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EXPERIMENTAL RESEARCH AND FEASIBILITY STUDY FOR THE USE OF GD-300 HYDROMONITORS IN KUZBASS MINES

The paper presents the experimental results for the new GD-300 hydromonitor used to determine the analytical dependence between the generalized hydromonitor resistance factor and nozzle diameters, and the algorithm for determining hydromonitor nozzle diameters subject to the operating conditions at the pump station. New hydromonitors improve hydraulic mining performance and efficiency.

Keywords: Kuzbass mines, hydraulic mining, hydromonitor testing.

INTRODUCTION

According to analysis, the amount of overburden rocks mined by hydraulic methods (hydraulic mining) in Kuzbass coal quarries has decreased in recent years [6, 7, 8]. One of the main reasons for this appears to be the fact that rocks become more complex for hydraulic mining equipment and require high-pressure water jets to break them [9]. New field blocks to be commissioned in Kuzbass in the coming years, including Sartakinsky-2 Block, are overlaid by thick Quaternary deposits, which makes it difficult to remove them using heavy-duty excavation equipment. Therefore, hydraulic mining technology needs to be developed further. Local experience shows that in such cases hydraulic mining offers substantial economic benefits [10–15].

The analysis [8] shows that GMD-250M hydromonitors with 100 and 110 mm nozzles are the most common type currently used in Kuzbass mines. These hydromonitors are able to supply up to 2,000 m^3 of water per hour for rock excavation. However, one such hydromonitor cannot cope with the regular seasonal scope of overburden removal operations. This is why two or more hydromonitors operating in parallel or several separate hydromonitor pump units are used for rock excavation. This results in an increased number of operating personnel and, therefore, impacts on the cost of mining operations.

Tests

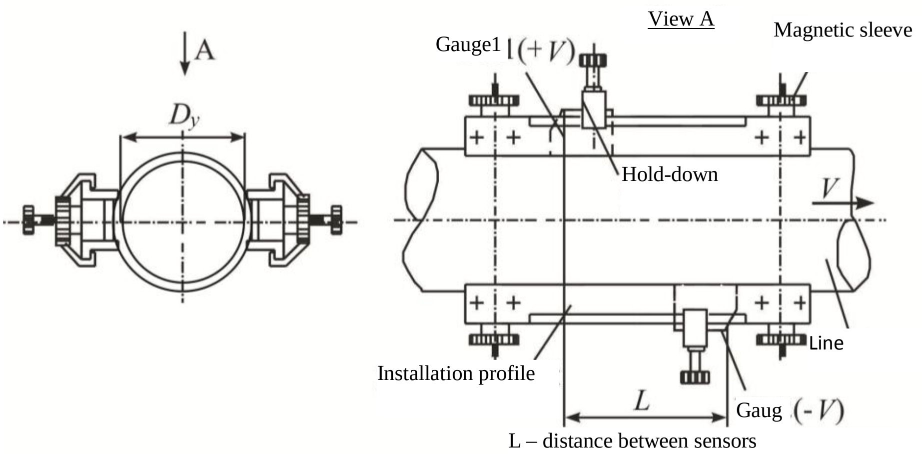
Coal Company Kuzbassrazrezugol OJSC ordered the development and manufacture of GD-300 hydromonitors (Zavod Gidromash OJSC, Novokuznetsk) and T-521 hydromonitors (Yurginsky mashzavod LLC, Yurga). Test programs were developed and test procedures approved by the Federal Environmental, Industrial and Nuclear Supervision Service (Rostechnadzor) for two GD-300 hydromonitors on site at Kedrovsky mine (Fig. 1). At the same time, the T-521 hydromonitor was tested in Taldinsky mine.

Fig. 1. GD-300 hydromonitor made by Zavod Gidromash OJSC at Kedrovsky mine.

