Seismic monitoring of hydrodynamic impact on coal seam at interval hydraulic fracturing

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Abstract. The article proves the importance of using interval hydraulic fracturing of coal seam for gas emission stimulation. The authors suggest using equipment for taking measures to intensify gas emission during implementation of hydraulic fracturing. They assess rock condition before and after hydrodynamic impact on coal seam by means of seismic reflection technique.

1. Introduction
As production capacity of coal mining companies is increasing, the perspectives of mining science further development lead to the increase in the depth of coal mining. Such seams have higher methane content and need a complex of measures aimed at advance and preliminary gas drainage implementation [1-3].

To stimulate preliminary gas drainage from unrelieved coal seams the interval hydraulic fracturing method has been developed [4,5]. It implies the formation of a network of cracks in the borehole walls which are located across the coal seam bearing with the chosen hydraulic fracturing interval. Gas goes to these cracks from more developed ones which are located along the bearing and remain pressed due to ground pressure.

2. Measurement technique, equipment and devices
To make a network of cracks in the walls of the borehole with the set interval the authors used a rupture mechanism which consists of two elastic extension sleeves and a rupture valve placed between them (figure 1) [6,7].

Such a construction makes it possible to spot the part of the borehole subject to hydrodynamic fracturing. In case of increase in the number of hydraulic fracturing intervals it allowed the authors to control the process of uniform crack formation along all borehole walls. The rupture mechanism was inserted into the borehole being positioned on the high-pressure pipe column having a quick-release coupling (figure 2).

To enhance efficiency of preliminary gas drainage and increase the discharge of the methane-air mixture in “Kirov” mine of JSC “SUEK” the authors conducted an experimental research in borehole 66 using interval hydraulic fracturing of the coal seam and controlled the effectiveness of the performed work. To register formation and advance of the artificial cracks in the coal mass the authors used seismic monitoring method to control hydrodynamic impact on coal seam and at the same time to record the readings of the autonomous digital manometer. After the work was finished and the
borehole was connected with the gas drainage system the personnel of the mine measured the methane-air discharge from the borehole, which was subject to hydraulic fracturing, as well as from the preliminary gas drainage borehole located nearby.

2.1. Brief mining and geological characteristic of the experimental area

Thickness of Boldyrev seam is 2.35 m; it has a complex composition: in the central and lower parts of the seam there is a thin rock clay interbed m=0.05-0.15 m; coal hardness is f = 1.5-2; coal is glossy mainly with vitrinite group components; seam inclination is 20-50°, it has wave-like hypsometry. Boldyrev seam is prone to rock bumps. Concerning gas output factor, the mine belongs to group IV of coal mines where specific methane emission is higher than 15 m³/t.

Borehole 66 diameter is 93 mm. It was drilled into the coal seam from the mine working of the belt road in the extraction district 24-62. Its depth was 140 meters. Figure 3 indicates the borehole location.

Before the authors started their work they installed high-pressure equipment as well as measuring and test equipment (figure 4).

2.2. Discussion of results

Seam hydraulic fracturing from borehole 66 was performed on two sites with 4.5 meter intervals. On the first site the seam had been affected for 11.8 min (figure 5).

During working fluid pumping at pressure of 10.29 MPa valve was opened to supply fluid into the interpacker interval. After that on the 38th second of work aimed at borehole stimulation when pressure reached 9.87 MPa (hydraulic fracturing (HF) 1) there was a seam breakdown. Pressure
dropped down to 9.58 MPa. When pressure reached 10.17 MPa, 10.12 MPa and 10.17 MPa (HF2, HF3, HF4) there were insignificant pressure drops. After that further hydrodynamic impact was accompanied by seam saturation without any changes in pressure. On the second site hydrodynamic impact had been implemented for 7.0 min. The valve opened on the 9.6 sec when pressure was 9.52 MPa. Further when working fluid was supplied into the interpacker interval, and pressure reached 9.52 MPa the authors registered insignificant pressure drop which meant crack opening. After that stimulation took place without any pressure changes.

**Figure 3.** Location of the gas drainage borehole for interval hydraulic fracturing.

**Figure 4.** Technological scheme of equipment placement: 1 – pumping station; 2 – high-pressure sleeve; 3 – working fluid supply valve; 4 – drain valve; 5 – high-pressure reservoir with autonomous manometer; 6 – mechanical manometer; 7 – high-pressure pipe column; 8 – borehole for hydraulic fracturing; 9 – rupture device; 10 – plug.
Figure 5. Changes in pressure $P$ and temperature $t$ at hydrodynamic impact on seam in borehole 66.

To assess the efficiency of hydrodynamic impact on coal seam the authors conducted research using seam seismic exploration method. They studied transmitted waves before and after hydraulic fracturing.

Seismic exploration method implies recording of transmitted elastic waves, which have been deliberately generated on the wall of the travelling roadway, from the belt roadway. Signal reception was organized by means of linear interval placement of seismic sensors and geophones on the wall of the working, which were connected with autonomous seismic recording system. To conduct that geophysical survey the authors used a set of seismic equipment. Autonomous seismic station “R-1” is used to provide multi-channel examination with unlimited number of seismic data receiving points (figure 6).

![Figure 6](image)

Figure 6. A set of mining equipment for seismic data recording:
(a) autonomous seismic station “R-1”; (b) geophone GS-20DX.

Presence of geological formations with different physical and mechanical properties has an influence on the propagation velocity of the wave through coal and rock mass. The denser the mass is, the higher the wave propagation velocity. The obtained results for wave propagation velocity were saved as a material velocity model [8-11].
Horizontal geophysical view of velocity characteristics distribution near extraction column 24-62 before hydraulic fracturing implementation, compiled according to the results of the performed office work, has the following look (figure 7).

![Geophysical view of velocity characteristics distribution near extraction column 24-62 before hydraulic fracturing implementation.](image)

**Figure 7.** Geophysical view of velocity characteristics distribution near extraction column 24-62 before hydraulic fracturing implementation.

Horizontal geophysical view of velocity characteristics distribution near extraction column 24-62 after hydraulic fracturing implementation, compiled according to the results of the performed office work, has the following look (figure 8).
Conclusion

The results of the performed coal and rock mass seismic examination before and after hydrodynamic impact on coal seam show that there is a decrease in the transmitted elastic wave propagation velocity characteristics near the borehole used for hydraulic fracturing. That demonstrates that the density of the material has reduced as a result of artificial crack formation. That is also confirmed by the autonomous manometer readings (during working fluid pumping the authors registered several seam breakups which were accompanied by abrupt decrease in liquid pressure in the system).

Methane-air mixture discharge and gas concentration in borehole 66 is significantly higher than the corresponding parameters of gas emission in the preliminary gas drainage boreholes without hydraulic...
fracturing. The aforesaid results of the conducted research confirm that there is an increase in the number of cracks and enhanced gas drainage from preliminary gas drainage boreholes when interval hydraulic fracturing method is used.

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