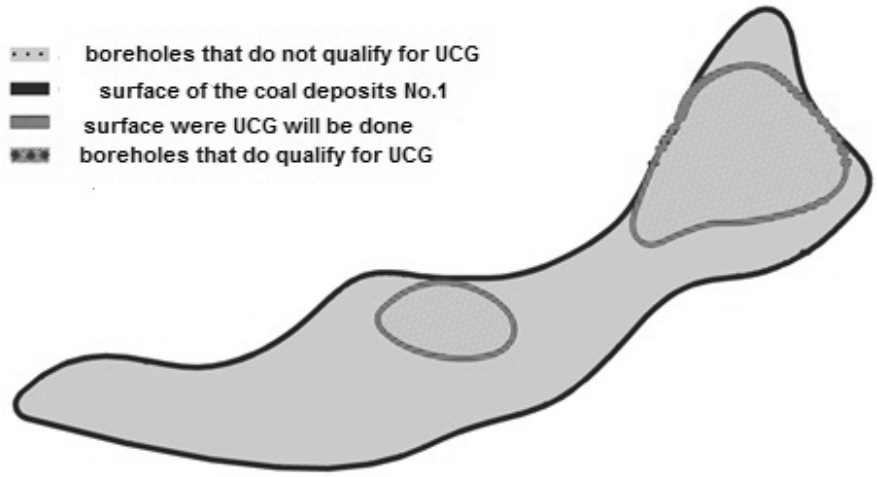

Fig.1 Surface of coal leyar in deposit No.1 and surface of leyar part that applying to 4-th underground coal gasifications conditions

For adopted model with an ash content of 35%, 38% from borehole meet these criteria

Table 2 Percent of file conditions

Model	Conditions	Met criteria			
		4	3	2	1
1	K3<=15%	3.33	43.89	97.22	100.00
2	K3<=20%	12.22	55.56	97.22	100.00
3	K3<=25%	23.33	70.00	98.89	100.00
4	K3<=30%	32.78	86.11	98.89	100.00
5	K3<=35%	37.78	91.11	100.00	100.00

Out of the total deposit No.1 approximately 27.40% 4 meet all given criteria for underground coal gasification.

Defining the model of underground gasification of coal deposit No.2

Were used tabular data from borehole investigations, their elevations on the ground, the depth of matching coal layers, their power (thick), then the content of ash and sulfur.
In total it is used 784 indexed data. According to the 5 surveys models of sub-variants of the model content of the ashes of 15, 20, 25, 30 and 35 percent the following is a table of met criteria.
For adopted model with an ash content of 35%, 6% from borehole meet these criteria.

Table 3 Percent of file conditions

Model	Conditions	Met criteria			
		4	3	2	1
1	K3<=15%	0.51	32.53	84.69	100.00
2	K3<=20%	1.40	45.03	87.37	100.00
3	K3<=25%	3.44	55.74	91.71	100.00
4	K3<=30%	4.85	64.16	94.64	100.00
5	K3<=35%	5.99	70.03	97.07	100.00

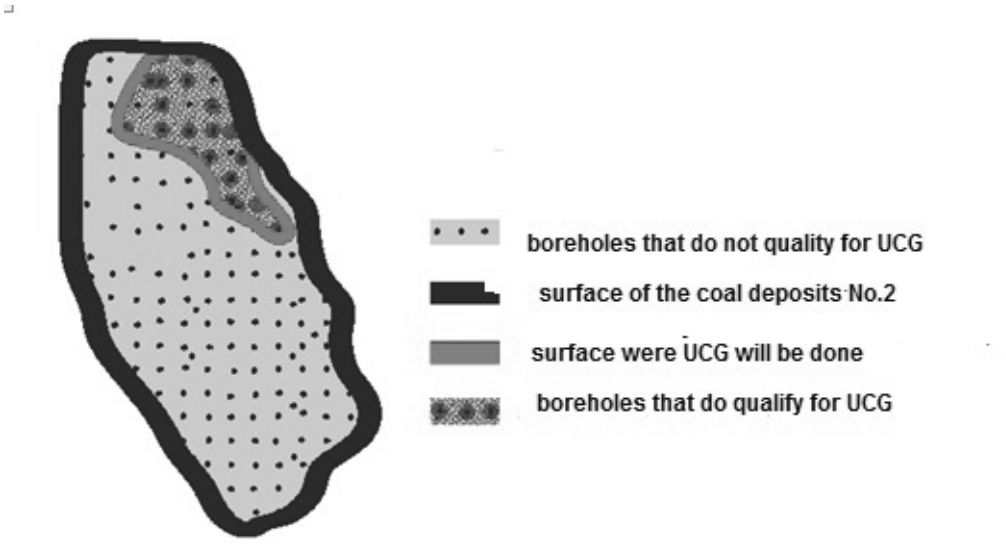

Fig. 2 Surface of coal leyar in deposits No.2 and surface of leyar part that applying to 4-th underground coal gasifications conditions

Out of the total deposit No.2 approximately 15 % 4 meet all 4 given criteria for underground coal gasification.

