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ESTIMATION OF CLAY ROCK BREAKAGE BY A TWO-PHASE WATER JET FLOW

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ABSTRACT

It is considered to be the most effective to use water jetting for placer deposits, composed of clay wall rock. To increase its production, various constructive and technological methods are possible to apply. For the breaking performance increasing, the use of a special device has been proposed, which ensures the ejection of solid abrasive particles into the hydro monitor barrel. The use of this device allows increasing the performance of the hydraulic breaking of the mined rock mass by 4.8-7.4 times. The use of the technology is most effective when applying a mining method with minor or side mine face at an angle of about 35° between the mine face and the jetting axis, but does not exclude the use of other mining methods.

Keywords: deposit, hydraulic monitor, hydraulic breaking, clay body, hard abrasive particles, breaking performance, ejection, jet impact force on the mine face, modeling.

INTRODUCTION

Water jetting is one of the most low-cost technologies for the development of deposits and is considered to be the most effective in placer deposits composed of clay containing wall rocks. However, the efficiency of the waterjet system itself is far from 100%. There are many opportunities to increase the performance of rock breaking waterjet system. Technologically it is possible by using preliminary operations: rock fragmentation by mechanical or drilling and blasting method, water saturation of rocks. But these actions will lead to cost and time supplement of the mine development. Increasing of the breaking performance is also achievable by employing design changes, for example, with the help of dampers of various designs, the use of the most energy-efficient forms of nozzles, optimization and reduction of pressure losses in the waterjet system, mobility of self-propelled jetters during hydroforming [1-5]. It has also been found that the presence of solid particles in the pressure water has a positive effect.

Various types of machinery for waterjet cutting are mentioned here [6-9]. In mining, this principle is proposed to be used in drilling machines, combining mechanical and abrasive effects on the wall rock [10-17]. About the contact of the pressure jet with the rock surface, the studies of V.G. Merzlyakov [10-13] are known, where the pressure jet of very small diameter is used for cutting hard (brittle) rocks. Also, the theory of breaking of various materials by a hydro abrasive jet has been investigated by such scientists as A.G. Evans, K. Faber, I. Finnie, J.J. Griffits, H. Oweinah, M. Hashish, G.L. Sheldon, M. Hessling, and others. There are known studies [20], where a pressure jet of a hydro monitor is used to break rock mass with air being ejected into it. The method efficiency is confirmed experimentally - the increasing of the breaking ability of the hydro monitor jet is 25-30%. The studies of the influence of two-phase flow are shown in [14-19], where, for cutting the rock mass, the authors proposed and tested the ejection of solid abrasive particles into a pressurized water flow, which showed its significant effectiveness.

The above-mentioned methods and studies demonstrate the efficiency of the two-phase flows implementation. However, the scope of the results obtained is limited by using very high heads (pressure from 10-70 to more than 400 MPa), small diameters of nozzles (from 0.6-1.2 to 2-3 mm), small distances to the object being processed (no more than 15-25 mm), a jet directed vertically downwards. The breakage analysis was carried out for brittle rocks, the properties of which differ significantly from the properties of clay rocks. Meanwhile, the greater part of placer deposits is represented by viscous clay rocks, the breaking mechanism of which differs significantly from the breaking mechanism of solid (brittle) rocks. Thus, it is known significant number of research in the field of effective contact of a pressure jet with a wall rock, including the presence of solid abrasive particles in its composition, but studies the results of which are applicable in the conditions of breaking clay body by hydro monitor jets which contain solid abrasive particles have not been found.

The purpose of the research is to determine the performance of water jet breaking by using an abrasive jet which is obtained through the ejection of solid abrasive particles into a hydro monitor jet.

MATERIALS AND METHODS

The experiments were performed at a scale of 1:10 (table 1) using a laboratory bench [21]. To accomplish the task, the system for water jet breaking by two-phase pressure flow has been designed [22] (Figure-1, Figure-2).

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Table-1. Experimental conditions at the laboratory bench.

