Selection of technological parameters in borehole mining production by technical deep drilling and hydroexploitation

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Abstract

This paper shows the estimate technological parameters for borehole hydro-production of sand by technical deep drilling slim well differently diameters, where are determinate calculation of radius of jet for selects hydro-monitor, the effect of hydro-caving, caving capacity, hydro-transport of pulp and drawings of the most important parts of necessary equipment for exploitation at the mining field exemplified by experimental borerhole hydro-mining of underlying quartz sand at surface open pit mine of coal named the Polje-D in Kolubara.

***Key words**: borehole exploitation, deep drilling, slim well, quartz sand, hydro-monitor, hydro caving, hydraulic transport.*

Summary

With organizing the excavation technology of loose raw materials through the boreholes, considering the complexity of technological operation, the most important thing is to calculate technical-technological parameters of exploitation and to make an optimal selection of pump aggregate, pipe line and pulp line, and also to project and construct the equipment for drilling and obtaining of concrete deposit conditions since there is no serial production. Hydro monitor presents its most important part that forms and directs the strength of water stream through the jets to break the quartz sand near the borehole, while the hydraulic elevator under the pressure lifts the pulp to the surface of the ground. The boreholes technology uses the strength of water stream to excavate and to lift excavated materials through the boreholes. The essentional engine for the exploitation is hydro monitor there the water pass through the jet and leaves it with great velocity and so disintegration of binded sediment the quartzes sand. The mixture of water and sand (hydro mixture) are transport by the gravitation along the bottom of chamber until the opening on the casing tube in the suction zone, there the mixture by the under pressure are lift and transport through the interior pipe to the surface of the ground. By the system of horizontal hydraulic transport hydro-mixture are transporting until the settling reservoir. Sand is deposit and water by the system of over flowing comes into the sump, and thence the water is, by pump, back into the system. Excavation of solid mineral row materials through the boreholes started in "Kolubara", their experts with that technology experimentally excavated floor sands on the open pit of coal in "Field-D.

Introduction

The 20-th Century saw the modern mining industry enriched by one outstanding method of extracting of mineral resources called Borehole Mining (BHM). Mean while, despite its successful track record in wide ranging locales, few specialists are yet aware of this technology. The intent of this article is to introduce borehole mining to a wider spectrum of drilling and mining professionals. The BHM method is based on in-situ water jet cutting of rock mass. On Fig. 1 the schematic of the method is presented. The borehole-mining tool 1 is lowered into the borehole 2 and high-pressure water 3 is pumped down. At the bottom part of the tool, one portion of that water comes out through the hydro monitor nozzle 4 in a shape of water jet 5 and cuts the material 6 creating slurry 7. The other portion of high-pressure water then comes to the hydro elevator 8 (jet pump, eductor), which produces a vacuum. When the slurry reaches this vacuum zone, the eductor sucks the slurry and pumps it up to the surface, where rock parts are separated from water in a tank 9 or a pond and clarified water is pumped down again closing the re-circulating BHM water supply system. The borehole-mining tool is suspended on a drill rig tower 10, which allows the tool to rotate and move vertically along the borehole axis. While extracting rock mass, underground caverns (stops) 11 are created. If necessary, compressed air 12 can be injected to the raising slurry flow to create an airlift effect. Also, a secondary agent 13 (such as oil, foam, etc.) can be added to the stop

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through the gap between the tool and the casing. As seen from the illustration, BHM is the remote mining method of extracting of mineral resources through boreholes by high-pressure water jets.

