Bottom hole hydro-transport system in oil shale borehole mining

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Abstract

Borehole mining is a promising new oil shale exploitation technology. With some methods such as high pressure water jet at the bottom of borehole, oil shale is crushed into particles by drilling into the formation. At the same time, the particles whose diameters are less than 60mm are pumped to the surface by the hydraulic circulating system. As ore particles discharge, the volume at bottom hole keeps increasing. The process of transporting ore particles in a large bottom hole mining field is one prominent part of the whole hydraulic system. Through numerical simulation and laboratory tests, a flow model of the hydro-transport system in the bottom hole mining field under the condition of borehole mining was established. This model helped define relevant factors, and enabled assessment of the influence of high-pressure jets on the hydro-transport field. To improve the efficiency of transport of ore particles, modeling results indicate that flow velocity at bottom hole, pressure, flow path, mass of mining volume, and ore slurry entry position must be taken into consideration.

Keywords:oil shale, borehole mining,hole bottom, ore particles transportation

1. Introduction

With the rapid development of the economy, high demand has challenged traditional mining methods all over the world to confront a variety of problems, including:

- Exhaustion of shallow rich ore
- Low labor productivity caused by mining deep mineral deposits and shallow lean ore
- Consequent high costs
- security and environmental protection.

In addition, serious accidents and mine disasters caused by explosion, flooding and landslide have happened frequently leading to mass casualties. Therefore, in order to reduce these concerns, it is urgent to develop new mining methods with high content of modern technology, low consumption, high efficiency and safety. A promising method is to transform solid minerals to liquids or gases under ground using heat transfer, mass exchange, chemistry and hydraulics, then separating products after they are pumped to the surface through boreholes. Borehole mining is one promising new technology (Chen et al., 2009, 2009,2008,2007). Studying this technology meets not only the requirement of the long-term development strategy of technological innovation in China, but also the requirement of Chinese 863 program ("twelfth five years") developing new mining technology in the technological field of planning resources and environment. Moreover, it also meets the demand for developing low energy consumption, low pollution and low-carbon technologies in China.

Oil shale has a wide distribution in China, of which that in Northeast Songliao Basin is the richest. The rock has a compressive strength of only 25MPa ~30MPa. In addition, groundwater in the mining area in Northeast Songliao Basin is abundant. Borehole mining is taken as a promising mining scheme because of the nature and environment of oil shale in Jilin Province.

The hydraulic system is one of the component elements in borehole mining technology. Modeling of this system requires understanding of various processes including hydraulic cutting in the bottom assembly, ore particles movement in the broken seam, transportation from the flow field to the lifting tube and lifting particles in tube to the surface. Chen at al. (2009, 2009, 2008, 2007, 2003, 1994) have completed considerable research on hydrofracture and vertical lift. However, situation of study of the flow field at bottom hole and the various influence rules is the opposite. The influence of the hydraulic transportation system in the flow field at bottom hole on vertical lift should not be underestimated. This is because, first of all, transport of ore particles to vertical tube must be considered, and only then can vertical lift be taken into account. Only through further research on the former can the efficiency of borehole mining be improved greatly (Zhao et al,2005; Yang et al, 2005; Zhang,Xi, 2004; Tang et al, 2004;Hu et al, 2004; Yuan, He, 2003; Yang et al,2002; Lin et al, 2002;Shen et al, 2002; Xiong et al, 1999; Б.И.Кондырев, И.Г.Ивановский, 2003).

2. Differences of fluid flow between borehole mining and horizontal wells

Research on horizontal wells in oil drilling includes inflow performance, flow curve , seeking for favorable areas that are suitable for exploiting horizontal well and determining the well trajectory and deliverability parameters, which are based on reliable geological understanding and use the method of oil pool numerical simulation (Chen, Zhang, 2007; Chen,2001;Du et al,1994). The horizontal flow field in the bottom hole for borehole mining is greatly different from that of a horizontal well. First of all, the dimensions are different. The diameter of a horizontal borehole is small in oil well drilling, and, consequently the excavation space is also small. However, the diameter influenced by slurry flow in borehole mining is large, which is general 200mm-3000mm, and the excavation volume is large. Secondly, there are not only water jets breaking rock above the plane of the bottom hole, but there is also slurry flow of ore particles towards the center, in the opposite direction, so that interaction must be taken into consideration. These counterflows are shown in figures 1 and 2.

Research findings in oil drilling are valuable for reference, but much work needs to be done to understand better the flow field in the bottom hole area for borehole mining.

