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HYDROIMPULSE IMPACT IN THE TECHNOLOGICAL CYCLE OF CONSTRUCTING PREPARATORY DRIFTS: EVALUATION AND ECONOMIC EFFICIENCY

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Abstract. The article examines the efficiency of using the hydroimpulse loosening method in outburst-hazardous coal seams in the face of a preparatory drift. The assessment of the method's effectiveness is based on the results of industrial experimental studies conducted in the mining-geological conditions of coal mines "Krasnodonvuhillia" PJSC in the Donetsk Basin of Ukraine. Rational parameters of the method were determined through a comparison of fluid injection modes. Static and impulse modes were considered, and criteria for monitoring the efficiency of injection were established.

It has been established that the use of a cavitation generator in the process of hydro-loosening coal seams allows for an increase in the effective zone of crack formation and fluid filtration in the seam by developing shear deformation. Therefore, the application of hydroimpulse impact on the outburst--hazardous coal seam in the face of a preparatory drift allowed for an expansion of the safe coal extraction zone to the depth of the borehole drilling. This, in turn, has increased the rate of drift construction by a shearer. Based on the results of mining-experimental works and studies, the parameters of the layout scheme for technological boreholes and control blastholes in the face of the drift are justified. The high reliability of the hydroimpulse impact device and the efficiency of the method have been established.

The economic efficiency of the method is determined based on the comparison of financial costs for measures to prevent sudden emissions of coal and gas in the conditions of the mines of "Krasnodonvuhillia" PJSC. The calculation compares the expenses when using the drilling and blasting method for drift construction and the method of drift construction with a shearer. The drilling and blasting method for drift construction in shock blasting mode was considered as the baseline. When constructing drifts with a stoping machine, the application of hydro-loosening or drilling of pre-advance boreholes is envisaged. The costs per 1 work cycle and 1 linear meter of drift construction, monthly expenses, and expenses per 1 kilometer of drift construction are compared. The economic effect of implementing the hydroimpulse fracturing method is established by reducing the costs of the production process and increasing the speed of constructing preparatory drifts from 3 to 8 meters per day.

Keywords: face of the working, coal seam, gas dynamic phenomenon, hydroimpulse impact, economic efficiency.

1. Introduction

In developed coal deposits, such as the Donetsk Basin (Ukraine) or Upper Silesian (Poland) basins, coal mining at great depths is accompanied by the manifestation of gas-dynamic phenomena (GDP). The greatest danger is posed by sudden releases of coal and gas. Sometimes they are accompanied by methane and dust explosions and fires with catastrophic destruction of mine workings and deaths of miners. That is why research, development and implementation of preventive measures continue unabated. The most difficult conditions arise in the face of preparatory drifts when they are constructed in unprotected zones and zones of high mining pressure. In these conditions, the drifts are constructed using drilling and blasting operations (DBO) in the mode of concussive blasting (CB). This reduces the speed of drifts advancement from 3–4 meters to 1 meter per day, while the cost of construction of 1 running meter of the drift doubles. For example, at "Sukhodolska-Shidna" Mine Administration (Ukraine), the speed of mine construction by stoping machine ranges from 4 to 6 meters per day, while the speed of DBO is reduced to 2 meters per day.

2. Methods

The method of engineering calculation (determination of dynamic parameters of fluid pressure oscillations) and the method of statistical processing of instrumental measurement results were used in the study. When performing mining experimental works, we were guided by regulatory methods of controlling methods for preventing sudden coal and gas emissions, such as control of hydroimpulse loosening parameters and diagnostics of the massif condition by acoustic systems SASTE-1 (Seismic and Acoustic Signal Transmission Equipment) and SCE -98 (Sound-Catching Equipment).

In the process of performing mining experimental works, we used serial equipment available at the mine and the developed cavitations' device.

The economic effect was calculated using:

- regulatory acts and unified operating standards for mines of Donetsk and Lviv-Volyn coal deposits;
- methodological recommendations for a comprehensive assessment of the effectiveness of scientific and technological progress in the coal industry;
- information and analytical base for management decision-making;
- analytical study of financial and economic activities of the mine.

3. Experimental part

For many decades, preventive measures have been taken to prevent underground mining accidents in difficult mining and geological conditions. In the conditions of the mines of the Donetsk Basin, the most developed over the past 50 years have been the method of hydro- loosening and the method of drilling the pre-advanced boreholes. However, these measures are not sufficiently effective in terms of safety when constructing drifts in the stress-strained zones of outburst-hazardous coal seams, in areas of high mining pressure and zones of plectative disruption. In such conditions, drilling of pre-advanced boreholes is accompanied by increased gas emissions, coal dust, drilling tool jamming, and fluid injection is accompanied by uncontrolled squeezing and coal collapse. In other words, the manifestation of GDP can be observed in the working face [1, 2].