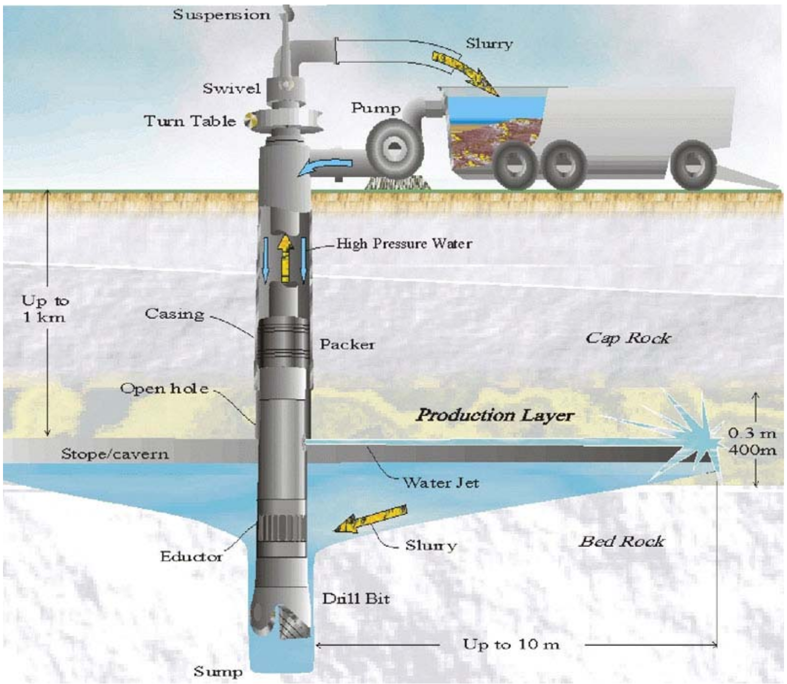

Fig. 1 Schematic of the method Borehole Mining (BHM)

Since BHM takes place below the land surface, this method belongs to the underground mining category. At the same time, working personnel - miners - never go underground, but operate it from the surface, so the method is remotely operated. This equates to significant advantages in terms of a high level of safety and automatization, and the ability to work in a collapsing environment. Following, are the main borehole mining technical characteristics: Depth of mining: 15 m–1 km OD diameter of the tool: 89-305 mm, working water pressure: 7-20 MPa, flow rate: 150-300 $m^3 \cdot h^{-1}$, tool capacity: 30-90 $m^3 \cdot h^{-1}$, slurry consistence (rock/water): 1/6-1/1, cutting reach radius - up to 10 m, thickness of developing interval 0.3-400 m. *All data given based on previous borehole mining

Table 1. Milestone Borehole Mining Projects

Years	Project	Location	Depth	Type of Ore
2003	CBM stimulation	West Arkansas	250 m	
2003	CBM stimulation	Powder River, wy USA	300 m	
2000	CBM stimulation	Zimbabwe, Africa	600-800m	Shale
1996-Present	Water stimulation	Columbia, So. America	100-150 m	Sandstone
1989-Present	Russian Diamonds	Archangels, Russia	80-800 m	Kimberlitic
1992-1994	CBM stimulation	New Mexico, USA	1km	Shale
1988-Present	Iron Ore	Kursk, Russia	400-800 m	Oxide Ores
1974-Present	Baltic Amber	Russian West	15-30 m	Quantz Sand
1987-1991	Kolubara	Yugoslavia (Serbia)	20-40 m	Quartz Sand
1970-1990	Kazakh. Uranium	West Kazakhstan	100 m	Clay stone
1976-Present	Titanium/zirkonium	Ukraine	40-100 m	Quartz Sand
1978-1982	Siberian Gold	Bajkal Lake Region	60-80 m	Gravel

The chief technical advantage of BHM is direct access to the production interval (ore body) where actual borehole mining takes a place. In compare to conventional mining, it allows eliminate several laborious, dangerous and expensive stages of mining process, such as overburden, shaft building, ventilation, de-watering, underground personnel transportation, life support and several more. It also minimizes safety, liquidation and re-cultivation expenses. This, in turn, decreases the overall cost of the final product dramatically: from 15% to 75%. For mining of most of natural resources and industrial minerals, it finally lowers economical break-even point far beyond the generally adopted levels allowing the development of not only small, poor, remote and difficult to access deposits, but increasing working mines reserves, as well. It also delivers an access to deposits located bellow the ocean floor. Thus, billions tons of mineral resources previously deemed "non-economical" (or even confineable) become "World's New Reserves" globally changing the face and strategy of mining industry.