The diameter of water jet nozzle, mm	**5**
	7
Pressure on the nozzle of the monitor, m	5
Discharge value in the ejector, m	-3,5
The distance to a mine face, m	2,5
Pressure water density, t / m^3	1
Ejector nozzle diameter, mm	2,3
Average size of solid abrasive particles, mm	0,15
	0,20
	0,26
	0,33
	0,41

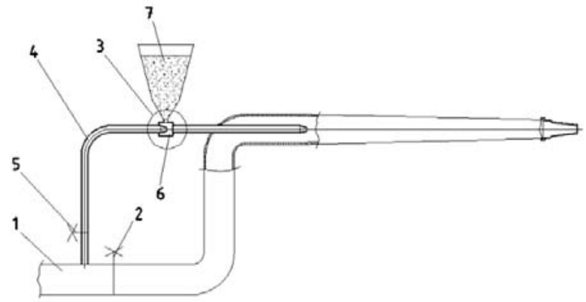

Figure-1. Hydromonitor with ejector:
1 - supply pipe; 2 - the main valve; 3 - ejecting device; 4 - flow passage; 5 - valve; 6 - mixing chamber; 7 - storage of solid abrasive particles

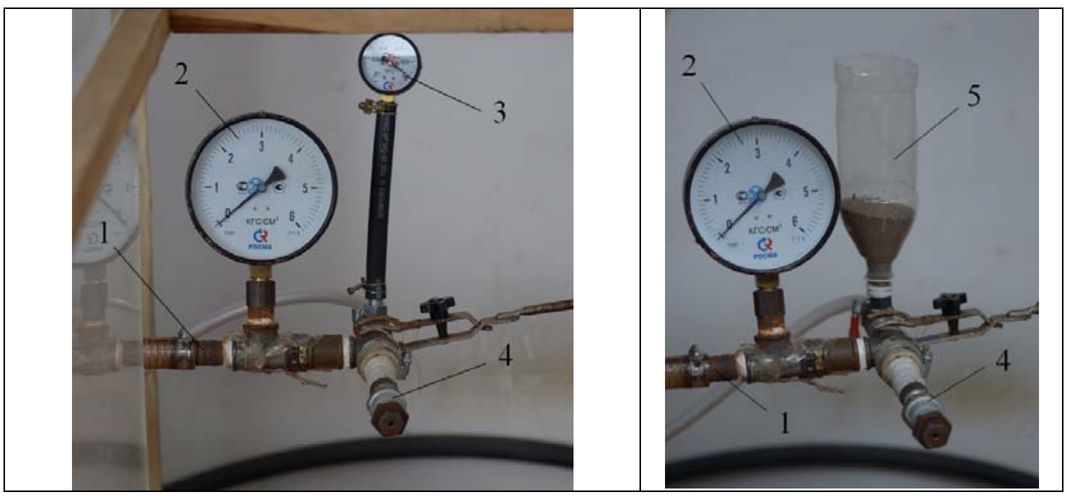

Figure-2. Hydro monitor model with ejector:
1 - supply pipe; 2 - manometer; 3 - vacuum gauge; 4 - a model of a hydro monitor barrel with a nozzle;
5 - storage of solid abrasive particles

The implementation of the process of ejection of solid abrasive particles into the mixing chamber outside the hydro monitor barrel and the supply of the ready-made mixture of water and the particles into the pressure flow hydro monitor barrel helps to stabilize the process of ejection, increase the vacuum in the jet and does not interfere with the control of the jet. The ready-made mixture of the ejected solid abrasive particles with pressure water is fed into the main stream through a tube that enters along the axis of the hydro monitor barrel.

From this perspective the highest efficiency of particle delivery to the main stream is achieved, which is confirmed by the studies conducted for water-jet cutting devices [23]: the closer to the center, the more energy a jet of water transmits to solid abrasive particles, the more efficient it is.

