Low-intensity vibration impact on a low-permeable coal seam

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Abstract. With a sufficiently high level of degassing works in the mines of a number of coal basins, their effectiveness is constrained by specific properties of the coal seams being mined. In particular, the filtration and reservoir properties of fossil coal differ significantly, in natural conditions, even within one coal seam. The article outlines the purpose of the new method, namely, the vibration impact on the coal seam to increase fracturing and as a consequence of increasing the gas recovery intensity. In this way, when mining a low-permeable gas-saturated coal seam, the gas recovery rate is very low due to the physical state of the array. Existing methods create insufficient conditions for the degassing of coal seams. Therefore, to increase the efficiency of the coal array it is required to create new, more efficient ways to crack open fractures and increase gas recovery from coal. This is achieved by applying vibration to a low-permeable gas-bearing coal seam.

1. Introduction

Incomplete and often insignificant extraction of methane from coal at the stage of preparation of a field for safe and efficient excavation is unfortunately a common disadvantage of the methods used for degassing coal seams nowadays, which later leads to methane explosions in the mines. However, a number of studies and test results support the theory that even low-intensity vibration effects can stimulate the formation of conditions in the array, namely the creation of new gas-conducting fracture systems in order to increase methane recovery from a gas-saturated low-permeable coal seam.

This search consists in the technological possibility of changing the physico-mechanical and filtration characteristics of the coal seam by using the effect of vibratory seam treatment, taking into account the block-hierarchical structure of the coal seam, creating methodological bases, as well as the technology of preparing the seam in the area of the resonant frequencies of the coal seam to implement new geomechanical state of high gas-bearing coal array with the use of controlled vibration effects [1].

The dominant value in the regulation of this state in the structure of coal, especially in ensuring maximum gas recovery, belongs to mechanical (vibration) effects.

In the process of separating the coal-methane system into different phases, it is possible to assume the following active mechanisms of action:

- gas release from the coal-methane system without destroying the structure of the coal array,

- gas release with complete destruction of the coal structure. This mechanism will be implemented under vibration impact (at forming waves of ultimate destructive stresses for a certain type of coal in a high-gas-bearing coal seam),
- gas release under shear deformation conditions as a result of local destruction of the coal structure.

It is known from the theory of small mechanical oscillations that the larger the attenuation coefficient is, the weaker the resonance effect is and, conversely, when the attenuation coefficient values approach zero, the amplitude of the forced oscillations in the resonance mode increases sharply [2].

Previously, this phenomenon was theoretically studied in the laboratory, considering the gas recovery from a coal array with an oscillating platform under the impact of a varying pressure gradient. For example, it is known that the natural pressure in a gas-saturated coal is no more than 1.0–2.0 MPa and at the opening of coal seam it is reduced to a minimum.

The coal arrays are areas of the development of physical and mechanical phenomena and processes as a result of the influence of natural or artificial factors during conduct of underground mining. At the same time, gravitational and tectonic stresses belong to natural factors, and stresses caused by undermining of a coal seam, etc., belong to artificial factors.

2. Methods

Coal arrays differ in the occurrence and degree of disturbance (fracturing and block structure) of the constituent rocks, the mineralogical composition, texture and porosity of the rocks, the presence of liquid (water) and gaseous (methane, etc.) fillers, their association with the coal substance, as well as indicators of geomechanical (acting forces, stresses and deformations of gravitational, tectonic and technogenic origin) and physical (technological processes, etc.) conditions. The selection of rocks array to conduct vibration impact is made by means of engineering-geological works, the scale of which is set depending on the goals in solving scientific problems and applied problems of the mineral deposits excavation.

Dividing coal seam array into separate gas-recovery coal blocks is possible by means of creating the necessary dynamic conditions for influencing the system under study. In such conditions, the separation of a heterogeneous coal-gas system is realized in practice, with an external supply of mechanical energy, accompanied by impact (shaking, shock, vibration). At the same time, high relative fluctuations of coal blocks can develop, at which the appearance of new systems of gas-conducting cracks in coal is observed. This phenomenon can also occur in the process of coal structure destruction under the impact of vibration, during which the process of gas recovery increasing occurs [3].

It is possible to change the mechanism of methane release from low-permeable gas-saturated coal through the walls of new fracture systems formed in the process of vibration destruction, and then through these cracks, connected with each other and the mine opening. The formation of man-caused self-destruction cracks is caused by the outcrop surface formed during vibration process. Therefore, they are called technogenic, and the deformation vector causing them is directed from the borehole to the coal array. At the same time, slowly growing cracks are observed, which are formed by opening natural ones and forming new ones. In this regard, it is necessary to distinguish between slow- and fast-flowing processes of crack formation. Natural cracks are slow-growing, which may grow or open. Man-caused cracks are rapidly growing and observed during vibration impact. As a rule, they grow instantly to the entire length, which is equal to the step of softening and spasmodically.