Calculation of radius of jet for select hydromonitor

Process of sand hydro-production on the open pit mine of coal named the "Polje-D ("Field-D") in Kolubara (Serbia), characterize the following basic parameters over which the select of hydro monitor is make:

Interior radius of pulp line $d_2 = 108$ mm
Starting pressure of water $P_0 = 6$ MPa
Depth of exploitation $H_2 = 36,4$ m

Water consumption $Q_{uk} = 150\ m^3 \cdot h^{-1}$

The greatest pressure in diffuser of the hydro elevator are calculate by Bernoulli's equation:

$$\frac{\Delta P}{\rho \cdot g} = H_2 + \lambda \cdot \frac{H_2}{D_{pr}} \cdot \frac{v_{pr}^2}{2g} + \Sigma\xi \frac{v_{pr}^2}{2g} \quad [m] \qquad (1)$$

Dimension of line-loss of pressure in the circle part of hydraulic engine, by Darcy-Weisbach equation is:

$$\Delta H = \lambda \frac{H_2}{D_{pr.}} \cdot \frac{v_{pr}^2}{2g}, \quad [m] \qquad (2)$$

Where is: D_{pr} -width of circle interspaces of hydraulic engine [m].

Velocity of water in circle part V_{pr} [$m \cdot s^{-1}$] is:

$$v_{pr} = \frac{4Q_{uk}}{\pi\left[(D_{un.})^2 - (d_2^{sp.})^2\right]} \quad [m \cdot s^{-1}] \qquad (3)$$

Coefficient of friction λ by Schefricson is dimensionless non-dimensional number:

$$\lambda = 0{,}11\left(\frac{0{,}15}{D_{ekv.}}\right)^{0{,}25} \quad [Dimensionless] \qquad (4)$$

Where is: D_{ekv} -radius of circle part [m], A-area of circle ring [m^2], O_{sp}-wet exterior circumference [m^2], O_{un} - wet interior circumference [m^2].

$$D_{ekv.} = \frac{4A}{O_{sp.} + O_{un.}} \quad [m^2] \qquad (5)$$

Local loss of pressure on the connections curves, widens narrows and the other obstacles along draw and in the hydraulic engine is proximate about $\Delta l \cong 5m$.

Method of Goriunov, as Darcy's equation, determine the loss of high in pulp line for lift the hydro mixture of sand and water, as system of vertically hydraulic transport:

$$h_m = (\lambda_f + \lambda_s) \cdot \frac{H_2'}{d_2} \cdot \frac{v_m^2}{2g} \cdot \gamma_m \quad [m] \qquad (6)$$

Where is: λ_f -coefficient of friction of pure water, λ_s -additional coefficient of friction by present of hard particle in the water and γ_m -volume weight of hydro mixture.

$$\frac{1}{\lambda_f} = \left(2\log\frac{d_2}{\delta} + 1{,}14\right)^2 \quad [Dimensionless] \qquad (7)$$

Where is: δ-the absolute roughness of technical pipe during the hydraulically transport δ=0,15 for the used pipe of steel in good condition. λ_s is calculating experimentally on the base of parameters, which are order in the VIII GROUP of sand by Goriunov on the base of volume concentration of mixture C_v, and the average radius of particle d_{sr}.

$$C_v = \frac{\gamma_m - \gamma_0}{\gamma_{\sim f} - \gamma_0} \cdot 100\% \quad [Dimensionless] \qquad (8)$$

d_{sr} quartzes sand on the open pit mine "Field D" is $d_{sr} \cong 0{,}20$ mm, and that order them in IV group d_{30} = 0,18-0,30 mm, with following values of parameters: K=0,67, n=3,12 and v_{min}=2,5 $m \cdot s^{-1}$.