Scientists of the M.S. Poliakov Institute of Geotechnical Mechanics of the National Academy of Sciences of Ukraine have developed a method of hydroimpulse fracturing. It is based on the use of periodic-burst cavitation. The parameters of the method were substantiated and established on the basis of the results of mining experimental studies in the mines of "Krasnodonvuhillia" PJSC (Table 1) [3].

In our previous works, for example [4], we considered the process of forming a cavitation fluid flow, its active phase, and the parameters of the method that allow us to eliminate the disadvantages of static fluid injection modes. We also applied methods for predicting emission hazard and found that stress redistribution in the formation the roof of the seam occurs at a distance of more than 10 meters from the working face. The efficiency of hydro-loosening was monitored by acoustic emission of the rock mass (sound-collecting equipment SCE-98) and by the amplitude-frequency characteristics of the acoustic signal (SASTE -1).

Table 1 – Number and location of mining experimental studies of the method of hydroimpulse fracturing

Enterprise	Mining working	Number of tests (injection mode)	
		static	impulse
"Douvanna" mine	Conveyor gradient of the coal seam k_2+k_2^U from the horizon 590m to the horizon 382m	1	2
"Sukhodolska-Shidna" Mine Administration	24 Eastern conveyor drift of the coal seam i_3^1, horizon 915 m	22	16
	25 Eastern ventilation air roadway of the coal seam i_3^1, horizon 915 m	4	5
"Molodohvardiiske" Mine Administration	33 Eastern conveyor passageway (from the air passage) of the coal seam k_2^l, horizon 615 m	4	2
	33 Eastern conveyor passage (from the diagonal passage) of the coal seam k_2^l, horizon 615 m	3	3
	Western ventilation drift and loading gradient of the coal seam i_3^1, horizon 617 m	1	2
Total:		35	30

In total, preparatory drifts with a total length of about 1.2 km were constructed during the mining experimental studies. A significant amount of research in different conditions (Table 1) enhances the reliability of the results obtained. In addition, the results obtained made it possible for the first time in practice to compare the methods of construction of drifts using different measures to prevent the GDP. The study and experimental determination of the depth of liquid penetration into the coal seam made it possible to substantiate the zone of safe coal mining by a shearer [5,6].

Given that it is impossible to study the penetration of fluid into the coal seam around the borehole in the preparatory drifts, the work was performed in the face 33 of the Eastern Orlovska longwall of the k2l seam.

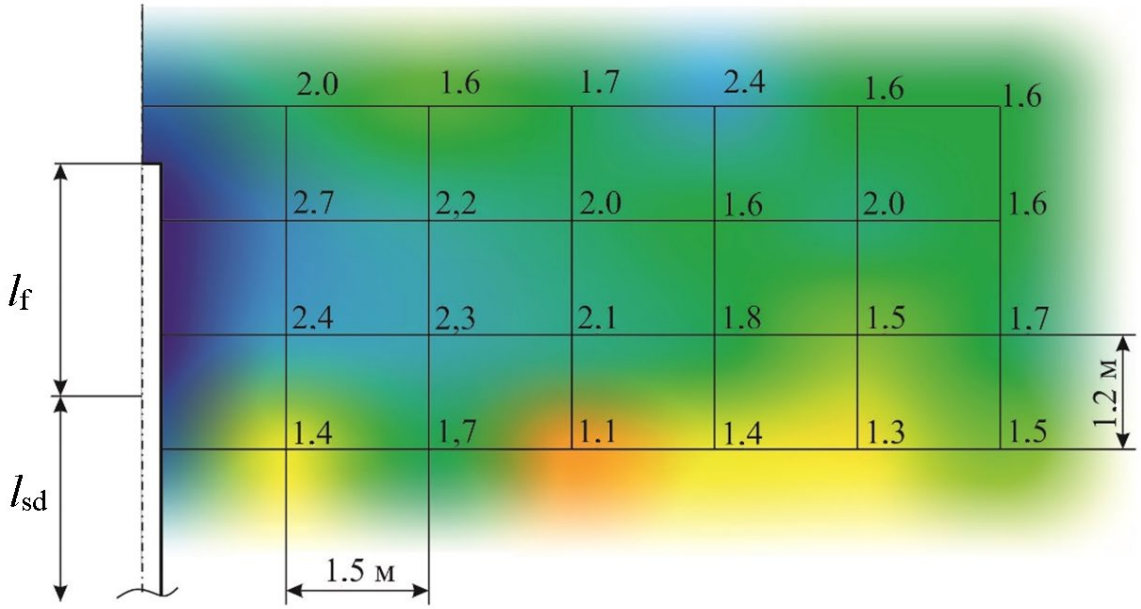
The change in the coal seam moisture content was used to study the zone of influence of the borehole under hydroimpulse impact . The study was carried out in accordance with the "Instruction..." [7]. According to the calculations, the value of the fluid injection pressure into the seam was Pc =15.2 MPa. For the experiment, we assumed a value of Pb = 12 MPa, provided that the fluid injection pressure should be 20 % lower than the calculated one. This corresponds to the range of fluid pressure at the inlet of GC-2.5 for a given mining depth. According to the method of coal seam wetting [6], the amount of fluid to be injected into the borehole was calculated as qc=0.88 m3 and the injection duration as t = 36.6 minutes.

