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Procedia Engineering 73 (2014) 264 – 268

Procedia Engineering

www.elsevier.com/locate/procedia

Geological Engineering Drilling Technology Conference (IGEDTC), New International Convention Exposition Center Chengdu Century City on 23rd-25th May 2014

Research to Break Oil Shale with High Pressure Water Jet Based on Bionic Nozzle

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Abstract

Oil shale is a sedimentary rock, it is increasingly attracting widespread attention as petroleum supplement energy. Using borehole hydraulic mining techniques to mine oil shale seams at a certain depth in the underground, first and foremost is the use of high pressure water jet to make the overall oil shale ore broken into small pieces and peel them off parent rock. Based on the bionic theories, to design the bionic nozzles are adding several bionic units in the internal flow channel surface of the nozzle, it makes the original smooth flow channel inside the nozzle has become bionic non-smooth surface structure, to some extent, effectively improved the hydraulic characteristics of the nozzle internal flow channel, and reduced the flow resistance of the water. Based on CFD simulation and analysis, the reasons for upgrading effect of the crushed oil shale by the bionic nozzle high pressure water jet are analyzed. Experiments show that, in the same working conditions, bionic nozzle compared with the normal nozzle of the same structure parameters, the diameter of the erosion and crushing pit on oil shale samples expanded 4mm, and the crushing pit depth deepened 3.8mm using bionic nozzle.

Selection and peer-review under responsibility of Geological Engineering Drilling Technology

Keywords: High Pressure Water Jet; Bionic Nozzle; Drag Reduction; Oil Shale

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Selection and peer-review under responsibility of Geological Engineering Drilling Technology
doi:10.1016/j.proeng.2014.06.197

1. Introduction

Oil shale is a kind of solid combustible organic rock, and belongs to the sedimentary rocks of three major rock categories. With the oil sands, coal-bed methane resources, it is collectively referred to as nonconventional oil and gas resources. With the advent of the era of high oil prices, as a supplementary energy of petroleum, oil shale has attracted worldwide attention.[1-2] Oil shale borehole hydraulic mining, within the borehole through seams, with high-pressure water jet washing out and cracking oil shale seam, so that the original integrity of the oil shale ore is broken into small pieces and peel off the rock, form a kind of water-mineral mixture at the bottom of the hole, which can be delivered to the surface using the hydraulic (pneumatic) power equipment. [3-4]In the implementation process of the technology, the most important is the use of high pressure water jet washing out and break oil shale ore into a small particles .As a core actuators of the high-pressure water jet, the nozzle's hydraulic characteristics of the merits directly impacts on wash out and crushing effect of high pressure water jet, so the study of the structure of the nozzle is extremely necessary. The paper, that the non-smooth surfaces drag reduction theory of bionics [5-6] is applied to the nozzle structural design improves the hydraulic characteristics of high-pressure water flow inside the nozzle. From the perspective of bionic drag reduction to promote the striking force of nozzle high pressure water jet, it strengthens the crushing effect of high-pressure water jet on oil shale.

2. The Nozzle for High Pressure Water Jet Crushing Oil Shale

2.1. Ordinary Nozzle for High Pressure Water Jet Crushing Oil Shale

There are many types of nozzle for high pressure water jet, but the project adopts the most used straight cone nozzle, which its speed factor is up to 0.98, and easy processing [7-9]. Based on this, the straight cone nozzle was used for high pressure water jet crushed rock. Fig. 1 is the three-dimensional model of an ordinary nozzle which produces high pressure water jet crushing oil shale and the schematic diagram of its internal flow channel.

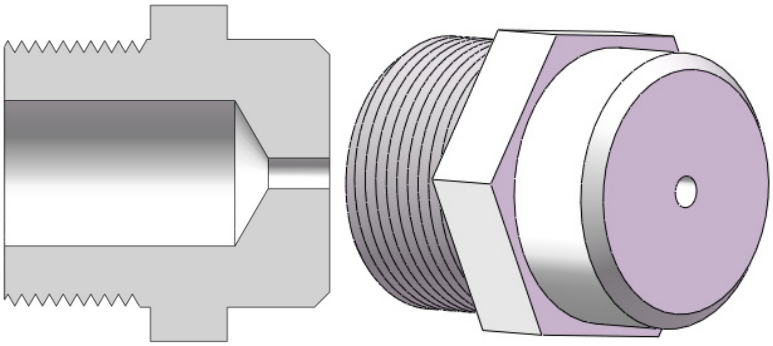

Fig.1 Three-dimensional Model of Ordinary Nozzle and Schematic Diagram of its Internal Flow Channel

2.2. Bionic Nozzle for High Pressure Water Jet

In order to enhance striking the force of high pressure water jets, the bionic nozzle which produces high pressure water jet for crushing oil shale reduces resisting force of the high pressure water flowing past the nozzle using these non-smooth grooved surface in the interior of the nozzle flow channel,. In this paper, the bionic nozzle adopts ring grooves as its bionic unit on its internal flow channel surface. Fig. 2 is the schematic diagram of bionic nozzle internal flow channel for high pressure water jet.