Flowing velocity of mixture along pulp line is calculated by formula:

$$v_m = \frac{Q'}{W} = \frac{Q + \Pi_{mah}}{\frac{d_2^2 \cdot \pi}{4}} \qquad [\mathrm{m \cdot s^{-1}}] \qquad (9)$$

There must be accomplish condition $v_m > v_{min}$ where: Q'-water consumption for lifting the mixture [$m^3 \cdot s^{-1}$] and W - area of cross cut of pulp line [m^2].

$$\lambda_s = \frac{K}{v_m^n} \qquad [\text{Dimensionless}] \qquad (10)$$

It is necessary to calculate needy radius of magistraly pipe on the base of the total water consumption Q_{uk} and assumption velocity of water movement through the pipe line $v_0 = 2 m \cdot s^{-1}$ and adapt the first bigger by JUS (Yugoslav Standard) standard and after that, by adapted radius calculate the real flowing velocity of water V_{stv} in the pipe line.

$$d_0 = 1{,}128 \sqrt{\frac{Q}{v_0}} \qquad [\mathrm{mm}] \qquad (11)$$

Reynolds's number R_e for the water flowing in the hydro-pipe line is:

$$Re = \frac{v_0^{stv.} \cdot d_0^{usv.}}{\nu} \qquad [\text{Dimensionless}] \qquad (12)$$

Coefficient of hydraulic resistant λ_o in the hydro-pipe line calculated for the value of Reynolds's number by formula of Alschtorl [7]:

$$\lambda_0 = 0{,}11 \left(\frac{\delta}{d_0} + \frac{68}{R_e} \right)^{0,25} \qquad [\text{Dimensionless}] \qquad (13)$$

Line of unit loss of pressure by friction in hydro-pipe line per m^1 is:

$$i = \frac{\lambda_0 \cdot (v_0^{stv.})^2}{d_0^{usv.} \cdot 2g} \qquad [\mathrm{MPa \cdot m^{-1}}] \qquad (14)$$

For the pipe line of length L total line loss ΔL is:

$$\Delta L = L \cdot i \qquad [\mathrm{m}] \qquad (15)$$

Total pressure in the laborious jet of hydro-elevator which must realize is P and presents adapted laborious pressure:

$$P = P_0 - \Delta H - \Delta L - \Delta l + H\,\gamma_0 10^{-2} \qquad [\mathrm{Mpa}] \qquad (16)$$

Jet radius of hydro elevator determining by flowing equation d_o determine with following equation:

$$Q_0 = \mu \sqrt{2g \cdot P \cdot 10^2} \cdot \frac{d_0^2 \cdot \pi}{4} \qquad [\mathrm{m^3 \cdot h^{-1}}] \qquad (17)$$

and get value:

$$d_0 = \sqrt{\frac{4Q_0 / 3600}{\mu\pi \sqrt{2g \cdot P \cdot 10^2}}} \qquad [\mathrm{mm}] \qquad (18)$$

Where μ is coefficient of useful effect of hydro elevator μ = 0,92.

Determination of the effect of hydrocaving

The effect of translation of quartzes sand from compactly state into the suspension is in fraction of pressure of water and depends by the physics and mechanics characteristics of sand. Strata of quartzes sand in layer are under the water, exploitation is doing in the area, which is under the water, and the estimate is for case those conditions.

Pressure on the end of hydro monitors jet (P) is reduces for friction by the way on the surface (ΔL), in the hydraulic engine ($\Delta H'$=l H'). By the way and in the hydraulic engine there are a local loses ($\Delta l \cong 0{,}05$ MPa), which are increase for the critical pressure. Per which is needful for disintegration the quartzes sand on the needy depth in the excavation chamber.

$$P = P_0 - \Delta H' - \Delta L - \Delta l + P_{kr} \qquad \text{[Mpa]} \qquad (19)$$

It is necessary to determine a starting velocity of the water stream on the hydro monitors jet:

$$V_0 = \mu\sqrt{2g \cdot P \cdot 10^2} \qquad [\mathrm{m \cdot s^{-1}}] \qquad (20)$$

Where is μ - coefficient of reduce of velocity in the jet (0,92-0,96).

The jet radius (D_d) when the ability of water flowing through the one jet Where is (q_0) - lose of water in the jet nozzle (0,0167 $m^3 \cdot s^{-1}$).