To carry out the research, a 6.0-meter-long borehole was drilled at a distance of 11.5 m from the conveyor drift between sections No. 5 and No. 6. The borehole was bored to a depth of lsd = 4.0 m, the length of the filtration part was lf = 2.0 m. The fluid injection operations lasted 40 minutes. After switching on the pumping unit, the injection pressure was set to 12.0 MPa for ≈0.5 min with a control valve. The volume

of injected fluid was 1.42 m^3, and the average flow rate of the GC-2.5 generator was G=37.4 l/min.

After 15 minutes of fluid injection, a noise effect was recorded ahead of the bottom hole in the area where the borehole was located. Usually, this phenomenon in the roof of the coal seam accompanies the process of stress redistribution and crack formation in the massif. At the same time, no disruption of the borehole sealing or fluid seepage from the coal seam was recorded.

At the end of injection, between sections 1 and 6, after moving the stopping face by 1.2 m, coal samples were taken and its moisture content was determined. The research results are shown in Figure 1.



l_f – filtration part of the borehole, l_{sd} – sealing depth

Figure 1 – Results of coal moisture content studies by distance from the filtration part of the borehole

According to the research results, it is known that the natural moisture content of coal at the experimental site ranges from 1.1% to 1.4%. Therefore, the value of 1.5 % was taken as the criterion for evaluating the efficiency. This value is set before the stopping face approaches the filtration part of the borehole 0.63 m (one chip) and at a distance of 7.5 m to the sides of the borehole.

Thus, the zone of coal moisture content increase is observed at a distance of 7.5 to 9.0 m to the sides and at least 0.5 m in the direction of the stopping face movement. Taking into account that the liquid is filtered uniformly in the layering plane along the filtration part of the borehole under the hydroimpulse impact, the measurement results will be symmetrical. Taking this into account, the zone of change in coal moisture content around the borehole after hydroimpulse impact is at least 7.5 m to the sides from the borehole and not less than the length of its filtration part plus 0.5 m in the direction of movement of the stopping face.

This conclusion corresponds to the established zone of influence of the hydroimpulse impact based on the observations of the hydro-loosening process by means of acoustic monitoring of the coal seam explosion hazard [4].

Taken together, the results of studies [3, 4] substantiated the zone of safe coal extraction and the safe speed of the drift construction. This made it possible to calculate the economic efficiency of using the method of hydroimpulse loosening of an outburst-hazardous coal seam.

4. Results and discussion.

The calculation of the expected economic efficiency was performed in accordance with regulatory documents [8–10] based on the technical and economic indicators of the methods of construction of drifts in the outburst-hazardous coal seams and diagnostics of the financial activity of the mines of "Krasnodonvuhillia" PJSC.

The basic method is the method of construction of workings using the DBO in the CB mode. Costs were calculated in 2014 prices (before the war in Donbas). The main cost indicators are shown in Table 2.

Table 2 – Results of calculating the costs of preventing the GDP during the construction of a preparatory drift

Equipment and economic indicators	Unit of measurements	Method of construction of the drifts and measures			
		DBO	hydro-loosening	hydro-impulse impact	Pre-advnced boreholes
Drilling and loading machine	unit	2PNB-2B			
Drill bit	unit		SER-19M	SER-19M	
Pumping unit	unit		2UGNM	UNI-01	
Drilling rig	unit				NKR-100M
Energy consumption	kWh	66	55	18,5	72
Injection time (average)	min		80	45	
Liquid flow rate (average)	m^3		1.72	0.56	
Drilling of boreholes	manpower	1.239	0.124	0.124	8.86
Number of cycles per day	cycle	1	1	1	0.33
Safe excavation area	m	2.0	4.0	6.0	10.0
Costs per 1 running meter of construction	UAH	4096.0	2346.4	2327.3	2867.5
Speed of construction	m/day m/month	2.0 60	4.0 120	6.0 180	10.0 100
Costs for 1 month. (30 days)	UAH ths	245.76	281.57	418.91	286.75
Costs per 1 km of construction	UAH ths	4.10	2.35	2.33	2.87
The duration of the construction of 1 km	days months	500 17	250 9	167 6	303 10

In accordance with [8–10], we calculated the costs of preparatory drifts construction according to the basic method using the DBO in the CB mode and methods of preparatory drifts construction by stoping machine ;

- without the use of methods of preventing GDP;
- with the use of DBO in hazardous areas;
- with the use of hydro- loosening of the coal seam;
- with the use of pre-advanced boreholes;
- using hydro-impulse impact.