Coal seam array, as an environment of vibratory impact, the development of deformations, displacements and fractures, has a certain feature – heterogeneity: developing deformations are concentrated mainly in weakened structural elements of the coal array with cracks; blocks of monolithic rock, bounded by cracks, are deformed to a lesser extent. The destruction of coal occurs, as a rule, with the formation of the tangential stresses of shear sliding surfaces in the directions of maximum values, which form in the shape of formation zones of elementary coal blocks of various orientations. Resistance to this shift is due to the resistance of coal seams to the destruction and during block formation. In cases of relative orientation of the maximum tangential stresses and surfaces of coal array weakening, the development of deformations and fractures occur mainly in the plane of this weakening. Therefore, the effect of gas release from a gas-tight coal seam is observed. Gas permeability of fossil coal seams is valid only for areas with a large number of cracks. The vibration effect causes a softening process in the shape of creating a significant network of branching cracks. In the other non-disturbed zone, coal seams are in bulk stress-strained state and release methane poorly.

Due to the lack of outcrop surface, the volume-compressed coal array simply has no place to deform, there is no reason to assume that there are natural cracks in it. However, from the experience of mining operations, it is known that cracks exist both at shallow and at great depths and mine gases are released into mine openings not only in the areas of mining and preparatory works, but also simply from the earth surface.

So, at vibration impact from underground openings, it is possible to change the state of the properties of the coal array at given frequencies, which will lead to the formation of new systems of gas-conducting cracks. Depending on the geological conditions and the nature of the work on the active influence, the behavior and properties of the rocks of the array are approximated by the mechanical laws of various idealized classical media [4]. Under conditions of high variable loads (at a distance from free outcrops of the seam), the mechanical state of the array is estimated by the provisions of continuum mechanics with a sufficient approximation rate. The condition for the correct application of these provisions to the array is to apply them to parts of the array, quite large in comparison with the dimensions of the structural elements. When the scale ratio of model and array sizes is not less than 10-50-fold ratio, the heterogeneity of the array is approximately considered as quasi-uniformity. The mechanical properties of the array in the calculations of its deformations are characterized by the corresponding indicators of the uniformity of the array, taking into account the coefficients of structural weakening, depending on the disturbance of the array (frequency and length of cracks).

Assessing the effect of active influence on the coal-methane system, it can be assumed that the loss of system stability with the release of methane into free phase is possible under dynamic conditions. In this case, the violation of the coal-gas system stability under dynamic conditions is associated with the processes occurring in the coal array.

Until recently, the source of energy when influencing a coal mass was hydraulic impacts through downholes from the ground surface with rates exceeding the natural pickup of the coal seam, but this method is not capable of causing significant effects in gas-bearing coal for significant methane release. Residual gas in the coal array is hard to extract due to its high sorption capacity. In order to increase gas recovery from coal, it has been proven in laboratory conditions that there is a significant increase in the flow of gas from coal if it is affected by elastic waves. However, there is a fundamental misunderstanding of the physical mechanisms of methane recovery from low-permeable coal when using the effect of elastic waves and there is virtually no such theory of gas release from coal. To describe the interaction of vibration with coal during vibration impact, it is necessary to describe the effects occurring in the array.

Previously conducted bench tests of vibration impact on gas-saturated coal made it possible to evaluate the effect of vibration on the coal-methane system in order to determine the optimal frequency at which the maximum methane release is observed, it was evaluated as resonant [2]. It can be assumed that the loss of stability of this system with the transition of methane into free phase is possible in dynamic conditions, when using vibration impact [5].

Technical solutions have been proposed to ensure the formation of cracks and ensure the methane desorption process upon vibration exposure, which allows varying both the vibration frequency within the range from 1 to100 Hz and the parameters of the vibration amplitude within the range from 0.8 to 4.5 mm. The effect of resonance vibration was determined by studying the methane release at various frequencies and amplitudes on samples of coal [2].

Varying the parameters of the amplitude and frequency on the shaking stand, the following problem was being solved: finding the optimal ratio of these parameters to transfer the maximum energy to the sample during vibration exposure in order to obtain the greatest methane release.

3. Results and discussion

Currently used technological solutions for the preliminary degassing of gas-bearing coal seams in preparation for effective excavation do not give the desired result, and in some cases become unacceptable. In this regard, research in the development of new technological solutions to increase the permeability of the seam for the intensification of its methane recovery (especially of low-permeable coal seams), which would not be distinguished by the high cost and complexity of the technological process, are of particular interest.