Defining the model of underground gasification of coal deposit No.3

Were used tabular data from borehole investigations, their elevations on the ground, the depth of matching coal layers, their power (thick), then the content of ash and sulfur.
In total it is used 48 indexed data. According to the 5 surveys models of sub-variants of the model content of the ashes of 15, 20, 25, 30 and 35 percent the following is a table of met criteria.
According to the 5 surveys models of sub-variants of the model content of the ashes of 15, 20, 25, 30 and 35 percent the following is a table of met criteria.
For adopted model with an ash content of 35%, 80% from borehole meet these criteria.

Table 4 Percent of file conditions

Model	Conditions	Met criteria			
		4	3	2	1
1	K3<=15%	18.75	87.50	100.00	100.00
2	K3<=20%	41.67	87.50	100.00	100.00
3	K3<=25%	70.83	91.67	100.00	100.00
4	K3<=30%	79.17	95.83	100.00	100.00
5	K3<=35%	79.17	95.83	100.00	100.00

In a continuation is a graphic representation of the total area of the coal deposits No.3 and outlined area of the same habitat that meets the 4 main criteria for underground coal gasification.

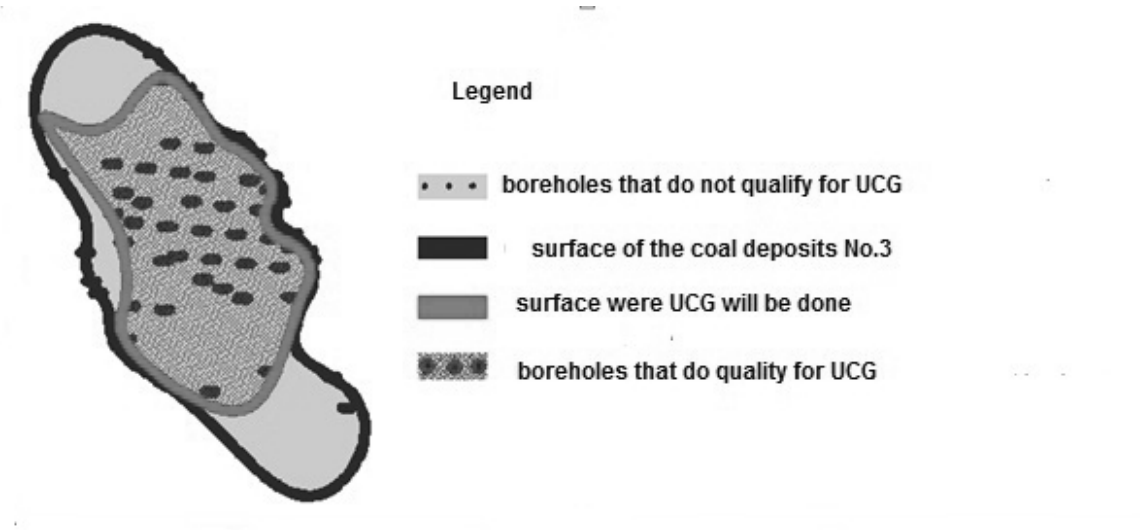

Fig.3 Surface of coal leyar in deposit No.3 and surface of leyar part that applying to 4-th underground coal gasifications conditions

Out of the total deposit No.3 approximately 60.55 % meet all 4 given criteria for underground coal gasification.

Selection and identification of criteria for Multicriteria Optimization

Criterion 1: Coefficient of utilization of coal reserves
Criterion 2: angle downs
Criterion 3: Structured – tectonics characteristics
Criterion 4: Hydro - geological features
Criterion 5: Configuration field
Criterion 6: Charge for exploitation by conventional methods
Criterion 7: Ability to use conventional methods

Multicriteria model is defined by descriptive marks required is their transformation into numerical values. For this purpose the simplest is using a linear scale transformation.

0	1	2	3	4	5	6	7	8	9	10
	distinctively low		low		medium		high		distinctively high	
worst		many low		secondary lower		secondary higher		very high		best

Fig.4 Linear transformations for the quality atributs

Resolving multicriteria model was made by the PROMETHEE II method and was used academic software version VISUAL PROMETHEE.

Statistical indicators

The following table shows the basic statistical indicators for entrance Multicriteria model.

Table 5 Statistical indicators

Feature	K1	K2	K3	K4	K5	K6	K7
MIN	15.31	1.50	3.00	3.00	3.00	10.54	3.00
MAX	60.55	5.00	7.00	7.00	7.00	23.61	7.00
Average value	34.42	2.83	5.00	4.33	5.33	16.38	5.00
Standard deviation	19.12	1.55	1.63	1.89	1.70	5.42	1.63

Table 6 Caracteristics of criterium function

Feature	K1	K2	K3	K4	K5	K6	K7
Min/Max	max	max	max	max	max	min	max
W	0.50	0.10	0.10	0.05	0.05	0.10	0.10
Type function	Ordinary	Level	Level	Ordinary	Level	Ordinary	Level
Indifirenca	-	1.00	1.00	-	2.00	-	1.00
preferences	-	3.00	3.00	-	5.00	-	3.00

Net flow

The following are the values of the net flow over the PROMETHEE II method.