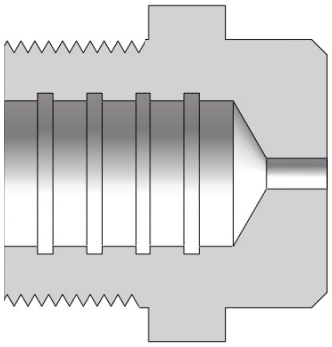

Fig.2 Schematic Diagram of a Bionic Nozzle Internal Flow Channel

3. Analysis on Reasons of Upgrading Crushing Effect Using Bionic Nozzle Based on CFD

Using CFD software Fluent, the flow field when the high pressure water jet produced by bionic nozzle is simulated and analyzed, and the velocity contours, velocity vector, trajectories of flow field and so on can be obtained. Fig.3 is the velocity contours of high pressure water jet produced by bionic nozzle. Fig.4 is the velocity vector of bionic ring grooves part flow field inside the bionic nozzle internal chamber. Fig.5 is the fluid particle trajectories inside the bionic nozzle internal chamber.

The reasons for improving the striking force of high pressure water jet produced by bionic nozzle, mainly is the following two aspects:

(1) As showninfig.4 and fig.5, the rotating vortex in side bionic ring grooves gives rise to liquid-liquid contacting between the high pressure water inside bionic ring grooves and outside bionic ring grooves, sequentially a vortex overlay effect could be formed.

(2) The inversion vortex inside the bionic grooves and the friction resulted in high pressure water flowing through nozzle channel could produce a additional power, which produces promoting effect on the high pressure water flowing inside the bionic nozzle channel.

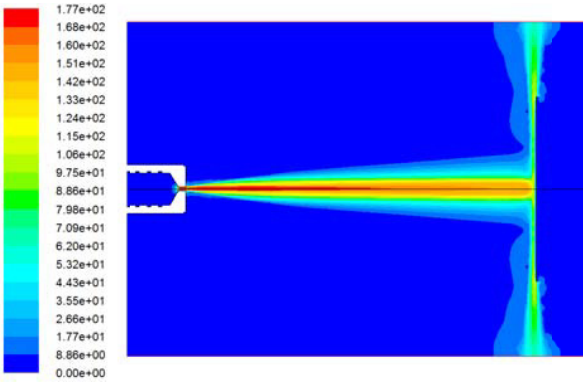

Fig.3 Velocity Contours of High Pressure Water Jet Flow Field Produced by Bionic Nozzle

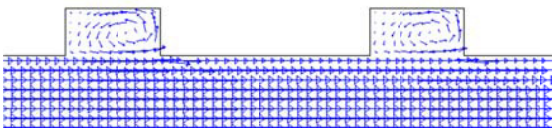

Fig.4 Velocity Vector of Flow Field at Bionic Ring Grooves Part of Bionic Nozzle

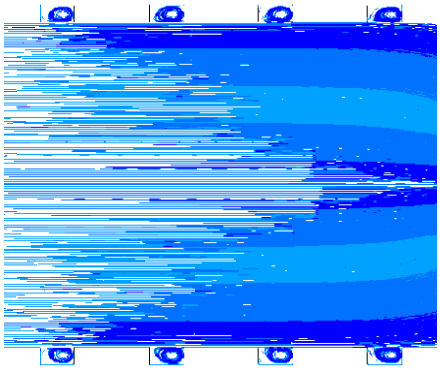

Fig.5 Fluid Particle Trajectories inside Bionic Nozzle Internal Chamber

4. Experiment on Crushing Oil Shale Using High Pressure Water Jet Produced by Bionic Nozzle

Respectively, using a ordinary nozzle and a bionic nozzle with the same structural parameters which outlet diameter is 4 mm, spray distance is 400 mm, the experiment on high pressure water jet crushing the oil shalelasts25 s. In order to compare with the experiment results, the two high pressure water jets hit in different place of the same oil shale sample. The spray direction of the high pressure water jet is perpendicular to the bedding of oil shale samples. The high pressure piston pump for testis driven by a variable frequency motor, the frequency of inverter motor is determined to 23.55 Hz, by this time, the pump pressure (ejection pressure) corresponding to a ordinary nozzle is up to 15 MPa, and the flow is 6.14 m^3/h.

The crushed pit on the oil shale sample which its diameter is 13 mm, and depth is 4.4 mm was caused by high pressure water jet of the ordinary nozzle, as shown in the fig. 6. Fig.7 is the crushed pit on the same oil shale sample caused by high pressure water jet of the bionic nozzle, its diameter is 17 mm, and depth is 8.2 mm. Experimental results show that, under the same operating conditions and same structure parameters of nozzle, comparing the crushed pits on the oil shale sample caused by high pressure water jet using the bionic nozzle with the ordinary nozzle, the former crushed pit diameter expanded 4mm, and depth increased 3.8 mm.

Fig.6 The Crushed Pit on Oil Shale Sample Caused by Ordinary Nozzle

Fig.7 The Crushed Pit on the Same Oil Shale Sample Caused by Bionic Nozzle

5. Conclusions

Through CFD simulation analysis and the experiments of high pressure water jet crushing the shale oil sample, the following conclusions can be got:

(1) Application of the bionic non-smooth surfaces drag reduction theory to the nozzle structural design, by processing several bionic ring grooves in the original smooth surface inside the nozzle flow channel, the additional bionic ring grooves is able to enhance the erosion and cracking effect on oil shale by the nozzle produced high pressure water jet.

(2) The reverse rotating vortex inside the bionic ring grooves is the main reason for that upgrades the crushed oil shale effect of bionic nozzle high pressure water jet.

(3) Under the same operating conditions, when the outlet diameter of bionic nozzle and ordinary nozzle are 4mm, and the spray direction of the high pressure water jet is perpendicular to the bedding of oil shale samples, comparing the crushed pit on the oil shale sample caused by the bionic nozzle high pressure water jet with the ordinary nozzle, the former crushed pit diameter expanded 4mm, and the depth increased 3.8 mm.

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