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Design and Preliminary Field Experiment of Hydraulic Borehole Mining Tool with Expandable Nozzle

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Abstract: *Hydraulic Borehole Mining (HBM) method is an important mining technology that has advantage for some special ore formation. However, the traditional hydraulic borehole mining tool's nozzle is fixed that limits the single well ore production. In this paper, hydraulic borehole mining tool with ratchet controlled expandable nozzle was designed. High pressure water channel, ore pulp discharge channel and ratchet controlled expandable nozzle are three important parts in this design process. Then, the tool was conducted preliminary filed experiment in nong'an area and infrared camera was used to observing breaking condition of the wall of experiment hole. The experiments showed that the ratchet controlled expandable nozzle can expand and back in the experiment hole. And the hydraulic borehole mining tool can break the wall of experiment hole obviously. This research is a preliminary study that provides an ideal mining method and mining tool for thin ore formation.*

Keywords: *Hydraulic borehole mining, Expandable nozzle, Design and field experiment, Ore particles*

1. Introduction

Hydraulic borehole mining method is researched from 19 century, which is different from traditional open pit and roadway mining [1,2]. Firstly, a well is drilled in the mining area and this well must drill through ore formation. Secondly, high pressure jet device is put down the hole at the place of ore formation and generates high pressure jet. High pressure jet broken ore formation and ore fragments peel off from ore formation. Finally, ore pulp mixed by ore fragments and water is delivered to the ground using hydraulic (pneumatic) lifting device and ore is filtered from ore pulp [3,4]. Hydraulic borehole mining method is mainly used for weak cementation and low strength ore and shallow burial depth, thin layer and lean ore, lake or ocean ore. In the 1920s, the United States has carried out the research of hydraulic borehole mining technology, which used for mining uranium, asphaltic sand, granular phosphate rock and so on. Russia had a lot of hydraulic borehole mining technology research, and application in coal and iron ore. In addition, Poland, India, Australia, Hungary, Yugoslavia also carried out the research of hydraulic borehole mining technology [5,6]. Hydraulic coal mining technology has been widely applied in China. Chen Chen, Yan Xuanchen, Zhao Guijie et al., have conducted some fundamental researches on hydraulic borehole mining [7-12]. However, Successful field cases of hydraulic borehole mining with expandable nozzle are few.

This paper put forward that hydraulic borehole mining method is applied to mining thin oil shale seam. Hydraulic borehole mining tool with expandable nozzle was designed and preliminary filed experiment was conducted using hydraulic borehole mining tool with ratchet controlled expandable nozzle.

2. Hydraulic Borehole Mining Tool

The hydraulic borehole mining tool must have high stability in consideration of that the mining tool works in the hole for a long time. Thus, hydraulic borehole mining tool with ratchet controlled expandable nozzle was determined, which has high reliability. Hydraulic borehole mining tool with ratchet controlled expandable nozzle have three main parts: high pressure water channel, ore pulp discharge channel and ratchet controlled expandable nozzle and others, shown in Fig.1.

2.1High Pressure Water Channel

High pressure water channel is the red part in Fig.1. It includes high pressure water pipe, high pressure rotary joint, hydraulic giant and nozzle. The high pressure water flow in above parts in turns and forms water jet out of nozzle finally. High pressure rotary joint is an important part that it is rotation axis of hydraulic giant.

2.2Ore Pulp Discharge Channel

Ore pulp discharge channel is the yellow part in Fig.1. It includes ore pulp suction mouth and ore pulp discharge pipe. Ore pulp discharge pipe is coaxial double pipe that two pipes can up and down along the central axis. This construction can match up with high pressure water channel's motion.

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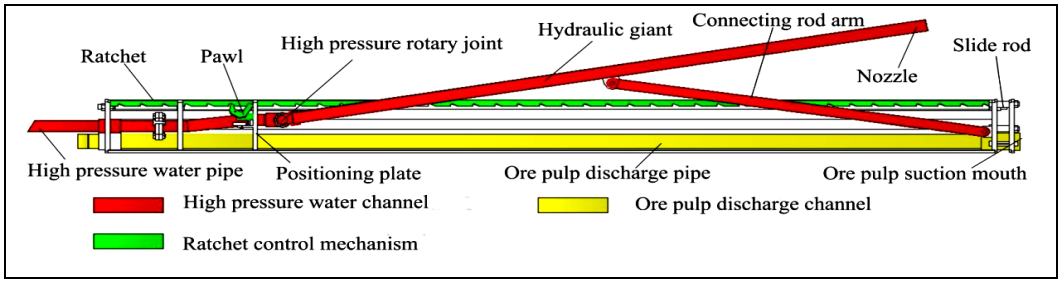

Fig.1 *Hydraulic borehole mining tool with ratchet controlled expandable nozzle schematic diagram*

2.3 Ratchet Controlled Expandable Nozzle

Ratchet controlled expandable nozzle is the green part in Fig.1. It includes ratchet, pawl, connecting rod arm, positioning plate and slide rod. The pawl fix on the positioning plate and positioning plate move along slide rod. The pawl located on the ratchet when positioning plate moves to down the tool, which hydraulic giant expand a certain angle under force from the connecting rod arm. The nozzle can broken more ore formation with hydraulic giant expanded. Single well ore production can be calculated by following process.