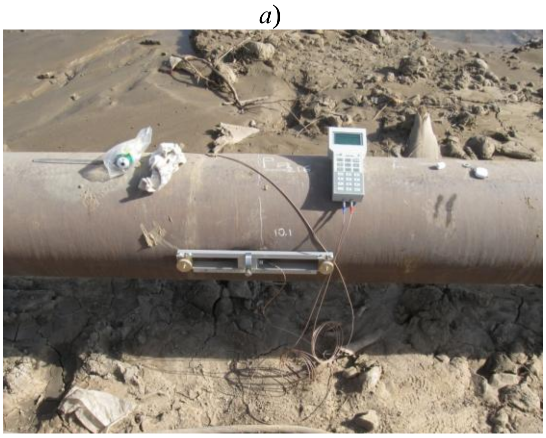
In both models, flow channel areas and nozzle diameters are larger than in the GMD-250M. These models use 125 ... 175 mm nozzles to deliver a flow rate up to 5,000 m^3/h depending on the head, i.e. more than double the flow rate of GMD-250M hydromonitors. The test results provide compelling evidence that these hydromonitors are much more efficient for rock mining than GMD-250M hydromonitors, which leads to substantial improvements in the technical and economic performance of hydromonitor dredging equipment. Since the hydromonitor meets all regulatory requirements, Rostechnadzor authorized its application for open-pit mining.

To demonstrate that these hydromonitors may be used to enhance the efficiency of overburden removal operations using hydraulic mining methods, various studies have been conducted to identify hydromonitor performance characteristics that allow for the optimization of hydromonitor dredging design parameters to reduce overburden removal costs.

The main hydromonitor operation parameters are known to be inlet head (or head upstream of hydromonitor nozzle) and flow rate, which determine the performance conditions for the hydromonitor and are interdependent. When the head at the hydromonitor inlet changes, the flow rate also changes. Each hydromonitor can have an infinite number of performance conditions depending on the head at its inlet. A combination of all possible hydromonitor performance conditions, i.e. numerical values of hydromonitor heads and flow rates in a specific operating environment (with a certain pump station which creates water head at hydromonitor inlet), shows a specific or actual performance of this particular hydromonitor. It should also be borne in mind that there is an optimum head for each nozzle at which the specific flow rate is minimal.



a)



b)

Fig. 2. Installation diagram for the primary instrument, *a*,
and the general view of the flow meter installed on the inlet line, *b*.

The ultimate goal of design calculations for hydromonitor pump units is to identify the actual performance of pumps and hydromonitors. To do so, a head-capacity curve should be available for the hydromonitor in addition to head-capacity curves for pumps and pipelines; the curve is a square parabola that passes through the origin of coordinates [1] and is described by the following dependence

$$H_{hm} = R_{hm} Q^2, \qquad (1)$$

where H_{hm} is the total specific energy consumption for water movement in a hydromonitor, which is called its resistance, m; R_{hm} is the generalized hydromonitor resistance factor, s^2/m^5; Q is the flow rate through a hydromonitor, m^3/s.

The experimental research into head-capacity curves of a hydromonitor on site in Kedrovsky Coal Mine, branch of Coal Company Kuzbassrazrezugol OJSC, provided numerical values of generalized resistance factors for GD-300 hydromonitors for different nozzle diameters. Nozzles 118, 125, 140 and 160 mm in diameter were tested. In this case, the generalized resistance factors R_{hm} were 518, 399, 276.5 and 168.5, respectively. Fig. 2 shows the installation diagram for the primary instrument, *a*, and the general view of the flow meter installed on the inlet line, *b*.

The generalized resistance factor R_{hm} describes hydromonitor resistance H_{hm}, m, which is the total specific energy consumption by water moving in hydromonitor channels and is equal to total head losses in the hydromonitor h_{hm}, m, head losses in the nozzle h_n, m, and dynamic head H_d, m, at nozzle outlet, i.e.

$$H_{hm} = h_{hm} + h_n + H_d. \qquad (2)$$

Again,

$$h_{hm} = k_h Q^2; \qquad (3)$$

$$h_{ps} = \xi_{ps}\left(\frac{V_{ps}^2}{2g}\right); \qquad (4)$$

$$H_d = \left(\frac{V_{ps}^2}{2g}\right), \qquad (5)$$

where k_h is the head loss coefficient for the hydromonitor; Q is the flow rate through the hydromonitor, m^3/s; ξ_{ps} is the hydraulic resistance coefficient for the nozzle; V_{ps} is the nozzle jet velocity, m/s.