To maintain the experimental integrity, a sample without impurities, consisting only of clay, has been selected. The sample material is the Cambrian lontov clay, the so-called "blue" clay mined in the Leningrad region in the Chkalovsky deposit from a depth of about 80 m. By its physical properties blue clay is characterized as gault clay and, as a result, has a relatively low natural moisture content (about 16%); clay density is 2,25 t/m^3, porosity is about 30%, yield strength under tension is 1,8 MPa, Young's modulus is 4,4 * 10^9 Pa, Poisson's ratio is 0,35, compression strength is 15,38 MPa.

According to their particle size, blue clays are classified as powdered clays. The content of clay fractions varies from 30 to 60%, dust fractions - from 40 to 50% and nothing of sand fractions.

According to its mineral composition, blue clays are polymineral: 18 minerals are found in their composition. The main number of them - light minerals, such as quartz (74%), feldspar, chlorite, glauconite, mica, etc. Pyrite, tourmaline, hornblende and some others are found among the minerals of the heavy fraction of clays. The fine fraction is represented by typical clay minerals (in order of predominance) - hydromica, kaolinite, montmorillonite. Thus, the Cambrian lontov clays can be attributed to the type of montmorillonite-hydromica. It should be noted that such soils are very difficult to erode.

The size of the ejected particles (Table-1) is determined by an effective action and stable outflow of the jet from the ejector and should comply to generally accepted standards - 10-30% of the diameter of the outlet of the mixing chamber of the ejector.

In [24], there are differences in the breakage of brittle and viscous materials by an abrasive jet: for brittle, it is preferable to use spherical (for example, lead shot or glass balls) abrasives, which, shall they split the material at the cut point. With viscous materials, it is advisable to use particles of a pointed shape, which act as a "sharp-cut flat blade". M. Hessling [25], having thoroughly studied the use of various types of abrasives for breaking a large number of materials, concludes that quartz sand is best suited for rock breakage. On this basis, in the work, solid abrasive particles of irregular shape with a density of γ = 1,7 t/m^3 (quartz sand) are used.

The technique of the experiments using a hydro monitor (Figure-1) is as follows: through valve 5 water is supplied to ejector 3. After the flow condition is stabilized, the amount of vacuum is measured (vacuum gauge 3, Figure-2), then the main flow is supplied to the jet monitor using valve 2, the required pressure on the nozzle of the jetting column according to the table. 1, controlling it with a manometer 2 (Figure-2). The vacuum gauge 3 is replaced to the storage of solid abrasive particles 7.

Solid abrasive particles are fed into the ejector through a feed opening with a diameter of 7 mm. A weighed portion of solid abrasive particles (Table-1) is placed in the storage of solid abrasive particles 7 (Figure-1), the time of the sand sample outflow is measured. At the same time over the same period the force of the impact of the jet on the mine face is measured. To determine the amount of rock mass jetted during each experiment, the rock mass sample is weighed, set to the place of mine face, washed out, weighed again, the difference in weight is determined – the quantity of broken rock mass.

RESULTS

According to the results of the experiments, graphs were built (Figure-3), based on which it can be stated that the applying of ejection of solid abrasive particles into a water jet flow can increase the breaking performance from 4,8 to 7,4 times with a head of 50 m and nozzle diameters of 76 and 52 mm, respectively.

At the same time (Figure-4), the impact force on the mine face increases relatively insignificantly (6.8-15.2%).