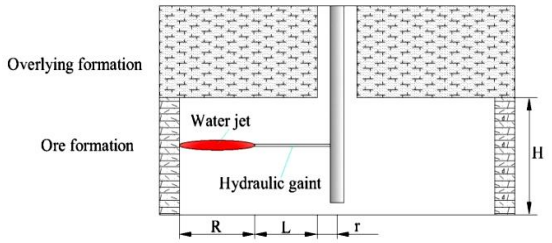

Fig.2 *Schematic diagram of mining cavern*

$$V_e = \pi(R + L - r)^2 H \quad (1)$$

Where, V_e is volume of ore production using designed tool; R is effective crushing distance of high pressure water jet; L is length of the hydraulic giant; r is radius of well; H is thickness of the ore formation.

Single well ore production using HBM with fixed nozzle is following:

$$V_f = \pi(R - r)^2 H \quad (2)$$

Where V_f is volume of ore production using HBM with fixed nozzle. Increase production rate can be calculated:

$$K = \left(1 + L/(R - r)\right)^2 \quad (3)$$

As can be seen from the formula (3), K increases with the lengthen of hydraulic giant L. however, the length of hydraulic giant is limited by ore formation's space and stability.

3. Field Experiment

Hydraulic borehole mining tool with ratchet controlled expandable nozzle was processed and debugged in consideration of mechanical reliability (Fig.3). Then, this tool was conducted preliminary filed experiment at "National Pilot Project for Oil Shale in-situ Exploitation" that conducted by Jilin University in China nong'an area.

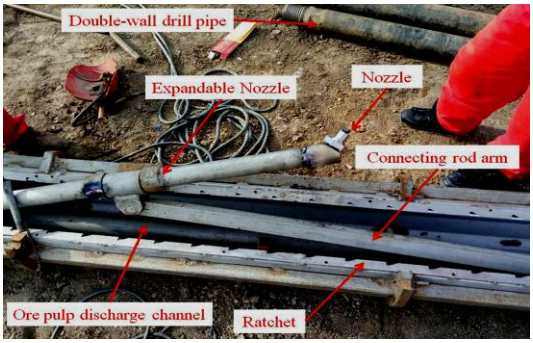

Fig.3 *Part of hydraulic borehole mining tool with ratchet controlled expandable nozzle*

3.1Experiment Equipments

Main experiment equipments are hydraulic power head drilling rig, slush pump, sand pump, high pressure pipe and drilling tools, infrared camera, computer and the mining tool. (Fig.4)

GK-5 type hydraulic power head drilling rig is special hydraulic borehole mining rig developed by Jilin University. It can conduct multiple drilling methods, such as directional (reverse) circulation drilling, air DTH hammer drilling and foam drilling. Of course, its main performance parameters are designed for hydraulic borehole mining. Its main performance parameters are following.

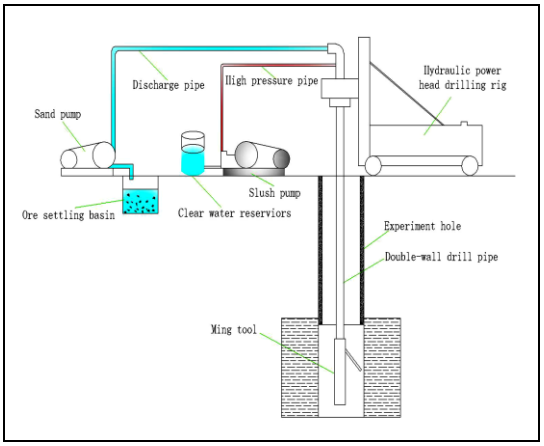

Fig.4 *Schematic diagram of the field experiment equipments*

Table1: *Main performance parameters of GK-5*

The parameter	Data
Drill pipe diameter(mm)	89/102
Drill pipe length(mm)	4500
Rotary torque(N*m)	11000
Rotary speed(r/min)	3-150

BW250 type slush pump provide high pressure water in this experiment. Its main performance parameters are following.