With regard to (3), (4) and (5), dependence (2) changes to

$$H_{hm} = k_h Q^2 + \frac{\left(\xi_{ps}+1\right)V_{ps}^2}{2g}.$$

Let us express V_{ps} in equation (6) in terms of flow rate Q, m^3/s, and nozzle diameter d_{ps}, m,

$$V_{ps} = \frac{4Q}{\pi d_{ps}^2}. \qquad (7)$$

Taking into account (7), we get

$$H_{hm} = \left(k_h + \frac{0,0827\left(\xi_{ps}+1\right)}{d_{ps}^4}\right)Q^2.$$

So, according to dependence (1)

$$R_{hm} = k_h + \frac{0,0827\left(\xi_{ps}+1\right)}{d_{ps}^4}.$$

Taking into account the fact that head losses in the hydromonitor described by coefficient k_h are negligible compared to dynamic water head at nozzle outlet, dependence (9) may be reduced to

$$R_{hm} = k \cdot d_{ps}^{-4}, \qquad (10)$$

where k is the empirical coefficient.

By processing the experimental data, we found the analytical dependence between the generalized resistance factor for GD-300 hydromonitor and the nozzle diameters [2] (Fig. 3) and the numerical value of the empirical coefficient *k*, which is equal to 0.10, i.e.

$$R_{hm} = 0.10 d_{ps}^{-4}. \qquad (11)$$

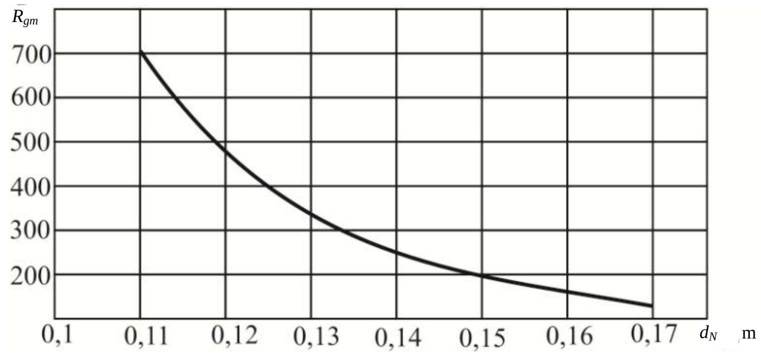


Fig. 3. The analytical dependence between changes in the generalized resistance factor for GD-300 hydromonitor and the nozzle diameters.

The relative error for calculations based on the semi-empirical dependence is 3.82%; the root-mean-square deviation is 10.31%, and the coefficient of variation is only 3.0%, which is quite fair for this type of calculation [3].

After the nozzles are selected, actual performance of the hydromonitor pump equipment is determined and analyzed [4]. If such performance fails to meet certain requirements, the selection should be adjusted by using bigger or smaller nozzle diameters.

If it is impossible to achieve the desired hydromonitor performance by adjusting nozzle diameters, the structure of pump stations should be changed, i.e. other types of pumps should be used, or the number of pumps connected in series or in parallel should be changed [5].

Fig. 4 shows the block flow diagram for selecting hydromonitor nozzle diameters subject to operating conditions at a pump station.

Assessment of Feasibility of New Hydromonitors

Hydraulic mining methods are used for overburden removal in Krasnobrodsky mine in Novosergeyevskoye Field (Razgen Block) located in the northwestern part of the Prokopyevsk-Kiselevsk geological and economic area in Kuzbass. The Krasnobrodskaya formation consists of mild clays and gray sand loams with greenish, bluish, and brownish shades; these are plastic and sometimes oversanded, with ocher-colored spots of ferrum oxides, both horizontally and cross-laminated. The rocks in the formation, especially at the bottom, have a lot of sand and gravel. The total volume of loose deposits within the hydraulic mining block is 78 million m^3. Taking into account the underbreak and the existing piles, the total volume of loose deposits to be removed by hydraulic mining methods is 68 million m^3 (87 %). In terms of development complexity, loose Quaternary deposits are classified as Group V. The overburden thickness in the hydraulic mining block varies from 5 to 25 m. The annual thickness of the hydraulic mining block is 2,000 thousand m^3 of overburden.

The calculations showed that two GMD-250M hydromonitors with 110 mm nozzles should be replaced with one GD-300 hydromonitor with a 160 mm nozzle, taking into account the operating conditions for hydromonitor dredging equipment in Krasnobrodsky mine.