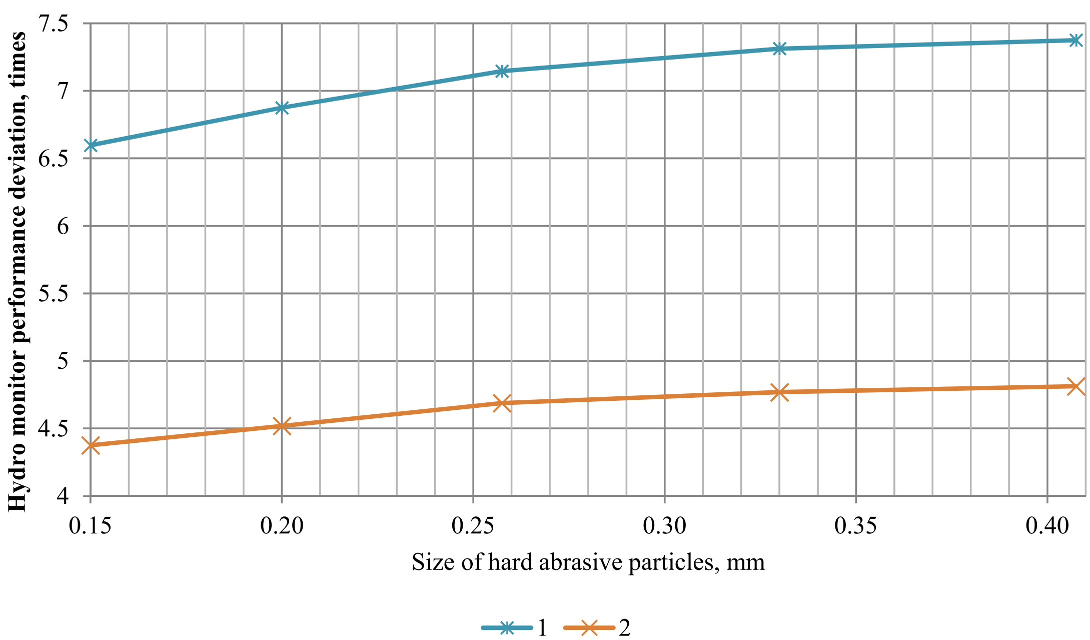

Figure-3. Deviation of the performance of the hydro monitor depending on the size of the ejected solid abrasive particles and the nozzle diameter: 1-52 mm, 2-76 mm.

(The performance of a hydro monitor when using pressure water without adding solid abrasive particles is taken as 100%).

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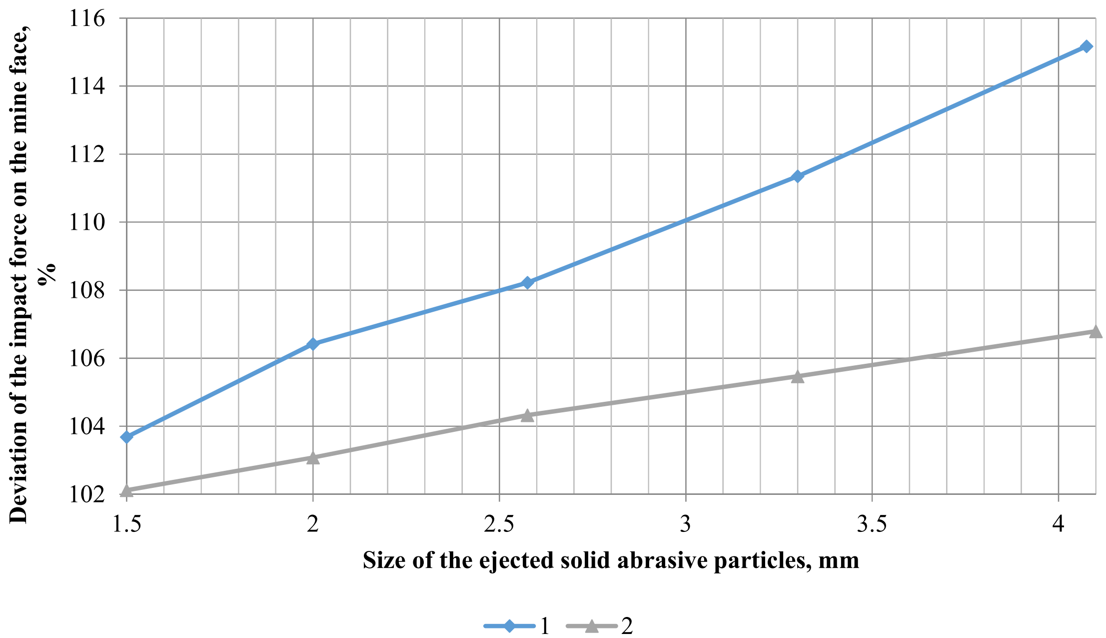

Figure-4. Deviation of the impact force of the hydro monitor jet on the mine face (P, %) depending on the size of the ejected solid abrasive particles and the nozzle diameter: 1-52 mm, 2-76 mm. The performance of a hydro monitor when using pressure water without adding solid abrasive particles is taken as 100%.