One of the most promising areas for improving the technology of preparing the coal seam is a complex method using vibration effects at the final stage (after hydro-impact) with the use of seam boreholes from underground openings [6].

The essence of the complex impact method on the coal seam consists in the following: treatment of the seam is carried out in two stages, continuously following each other. At the first stage, a network of large cracks inseam blocks is created (in the process of hydraulic exposure), and at the second stage, a system of additional small cracks is created in the process of vibration by branching out large cracks formed in the seam during the first stage [7].

The used vibration equipment is designed to create pressure waves in the borehole to form acoustic energy. It is similar to seismic waves, which affect for a long time and lead to a change in the state of a gas-saturated coal array. However, such impact can significantly improve gas release from the seam.

The basis for increasing permeability is creation of additional systems of cracks in the coal seam, oriented to the main cracks in coal blocks, obtained in the process of hydraulic exposure, and contributing to the effective drainage of methane to the borehole [6]. The main idea of the experimental technology lies in the vibration effect on the coal blocks of the seam with a vibration frequency coinciding with the resonant one [2]. This creates a network of additional crack systems to improve methane recovery from the coal seam [5].

Over the past decade, significant studies of the effects of acoustic excitation of the medium have been conducted, and this has shown in practice that the energy generated by earthquakes and other mechanical vibrations can have a significant impact on the productive strata. Many mechanical devices have been designed and manufactured to prove the effect of acoustic excitation on mineral deposits in order to stimulate a response. However, these mechanical devices were not capable of producing sufficiently powerful acoustic energy through a borehole directed into a coal array, which is due to the lack of acoustic technology for influencing the seam. This is also due to the fact that there was a shortage of accurate field studies capable of proving the phenomenon established in the laboratory.

Drilling of boreholes is required to accommodate and start operation of the oscillation mechanisms in an array of a coal seam section. This provides the ability to adjust the depth of movement and the distance between the boreholes during the processing of the array. The number of sources of vibration is taken on the basis of technological decisions. Due to the fact that the resonant cyclic frequency of forced oscillations of each structural element depends on its mass, which varies in fractured rock, initially vibration mechanisms are set to oscillation frequencies equal to the calculated resonant frequency of oscillations of blocks in the section to be destroyed. Since the volume of the coal seam being processed, and the natural vibration frequency are related to each other by functional dependence, the frequency of impacts varies according to the variation of the mass of coal in the area.

In order to cover the calculated section of the array of the section to be destroyed by means of vibration in resonance mode, vibration mechanisms are gradually moved in the seam array, choosing the movement rate corresponding to the most intensive gas recovery from the coal array [2].

The advantages of the proposed method of vibration impact onto a coal seam over the analogues are: low energy intensity, efficiency and reliability of technical implementation in mining conditions.

The essence of the proposed method of complex impact lies in the fact that vibration boreholes are drilled from the underground preparatory openings through the rock plug onto the coal seam. The treatment of the seam is done through the cased part of the vibration borehole of estimated length. At the end of the process of additional cracking, there comes a process of gas recovery from the porous-fractured structure of coal. A schematic diagram of the technology is presented in Figure 1.