Table2: *Main performance parameters of BW250*

The parameter	Data
Power(KW)	15
Maximum pressure (MPa)	8
Maximum flow (L/min)	250

Sand pump lifts ore pulp from bottom of the hole to the ground. Its maximum return flow is 15m^3/h.

3.2Experiment Design

The experiment purpose is testing work feasibility of the tool. There were two different diameters nozzles selected in this experiment. Thus, two experiments were conducted and the experiment parameters were shown in Table 3.

Table3: *Experimental parameters*

Number	Nozzle diameter (mm)	Pump pressure (MPa)	Pump flow (L/min)	Flow velocity (m/s)
1	4.8	4	90	82.9
2	6.4	4	145	75.1

3.3Experiment Procedure

Fig.5 shows field experiment site. First of all, a ϕ500mm hole was drilled by hydraulic power head drilling rig. Then, the casing was put on the top of the mining formation. After that, hydraulic borehole mining tool was put down the hole. High pressure water was transported into the tool and drill pipe string began rotating. High pressure water jet out from expandable nozzle broken hole wall constantly with the tool going up until the expandable nozzle at the top of mining formation. The tool was put on the hole bottom and press a distance using hydraulic power head for opening the expandable nozzle. Above steps were repeated again. A cylindrical mining cavern formed. Infrared camera was put down the hole to observing broken hole wall, which is more intuitive observation means.

Fig.5 *Field experiment site*

4. Result and Discussion

(1) Part of ore particles that was filtrated from settling basin during mining process was filtrated as different particle diameter, shown as Fig.6. And, Fig.7 shows ore particle size distribution. From two figures, ore particles that particle diameter less than 2cm have a percentage of 60%, which proves the mining tool can fully broken this formation. This particle diameter is suitable for reverse circulation pipeline transport. Percentages of that particle diameter is 2-5cm, 5-10cm, ＞10cm are 15%, 10%, 15% respectively. Low mechanical strength and natural fractures in this formation may lead to some big particle peel off.

Fig.6 *Ore particles filtrated from settling basin*

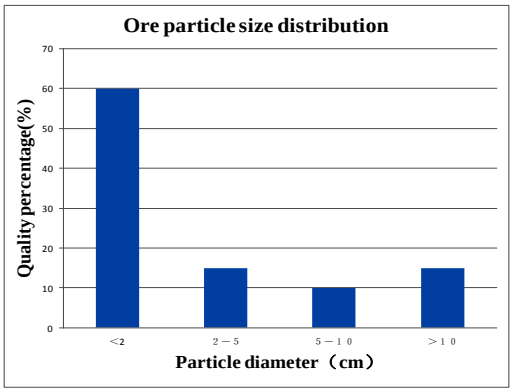

Fig.7 *Ore particles size distribution*

(2) Infrared camera was put down the hole to observing broken hole wall and computer record video, shown as Fig.8 and Fig.9. A obvious annular boundary between hole wall and mining cavern was formed on the top of mining formation according to Fig.8. This explains that high pressure jet cutting the formation and the mining cavern become a larger diameter cylindrical space. The tiny fracture faces in Fig.9 account for high pressure water jet has broken the formation into small diameter particles.

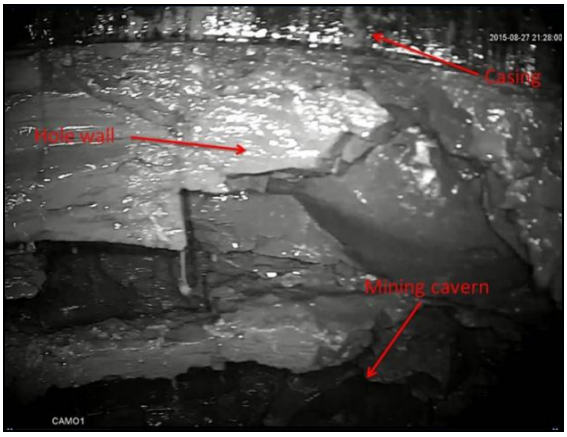

Fig.8 *Top of the mining formation*

Fig.9 *Middle of the mining formation*

5. Conclusion

(1) Hydraulic borehole mining tool with ratchet controlled expandable nozzle can open and back in field experiment. The ratchet controlled mechanism can accurately lock and control the expandable nozzle opening angle. So, this tool can expand mining volume and increase single well ore production.

(2) Most particles have a suitable size for hydraulic transmission. However, some big particles generate in field experiment because low mechanical strength and natural fractures in formation. Also, it is relate to water jet pressure, rotational and lifting speed of drill pipe string. Mining parameters will be modified according to formation mechanical strength and other special properties in future research.

Acknowledgements

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