Analyzing the obtained results, we can conclude that the abrasive effect of the water jet flow is to a greater extent in the basis for increasing the performance of breaking under the conditions of ejection of solid abrasive particles into the pressure flow in the barrel of the hydro monitor.

The mechanism of this effect can be described as follows: penetrating into a soft clay body, hard abrasive particles damage the hard-to-break solidity of the clay, form the wells and places of concentration of the pressure effect and penetration of the water jet into the solid [1, 26]. The more unconsolidated formation particles in the host rock mass, the higher its erosion.

The considered effect varies significantly depending on the diameter of the hydro monitor nozzle used - with a smaller nozzle, the breaking performance is higher.

This phenomenon is in good agreement with the conclusions of the Bernoulli equation - with the increasing of the nozzle diameter, the water flow rate decreases and, accordingly, the amount of energy that can transfer the flow to solid abrasive particles decreases.

Increasing the size of solid particles, a decrease in the dynamics of the breaking performance is observed. This effect is also noted in the studies of J.J. Griffits [27] and explained by the impossibility for this design of a hydroabrasive tool to accelerate an abrasive particle to the required speed. The same conclusions were made by Faber K., Oweinah H. [28]. In addition, Tikhomirov and Guenko [29] note the need for abrasive concentration in the jet from 10 to 50%.

The use of a water jet flow with ejected solid abrasive particles implies a more intensive destruction of the mountain massif, therefore the greater efficiency of the considered method with small diameters of nozzles confirms the expediency of its use in cutting and destruction of the massif, especially clayed.

For rock breaking, when it is advisable to use nozzles of large diameters, the dismantling of the ejecting device from the hydro monitor (Figure-1) is not required - it is enough to turn over the valve 2.

Also it is obvious from the graphs of Figure-3 that the ejection of solid abrasive particles into the water jet flow provides an increase in breaking performance (at least in 4,4 and 6,6 times depending on the diameter of the jetting nozzle). The effect in breaking performance of increasing the particle size is less pronounced - in 1, 4 and 1, 8 times.

Therefore, in the development of deposits using the described water jet system (Figure-1, Figure-2), compliance with the size of solid abrasive particles fed into the jet of hydro monitor is not required. It is enough not to exceed the maximum particle size, based on the size of the ejecting device and the criteria for its operation, which, according to generally accepted standards, is about 10-30% of the diameter of the outlet of the ejector mixing chamber.

The ejection coefficient, which characterizes the ejector operation and shows the ratio of the mass flow rate of the ejected solid abrasive particles to the mass flow rate of water, is demonstrated in the graph (Figure-5). It is seen that the mass fraction of solid abrasive particles increases versus the mass fraction of water. The intensity of the

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increase is higher for a smaller nozzle diameter. At the same time, the volumetric flow rate of solid abrasive particles with increasing particle size, determined from the ejection coefficient, remains the same. However, the inertia of larger particles is higher and, as it can be seen in the graph (Figure-3), the performance of the hydraulic breaking is increasing.