The Reynolds's number for the jet radius is (D_d):

$$R_e = \frac{V_0 \cdot D_d}{\nu} \qquad \text{[Dimensionless]} \qquad (22)$$

Calculate of the length of starting part of water stream (L_{poc}) for the radius of jet (D_d) $_{is}$:

$$\frac{L_{poc.}}{D_d} = A - B \cdot R_e \Rightarrow L_{poc.} = (A - B \cdot R_e) \cdot D_d \qquad \text{[m]} \qquad (23)$$

Where is: (A) and (B) are emperies coefficients for the cone hydro monitors jets and they have a value (A = 42,4 and B =$16 \cdot 10^{-3}$).

The change of dynamic pressure by the axis of water stream is given by expressions;

$$\frac{P_0}{P_{kr}} = \left(\frac{L_{poc.}}{L}\right)^k \qquad \text{[Dimensionless]} \qquad (24)$$

On the base of (23) we determine influence of hydro monitors stream:

$$L = \left(\frac{P_0}{P_{kr}}\right)^k \cdot L_{poc.} \qquad \text{[m]} \qquad (25)$$

Where is: k-coefficient which characterize intesity spraying of water stream (it depend of jet construction k=0,85), P_{kr} -needful critically pressure for the breaking sliding resistant (τ_0) of quartzes sand, by condition $P_{kr} \geq \tau_0$, there (τ_0):

$$\tau_0 = c_0 + \sigma_\varepsilon \mathrm{tg}\varphi \qquad \text{[Mpa]} \qquad (26)$$

Where is: c_0 - cohesion of quartzes sand (MPa), φ - friction angle (^{0}) and σ_ε-effective stress (Mpa).

Effective stress has a velocity:

$$\sigma_\varepsilon = \sigma - P_h \qquad \text{[Mpa]} \qquad (27)$$

Where is: P_h -pores pressure (MPa), and σ - normal stress of flush mass (MPa), which is deterring as the influence of width of litho logical bodies in the level bottom of the borehole.

When the critically pressure calculated, there calculate the radius of caving chamber. Normal load is determining as effect of weight litho logical bodies, which lies under the sand strata, which are exploitation:

$$\sigma = \sum \left(H_i \cdot \gamma_i \cdot g \cdot 10^{-6} \right) \qquad [\text{Mpa}] \qquad (28)$$

Where is: H_i (m), thickness of litho logical body and γ_i, specific gravity weight (kg·m^{-3}), g-gravity acceleration (9,81m s^{-2}).

Minimum of pressure, which is needful for desintegration, must be equal or bigger by the critical pressure $P \geq P_{kr}$. On the base of that the critically velocity of water stream (v_τ) which make a needful dynamic pressure, is:

$$v_\tau = \sqrt{\frac{2g \cdot \tau_0}{\gamma_0}} \qquad [\text{m·s}^{-1}] \qquad (29)$$

Determination of caving capacity

Maximum of caving capacity - disintegration of binded sediment quartzes sand, determining by the expression:

$$\Pi_{max} = \frac{12 \cdot D_d^2 \cdot H_0^{0,5} \cdot (P_0 - P_{kr.}) \cdot 10^4}{\varepsilon} \qquad [\text{m}^3\text{·h}^{-1}] \qquad (30)$$

Where is: ε -emperies coefficient, which characterize specific resistant of breaking (for sandy, weak bond sediment has value ε =10) and H_0 -hydro monitors depth exploitation (m).

$$Q = v_0 \frac{D_d^2 \cdot \pi}{4} \qquad [\text{m}^3\text{·h}^{-1}] \qquad (31)$$

Quantity of water which is spend for lifting hydro mixture present a difference of whole water (Q_{uk}) in the pump system and quantity of water which is spend for disintegration (Q):

$$Q_0 = Q_{uk.} - Q \qquad [\text{m}^3\text{·h}^{-1}] \qquad (32)$$

Specific spend of water q for the translation of sand from state of disposal conditions into the hydro mixture are determining for every layer and present relation of quantity of water which are spending for breaking the sand (Q) and quantity of water for making under pressure in diffuser and lifting hydro mixture (Q_0), that is, relation of whole quantity of water ($Q_{uk.}$) and maximum of capacity of exploitation (Π_{mah},) given by expression:

$$q = \frac{Q_{uk.}}{\Pi_{max}} = \frac{Q_0 + Q}{\Pi_{max}} \qquad [\text{Dimensionless}] \qquad (33)$$

