CURRENT STATE AND DEVELOPMENT TRENDS
IN THE THEORY OF HYDRAULIC COAL EXCAVATION

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Water pressures of up to 10-12 MPa have been used in hydraulic mines for over 15 years. It had been predicted that the transition to such pressures would produce a drastic (two- or threefold) increase of output in hydraulic coal excavation. The introduction of hydraulic giants with higher airflow rates in recent years pursued the same goal. In reality, however, the efficacy of hydraulic excavation was much lower than what had been expected based on theoretical calculations and scientific predictions. The output that was expected to be proportional to the airflow increased hardly by one-third instead of the expected doubling. The energy-intensiveness of the process, however, did double. Currently, the power fed to one hydraulic giant is 750 kW, which is 7-8 times the power of a modern coal excavation machine. The problem of wear-resistance of nozzles has become acute and has not been solved in a satisfactory manner as yet.

Hopes for improving the hydraulic excavation performance are now pinned on raising the presence up to 16 MPa. Without going into all the aspects of this complex engineering problem, we would like to note that this pressure involves using a much higher energy level, which could only be justified by an appropriate (unrealistic) increase of the hydraulic excavation rate.

An analysis of studies in hydraulic excavation over the past 20 years offers an insight into the principal causes of this situation. The scientific theory of hydraulic destruction of coal and the principles for calculation of coal excavation by hydraulic giants based on that theory failed to reflect the real process of jet impact against the coal mass, and the criteria used in calculations were, in principle, incapable of yielding a correct estimate of the effects [1, 2, 7]. Efforts to improve the efficiency of hydraulic mining are being made in the dark, with no clear understanding of the interaction of the hydraulic jet and the face or the conditions of face destruction. This calls for reevaluating the principles and theories applied to calculations of hydraulic mining parameters.

The efficacy of hydraulic mining of coal, as suggested by experience and numerous studies, is affected by factors of quite diverse nature. In addition to the strength characteristics, represented in mining by the generalized criteria of Protodyakonov's Hardness Scale, there is the fissure density, the nonuniformity of seam structure, and the presence of interlayers with various properties. Factors such as the shape and size of the face, the distance from the hose nozzle to the face, the rock pressure, the water pressure, the speed of the jet, and its angle of attack at the face surface are also important.

Without discussing the specific contributions of all of these factors, we may note that some (such as fissure density) may sometimes, according to [2], be more important than strength characteristics, so that the efficacy of hydraulic breakage of a harder coal (after Protodyakonov) will be higher than that of a less harder variety if the former contains a large number of cracks.

The diversity of factors influencing the efficacy of hydraulic mining makes one doubt the possibility of success in the search for a common generalized criterion that could be used to evaluate the hydraulic mining efficacy for various conditions. The analysis of the theoretical aspects of hydraulic mining of coal thus has proved to be incomparably more complex than was believed before.

Modern methods of calculations of the parameters of hydraulic mining are based on criteria such as conditional ultimate strength and specific water absorptance of the seam. For fitting calculation methods to actual data, coefficients are introduced, which represent the specifics of hydraulic mining in particular conditions.

More than three decades ago, in the early days of industrial use of hydraulic mining, the effective water pressure recommended was 50f (where f is the hardness coefficient), or, in practical terms, 0.01 instant.
coal resistance to uniaxial pressure. This recommendation was based on an oversimplified notion of the interaction between the water jet and the coal mass, which assumed the jet pressure at the face to be double the pressure at the hose nozzle. The stress characterizing the strength at uniaxial pressure was assumed to be sufficient for breaking coal.

Experience with hydraulic mining on hard uncracked coal proved this recommendation wrong, and later (in 1962) it was replaced with the recommended effective pressure of $100f [3]$. 

It should be stressed that realizing that the above recommendation was not valid either was no easy task. Under certain conditions, hydraulic breaking of coal was quite effective thanks to such factors as cracks in the seam, dynamic pattern of stress application, rock pressure, etc. These factors created an illusion that the assumptions were correct. One can recall the experiments by Sukharevsky (4) and the first successful industrial uses of hydraulic breakage at pressures of just 3.5−4 MPa.

At present, however, the concepts of the mechanism of destruction of coal by a water jet, the principles of calculation, and the criteria of extreme states of coal have to be revised entirely.

We will review the method for calculating the hydraulic mining parameters that are currently in force [1]. It recommends setting the working pressure in the range

$$2P_K < P < 4P_K, \quad (1)$$

where $P_K$ is the critical pressure at which, by definition, the jet begins to intrude into the coal seam. The value of $P_K$ is defined as

$$P_K = 3R_y, \quad (2)$$

where $R_y$ is the criterion of coal strength to hydraulic destruction, the so-called conditional ultimate strength of coal. It is evaluated as

$$R_y = \sqrt{\frac{R_c R_p}{3}}, \quad (3)$$

where $R_c$ and $R_p$ are uniaxial compressive and tensile ultimate strengths of coal, respectively.

The method allows defining the critical pressure in terms of hardness, $f$; the following empirical relationship linking $R_y$ with $f$ is given:

$$f = 0.06 R_y. \quad (4)$$

In addition to (4), an improved expression is offered:

$$R_y = 2.275f - 0.636. \quad (5)$$

These relations are recommended for use at $5 \leq R_y \leq 50 \text{ kg/cm}^2$. The following conditions for coal testing are recommended: compression testing by static-load breaking of cubic specimens with an edge of 50 mm, cut by a circular abrasive tool without cooling liquid; distension testing by breaking the specimen along the normal to the bedding using cylindrical rollers 7 mm in diameter. The hardness coefficient is measured on a hardness-measuring instrument POK [11].

Note that this method of evaluating the mechanical characteristics of coal does not in any way take into account the specifics of hydraulic destruction.

It can readily be determined from (4) that $R_y = 16.6f$; hence, the critical pressure by (2) will be

$$P_K = 3R_y = 3 \cdot 16.6f = 49.999f \approx 50f.$$

The same result is obtained with (3), assuming that $R_p$ on average for coal is $8.333\%$ of $R_c$:

$$R_y = \sqrt{\frac{11.5f - 0.633 \cdot 100}{4}} = 16.6f.$$

The critical pressure computed by using the improved expression (5) yields for hardness coefficients 0.8, 1.0, and 1.2 the values 35.52, 49.17, and 62.82 kg/cm$^2$, respectively, i.e., practically the same 50f.

An analysis of this method indicates that basically apart from increasing the recommended pressure it contains nothing new compared with the earlier recommendations. As before, the specifics of hydraulic destruction are not considered. The main destructibility criterion, the so-called conditional ultimate strength, in fact contains a substantive error. Taking the product of ultimate tensile and compressive strengths masks the