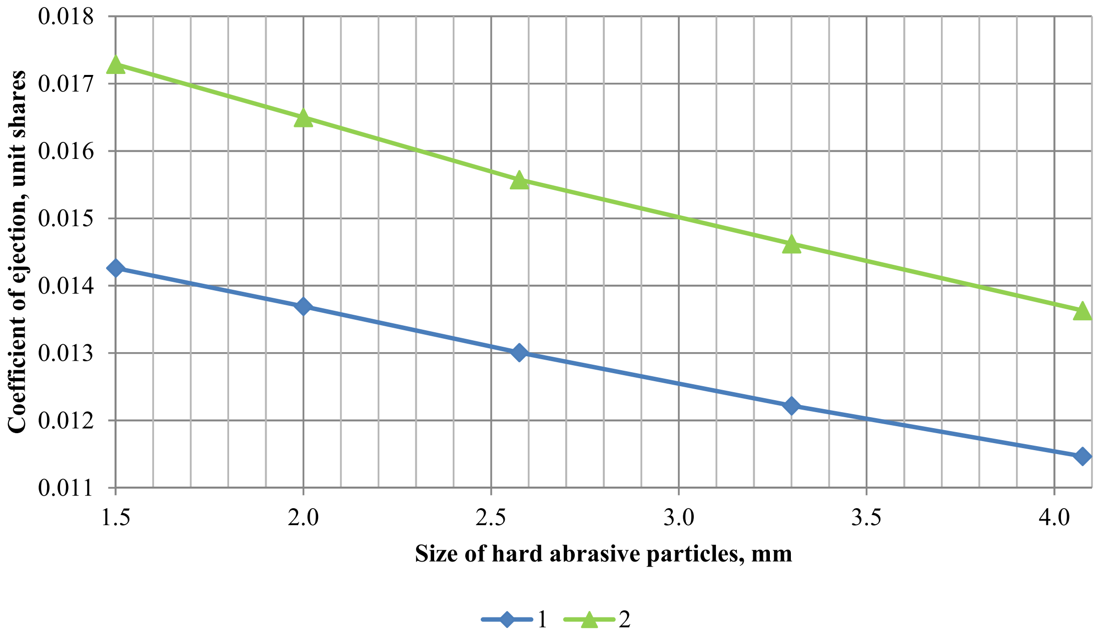

Figure-5. Ejection coefficient values due to the nozzle diameter (1-52 mm, 2-76 mm) and the size of solid abrasive particles.

It is noted [30] that the effective transfer of the amount of movement from the water jet to the abrasive particles is provided with a ratio of the mass flow rates of abrasive particles to water in the range of 0,1-0,3. Under this condition, the design parameters of the device do not affect the performance of the breaking. This parameter is 0,19 [31] and 0,33 [32].

At the same time, it is stated [33] that there is no fixed optimal value, abrasive consumption for cutting any particular material, as it is a function of the carrying capacity of the water jet entering the mixing chamber, and efficiency, with which the energy of water can be transferred to the abrasive. The ejection coefficient is a parameter characterizing each specific tool and an abrasive used [34].

From the graph (Figure-5) it can be seen that the ejection coefficient of the described hydro monitor with the ejecting device is equal to 0,02-0,13, which is quite consistent with the well-known observations made for waterjet cutting.

The authors [28] indicate that when an abrasive jet destroys brittle materials, it is preferable to use the abrasive jets supplied at right angles to the material being processed, and for viscous materials - at a sharp angle: in this case, the action of the abrasive particles is more efficient, they create channels in a destructible material, carrying a part of it out.

In this connection, a series of experiments was carried out to determine the dependence of the performance of the water jet system on the angle between the face and the flow (α). The 5, 15°, 35°, 55°, 75°, 90° angles have been studied. The results are shown in the graphs (Figure-6).