When calculating the cost savings from the use of hydro-impulse impact, it was determined:

- the difference in technical and economic indicators of the measures to prevent GDP per 1 m of production per day, month and year;
- savings from the purchase of equipment necessary for the application of fracturing and hydro-impulse impact;
- savings from electricity consumption when applying hydro-fracturing and hydro-impulse impact.

The economic effect of applying the new method was determined by comparing the indicators with the baseline and other methods (Table 3).

Table 3 – Economic efficiency of the new method

	Regulatory methods		
	DBO	Hydro-fracturing	Pre-advanced boreholes
Economic effect of the method of hydro-impulse loosening, thousand UAH.	4227.56	1378.18	2098.10

4. Conclusions

The static and impulse modes of fluid injection were compared. It has been established that the use of hydro-impulse impact can increase the efficiency of hydro- fracturing of the coal seam and increase the safe zone for mining operations. This makes it possible to increase the speed of drifts construction from 4.0 to 8.0 meters per day. Reducing the fluid consumption by up to 60% makes it possible to apply the method in the conditions of side rocks prone to soaking.

According to the assessment of the efficiency of the method of hydro-impulse fracturing of the outburst-hazardous coal seams, the expected annual economic effect per shearer will be:

- compared to the DBO (basic method) - UAH 4227.56 thousand;
- compared to the pre-advanced boreholes - UAH 2098.10 thousand;
- compared to hydro-fracturing - UAH 1378.18 thousand.

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ГІДРОІМПУЛЬСНА ДІЯ В ТЕХНОЛОГІЧНОМУ ЦИКЛІ СПОРУДЖЕННЯ ПІДГОТОВЧИХ ВИРОБОК: ОЦІНКА ТА ЕКОНОМІЧНА ЕФЕКТИВНІСТЬ

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Анотація. У статті розглянуто ефективність застосування способу гідроімпульсного розпушування викидонебезпечних вугільних пластів у вибої підготовчої виробки. Оцінювання ефективності розробленого способу виконано на підставі результатів промислових експериментальних досліджень, що були проведено в гірничо-геологічних умовах вугільних шахт ПАТ «Краснодонвугілля» Донецького басейну України. Було встановлено раціональні параметри способу за результатами порівняння режимів нагнітання рідини. Розглянуто статичний та імпульсний режими та встановлено критерії контролю ефективності нагнітання.

Встановлено, що використання кавітаційного генератора в процесі гідророзпушування вугільних пластів дозволяє збільшити ефективну зону тріщиноутворення та фільтрації рідини у пласті за рахунок розвитку деформацій зсуву. Тому застосування гідроімпульсної дії на викидонебезпечний вугільний пласт у вибої підготовчої виробки дозволило збільшити зону безпечного виймання вугілля до глибини буріння свердловини. Це дозволило підвищити швидкість спорудження виробок комбайном. На підставі результатів гірничо-експериментальних робіт та досліджень обґрунтовано параметри схеми розташування технологічних свердловин та контрольних шпурів у вибої виробки. Встановлена висока надійність пристрою гідроімпульсної дії та технологічність способу.

Економічна ефективність способу визначена на підставі порівняння фінансових витрат на заходи запобігання раптовим викидам вугілля й газу в умовах шахт ПАТ «Краснодонвугілля». У розрахунку порівняно витрати при застосуванні буропідривного способу спорудження виробок та способу спорудження виробок комбайном. Базовим вважали буропідривний спосіб спорудження виробок в режимі струсного підривання. При спорудженні виробок комбайном передбачено застосування гідророзпушування або буріння випереджальних свердловин. Порівняно витрати на 1 цикл виконання робіт та 1 погонний метр спорудження виробки, витрати за 1 місяць та на 1 км виробки. Економічний ефект від застосування способу гідроімпульсного розпушування встановлено за рахунок зниження витрат на виробничий процес та підвищення швидкості спорудження підготовчих виробок з 3 до 8 метрів на добу.

Ключові слова: вибій виробки, вугільний пласт, газодинамічне явище, гідроімпульсна дія, економічна ефективність.