To determine costs benefits, water supply costs were calculated for one hydraulic transport system. For Krasnobrodsky mine, these cost benefits are doubled because the project provides for the operation of two hydraulic transport systems. Based on the above calculations, costs were compared for two options: the operation of two GMD-250M hydromonitors (in service) with 110 mm nozzles, and the operation of one GD-300 hydromonitor (in service) with a 160 mm nozzle. The calculation results are given in Table 1.

After hydromonitor nozzle diameters were selected subject to pump station performance, the value of the actual water head upstream of the

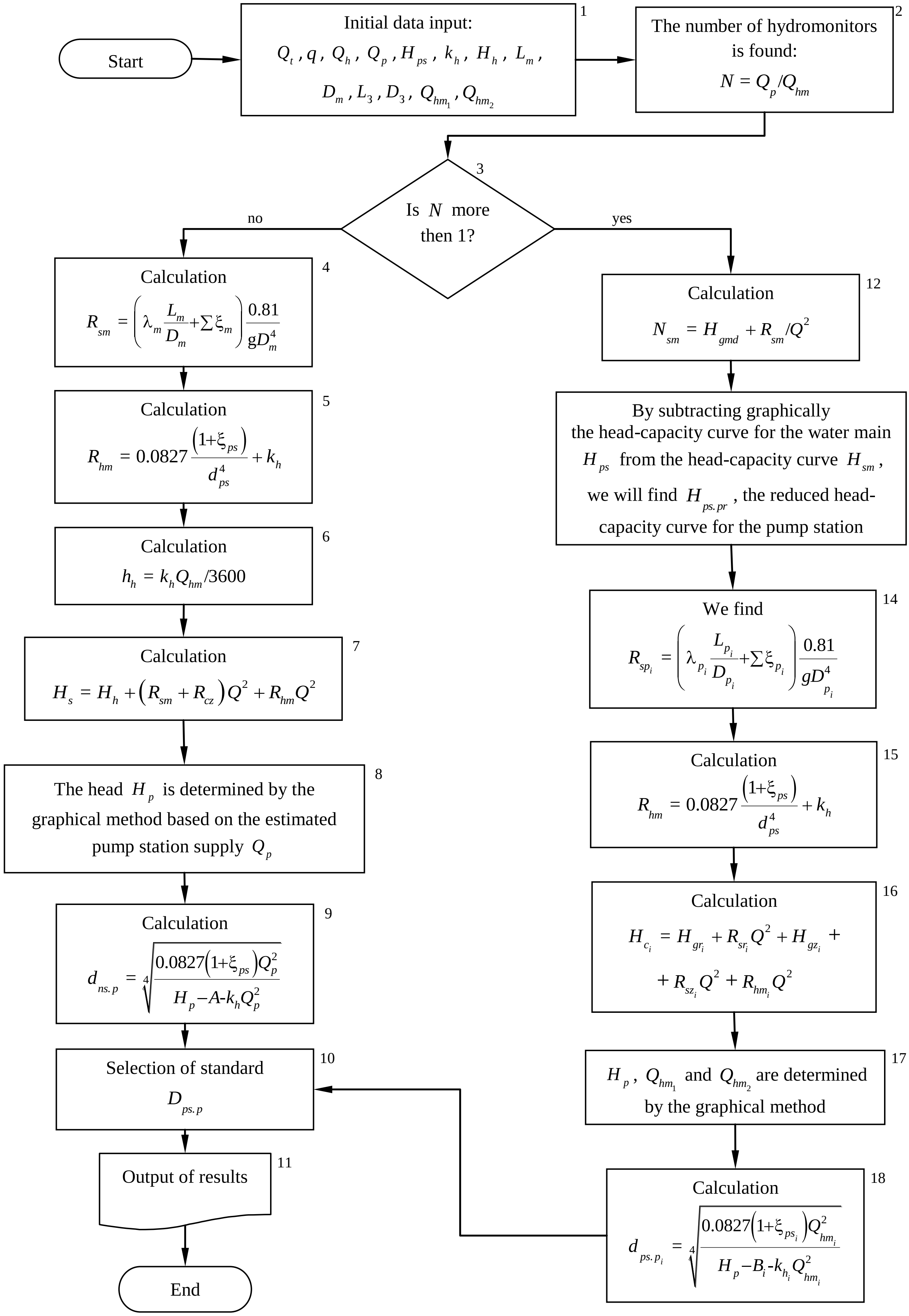


Fig. 4. Block flow diagram for selecting hydromonitor nozzle diameters subject to operating conditions at a pump station