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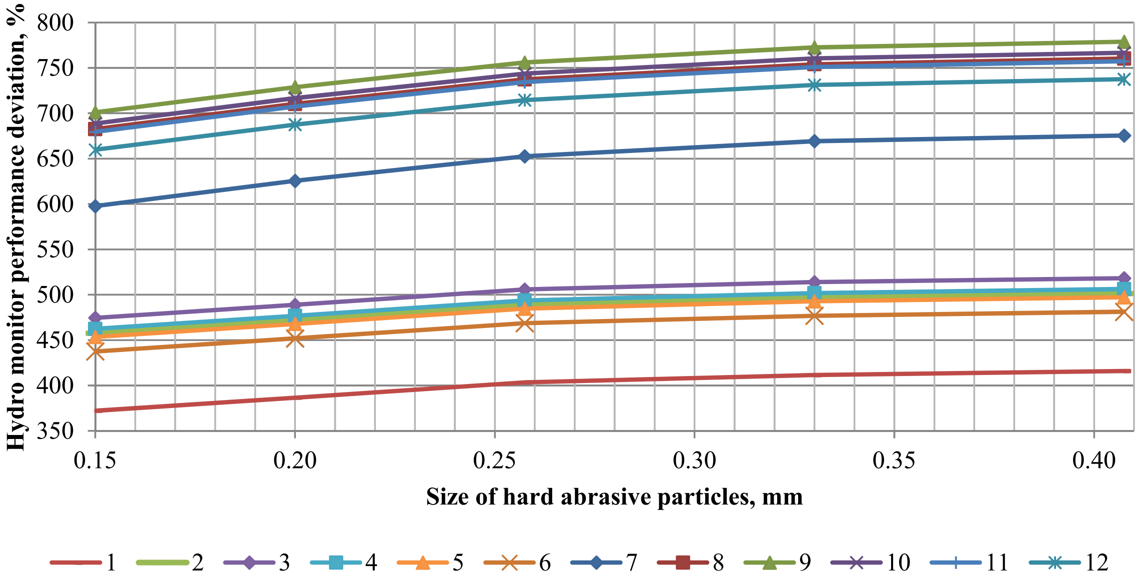

Figure-6. Deviation of the performance of the water jet system depending on the size of the ejected solid abrasive particles (d), the nozzle diameter (d_n) and the angle between the face and the flow: 1-6 – d_n = 52 mm; 7-12 – d_n = 76 mm; 1 and 7- α = 5°; 2 and 8 – α = 15°; 3 and 9 – α = 35°; 4 and 10 – α = 55°; 5 and 11 – α = 75°; 6 and 12 – α = 90°.

The performance of a water jet monitor when using pressure water without solid abrasive particles is taken as 100%.

Based on the results obtained, we can conclude that the maximum breaking performance is achieved when the hydro monitor jet is directed to the face at an angle of 35°. Therefore, for the development of a clay body, it is advisable to use hydro monitor breaking with ejection of solid abrasive particles in case of face and side rock breaking. At the same time, in case of counter headway, the use of an abrasive hydro monitor jet will also bring a significant increase in the breaking capacity.

CONCLUSIONS

The ejection of solid abrasive particles with a hydro monitor jetting of clay alluvial deposits is practicable and effective.

The application of the proposed device [22] (an ejector supply development outwith of the hydro monitor and the delivery of the mixture of water and solid abrasive particles into the center of the pressurized flow in the hydro monitor shaft) allows the most efficient transfer of energy of the water jet to solid abrasive particles, stabilize ejection, prevent additional erosion of the inner walls of the hydro monitor shaft by the solid particles. The device is ergonomic.

Ejection of solid abrasive particles into pressurized water by means of the described device allows to wash out the soils, which are considered to be flow-resistant, with less than 2 times pressurized water flow than recommended by the conventional technology, which, in turn, leads to a reduction in the consumption of pressurized water and electricity, the area of the ponds of the circulating water supply, and, as a consequence, an increase in ecological breaking.

The increase in the performance of the hydraulic breaking of the rock mass due to ejection of solid abrasive particles into the pressurized water flow is possible in 4.8-7.4 times. The increase of the impact force of the hydro monitor jet on the mine face - 6.8-15.2 %. The size of the ejected particles is not important for the performance of the hydraulic breaking (the difference is 1.4-1.8 times).

This condition makes the proposed technique technologically advanced: in a mining enterprise, there is no need to classify solid abrasive particles by size (it is enough to comply with the particle size that meets generally accepted standards: about 10-30 % of the diameter of the nozzle of the ejector mixing chamber), which, among other things, reduces the labor and the time, and, as a result, the cost of the technological scheme with the use of ejection of solid abrasive particles.

The consumption of solid abrasive particles with increasing their size decreases by 19.6-21.14 %. The size and number of ejected particles is limited by the ejecting efficiency of the device. In this case, the optimal operating parameters depend on the design parameters of the device used and the properties of solid abrasive particles.

The use of the technology is most effective when using a water jetting system with side mine face at an angle of about 35° between the face and the jetting axis, but does not exclude the use of other jetting systems.

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