Table 7 Total values according PROMETHEE II

Alternative	Phi	Phi+	Phi-
Coal deposit No.3	0.3375	0.5625	0.2250
Coal deposit No.1	0.1250	0.5250	0.4000
Coal deposit No.2	-0.4625	0.1875	0.6500

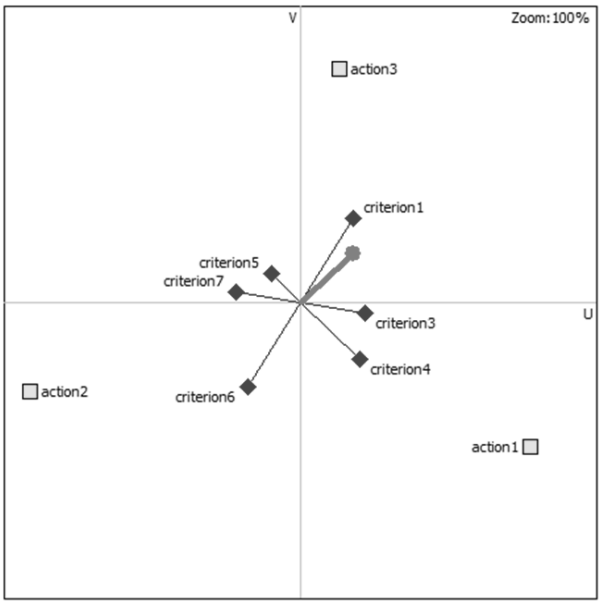

Fig.5 GAIA diagram

Since output tables and diagrams can be concluded that the first alternative is ranked alternative A3: the coal deposits No.3 which has a value of 0.3375 over the net.

CONCLUSION

Underground coal gasification is a technology that has long been in the experimental stage. Exceptions exist in several countries in the world, such as Russia, Canada, Kazakhstan, China, where attempts are made to obtain commercially. Studies have confirmed the importance of coal as the main energy source in the country. It's made a complete analysis of the profile of coal deposits in the country.
Were analyzed potential deposits of coal, their qualitative - quantitative characteristics, then structural - tectonic, hydro - geological, chemical composition, socio - economic and above all economic parameters. The application of underground coal gasification as typical unconventional method for exploitation of coal by minimizing emissions, reduce harmful emissions of CO_2 by at least 73% of NOx by at least 67%, emissions of SO_2 and PM particles will completely eliminate. With this underground coal gasification became a technology which is close and goes towards clean technologies with zero emissions.

REFERENCES

1. Blinderman, M.S.; Anderson, B. Underground coal gasification for power generation: Efficiency and CO2-emissions. ASME 2004 Power Conference, Paper No. POWER2004-52036, pp. 473-479
2. Blinderman, M.S.; Saulov, D.N.; Klimenko, A.Y. Forward and reverse combustion linking in undergroundcoal gasification. Energy 2008, 33, pp. 446–454
3. Kuznetsov AA, Kapralov VK. UCG in Russia and prospects for electric power production in gas–electric complexes. In: International workshop on underground coal gasification, DTI conference centre, London, 1–2 October 2003
4. Friedmann, S. J. North America Prospects for UCG in a Carbon Constrained, Energy Secure World. Presented at the Twenty-Fifth Annual International Pittsburgh Coal Conference, Pittsburgh, PA, Sep 29-Oct 2, 2008; pp. 26-1
5. Pana, C., Review of Underground Coal Gasification with Reference to Alberta's Potential, in Alberta Geological Survey. 2009. Redman, E., Fenerty, K., et al., 2009. *Mobilizing Next Generation Coal Gasification Technology for Carbon Capture and Sequestration*. Coal without Carbon: An investment plan for Federal Action, A Clean Air Task Force(Chapter 2), 17-36
6. Ray, S. K., Panigrahi, D. C., et al., 2010. *Cleaner Energy Production with Underground Coal Gasification - A Review*. The Institute of Engineers India: IE(I) Journal-MN, 91
7. Brown, K. M., 2012. *Insitu Coal Gasification: An Emerging Technology*. Sustainable Reclamation. R.I.Barnhisel. Tupelo, MS, American Society of Mining and Reclamation (ASMR)
8. Perkins G, Sahajwalla V. A mathematical model for the chemical reaction of a semi-infinite block of coal in underground coal gasification. Energy & Fuels 2005;19(4):1679E92. http://dx.doi.org/10.1021/ef0496808