Table 1

Calculation of Cost Benefits

Hydromonitor dredging equipment costs	Current option with two GMD-250M		Proposed option with one GD-300	
	Investments, thousand RUB	Annual operating expenses, thousand RUB	Investments, thousand RUB	Annual operating expenses, thousand RUB
For one GR-4000/71 hydraulic transport system	5,695.23	2,085.855	3,944.14	1,040.81
For Krasnobrodsky mine with two hydraulic transport systems	11,390.46	4,171.71	7,888.28	2,081.62
Cost benefits for Krasnobrodsky mine	–	–	3,502.18	2,090.09

hydromonitor was found: $H_{gmd} = 191.7$ m. Taking into account the head loss coefficient for the hydromonitor ($k_h = 26.6$ for GD-300 hydromonitor), the actual flow rate through the hydromonitor $Q_{gmd} = 3.780$ m^3/h, and the head upstream of each hydromonitor $H_{gmd} = 191.7$ m, we can now find the actual head losses in the hydromonitor $H_h = k_h \left(Q_{gmd}/3600\right)^2 = 2.6 \times \times \left(3780/3600\right)^2 = 29.33$ m and the head for breaking $H_h = H_{gmd} - h_h = 191.7 - 29.33 \approx 162$ m.

The research results allow us to validate key mining design parameters when GD-300 hydromonitor is used, as well as block parameters, their number, and the front advance rate of mining operations per season, taking into account the seasonal capacity of 2,070 thousand m^3/year.

Design parameters for hydromonitor dredging equipment with a GD-300 hydromonitor recommended for Krasnobrodsky mine are given in Table 2.

CONCLUSIONS

The research results show that head-capacity curves found by experiment for GD-300 hydromonitors and the known pattern of changes in key parameters of hydromonitor pump units allow for the optimization of hydromonitor dredging designs, which substantially reduces hydraulic stripping costs and improves coal mining economics.

Table 2

Design parameters for hydromonitor dredging equipment with a GD-300 hydromonitor for Krasnobrodsky mine

Design parameter	Symbol and value
Actual head provided by the hydromonitor, mm w.g.	H_d = 159.7
Hourly capacity of the hydraulic transport system for hydraulic fluid by solids, m^3/h	Q_p = 540
Seasonal capacity of a hydraulic system (block), thousand m^3/year	2,070
Open pit bench height, m	h = 20
Hydromonitor/face approach coefficient	ε = 0.4
Safe distance from hydromonitor to face, m	l_{min} = 8
Hydromonitor advance increment, m	S = 21
Length of the working section of a hydromonitor jet, m	L_p = 37
Hydromonitor pull width, m	A = 46
Block width, m	l = 230
Length of a block covered by one sump position, m	L = 460
Sump depth, m	$h_з$ = 6
Sump width and length (min), m	$\alpha \approx$ b = 5
Total front length covered by one hydraulic transport system per season, m	L_f = 900
Front advance rate in the hydraulic block, m per season	v_f = 230

Recommendations for operating equipment provided by the authors ensure a match between the water supply and hydraulic transport system parameters for hydromonitor dredging equipment in Krasnobrodsky mine. The calculation of cost benefits demonstrated that the replacement of GMD-250M hydromonitors by a GD-300 hydromonitor to ensure operation of the hydraulic transport system in Krasnobrodsky mine reduces investments by RUB 3,502.18 thousand and annual operating expenses by RUB 2,090.09 thousand.

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Abstract:	The results of experimental studies of the new jetting DG-300, on the basis of which set of generalized analytical dependency jetting resistance ratio of the diameter of nozzles used and developed an algorithm for determining the diameter of the jetting nozzles, taking into account the mode of operation of the pumping station. Application of new jetting improves performance and efficiency jetting.
Keywords:	cuts of Kuzbass, hydromechanization, jetting test
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