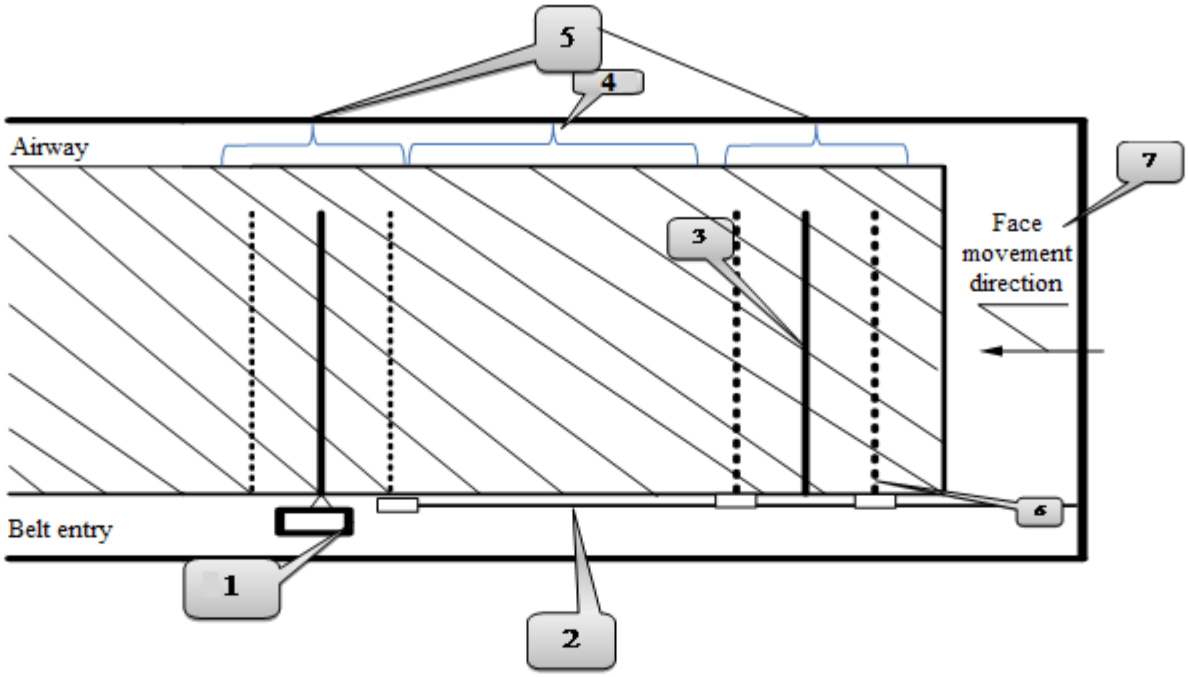

Figure 1. Scheme of vibration impact on coal seam through underground boreholes.
1- oscillator; 2- degassing pipeline from degassing boreholes; 3- vibration boreholes; 4- reference areas (length 300-400 m); 5- coal seam vibration treatment zones; 6- seam degassing boreholes; 7 – mounting chamber 10-20 m longalgorithm.

Vibrational oscillations in the borehole are capable of creating wave pressure in the seam, while developing powerful energy. The impact can be carried out by using multiple cycles, and this in turn leads to an effective vibration impact and transmission of vibrations to the coal array.

Vibrational impact is a source of oscillations capable of creating the necessary acoustic energy through the borehole, which will increase gas recovery from the array, this proposed technology is likely to make more effective impact on the coal array, introducing vibration waves through the borehole into the gas-saturated coal seam, and high energy density leads to the creation of a significant system of cracks and redistribution of stresses in the coal seam.

According to preliminary considerations, the main effect on the extraction of methane in the section under vibration impact should be expected directly from the boreholes through which the vibratory treatment is done, drilled and operating in the vibration zones under conditions of significantly increased fracturing and, consequently, the gas permeability of the coal seam.

The coal seam array is a discrete-block environment. A number of methods are used to quantify the impact of structural weakening of the rock array on its gas recovery. Among them is the mechanical destruction of coal samples with natural weakening or with a system of artificially created surfaces of coal discontinuity in special vibration installations. Field tests are also applied without extracting an array from a coal seam by means of artificial vibration impact with the use of vibration devices onto a section, contoured in an array.

After analyzing the vibration effects in the coal array on the dynamics of fluid injection into a porous gas-saturated coal array, along with degree of saturation of the coal array with liquid, which not only fluctuates in the formed fractures of the seam, but also is subject to an oscillating pressure gradient, was studied [4].

The conducted study showed that the propagation of elastic waves in a porous medium (coal) of the injected fluid showed effects that are important for the treatment of gas-saturated coal seams. Studying the impact frequency, the processing time while converting the energy of liquid oscillations into the energy of cracking, we achieved an increase in the area of seam treatment and determined the dynamic potential of this phenomenon. This provided a more complete degree of processing of the array when exposed through a hydraulic dissection from the surface with an oscillating pressure gradient, which has important practical applications.

This study shows the transition from the scattering mode of action to the elastic mode, in which frequency resonances are established for the response of the gas component to vibration effects [2].

The effects of vibration have also been studied on gas-saturated coal seams, into which fluid was previously injected to create hydroconductive cracks. Studies have been conducted to increase the injectivity of a coal seam (the field of the Komsomolskaya mine of 'Vorkutaugol' OJSC), which is subject to dynamic fluid exposure, under the effect of an oscillatory pressure gradient.

From the data obtained in the conducted research, it is possible to conclude that a change in the injectivity of the seam was established above a certain natural level existing for a fractured porous coal array.

4. Conclusion

The article discusses the laws of deformation and fracture by vibration wave impact under the conditions of heterogeneous stress states of the coal seam before the formation of additional fracture systems in the process of their development.

It is important from a scientific point of view to understand why penetration of acoustic pressure waves in a coal seam leads to an increase in methane recovery.

A vibration method for ensuring structural damage and softening of a coal seam, based on the parameters of frequency and amplitude, predicting the intensity of methane recovery from coal, taking into account the resonant frequencies of a fractured block array, is proposed and justified.

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