Estimate of hydrotransport of pulp

Test of hydro transport of hydro mixture and determining a needful power of pump for hydro transport is important condition for boreholes excavation. It is necessary to determining volume mass hydro mixture - pulp density (γ_{hm}) in chamber:

$$\gamma_{hm} = \frac{q + \gamma_{sio_2}(1-m)}{q + (1-m)} \qquad [\text{kg·m}^{-3}] \qquad (34)$$

Where is: γ_{sio_2} -volume mass of solid phase (quartzes sand), m-porosity of quartzes sand, m=0,35 p.u. - Parts of unit, (35%).

There must be condition $V_{st.} > V_{kr.}$, to avoid sedimentation of solid material in the pulp-line and when the production stopped, where is ($V_{st.}$) a real velocity of flowing through the pulp-line, and ($V_{kr.}$) critically velocity, when the sedimentation of solid phase in the pulp-line is no present. Critically velocity of flowing of pulp is determining by the expressions of V.V. Trainees:

$$V_{kr.} = \sqrt{g \cdot D} \sqrt{\frac{\gamma_{hm} - \gamma_0}{K \cdot \psi \cdot \lambda_0 \cdot \gamma_{sio_2}}} \cdot C \qquad [\text{m ·s}^{-1}] \qquad (35)$$

Where is: K-emperies coefficient of resistant in free falling in the hydro mixture and has a value K=1,45, ψ-coefficient of resistant in transport of pulp ψ=0,55, D-diameter of pulp, λ_0 -coefficient of hydraulic resistant by the moving of clear water, C-coefficient inclusive content size class (<2mm).

Real velocity of flowing of hydro mixture is determining by the expression:

$$V_{st.} = \frac{4Q}{\pi \cdot D^2} \quad [m \cdot s^{-1}] \quad \text{There must be conditions} > V_{kr} \qquad (36)$$

Needful power of pump for pumping hydro mixture is calculating after determined lose of pressure by the flowing of hydro mixture on the respondent length of pulp-line:

$$i_l = \left[i_0 \cdot \frac{\gamma_{hm}}{\gamma_0} + \frac{\sqrt{g \cdot D \cdot (\gamma_{hm} - \gamma_0)}}{K \cdot \psi \cdot V_{st.} \cdot \gamma_0} \cdot C \right] \cdot l \cdot k \quad [MPa \cdot m^{-1}] \qquad (37)$$

Where is: i_0 -hydraulic resistant by the moving of clear water, (m-height of water), k-coefficient of local resistant, k=1,1

$$i_0 = \frac{\lambda_0 \cdot V_{st.}^2}{2D \cdot g} \quad [MPa \cdot m^{-1}] \qquad (38)$$

Pulp-line for exploitation pulp-line till the settling reservoir is with permanent fall. Settling reservoir is on the lower niveau from exploitation borehole with needful height difference. To hold a velocity in pulp-line bigger than critically is, it is necessary to determine a needful additive pressure - total head of pump (H').

Needful power of pump is calculating on the base of parameters of work pressure and quantity of water (capacity of pump) and height difference of grooving of water level.

$$N = \frac{Q_{uk.} \cdot H' \cdot \gamma_{hm}}{102 \cdot \eta_e \cdot 3{,}6}, \quad [kW] \qquad (39)$$

Where is η_e -effective coefficient of useful effect of pump aggregate (0,7).

Conclusion

The paper determines a capacity caving and estimates hydro transport of mixture of sand and water as well as construction parameters of hydro monitor. In this paper are given the estimates of those parameters as the base for use the boreholes technology. Named parameters make possibly construction equipments for the borehole excavations of sand and give the starting parameters for dimension of area in zone of excavations boreholes. Special care dedicated by construction of hydro monitor, which is not in standard production, and which present the most important part in the technology system in the excavation of sand through the boreholes.

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