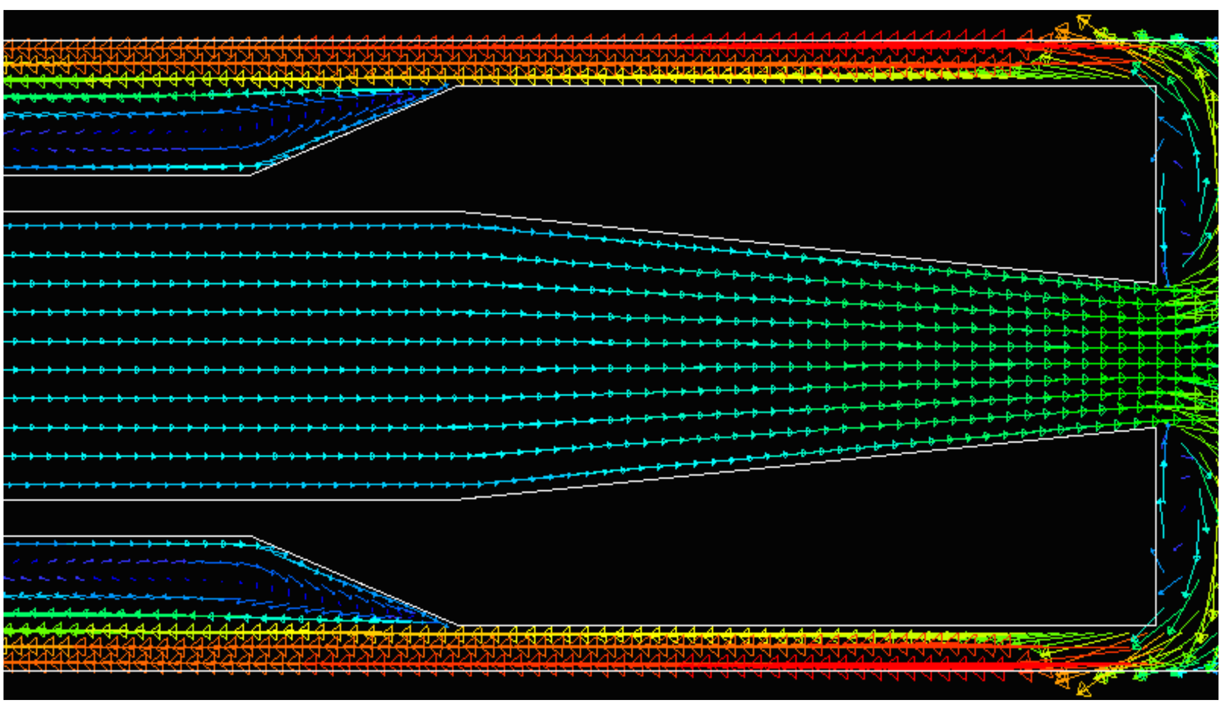


Figure 1: velocity vector in horizontal hole

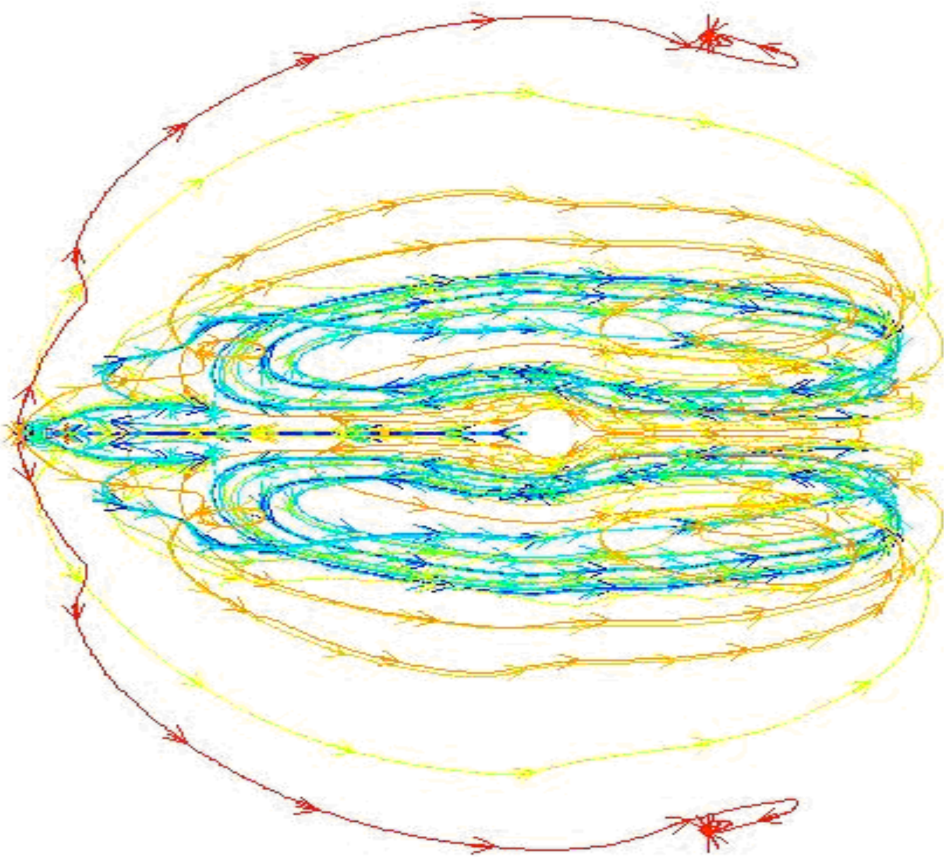


Figure 2: velocity vector in borehole mining

3. Research approach

There are three important aspects to our research approach:

- **Multi-disciplinary theory** such as hydromechanics, fluid-particle dynamics and solid-liquid two-phase flow should be adopted in the analysis of the flow field in the hole bottom under the conditions of borehole mining.
- **Computer simulation** - Computational Fluid Dynamics (CFD) combined with the Discrete Element Method (DEM)was defined CFD-DEM coupling method. The basic thought process of the CFD-DEM coupling method: CFD was used to solve the flow field, and DEM was used to calculate the motion force, then the coupling could be realized according to transmission of quality, momentum and energy by a suitable model. Concrete method: firstly, flow field of a certain time point was iterated to convergence by Fluent, then information from the flow field was transformed into fluid drag acting on the particles in EDEM (Experts in Discrete Element Method, was the first general CAE software based on the most advanced discrete element method in the world, which was designed to simulate and analyze particle system) through a drag model. EDEM could calculate the forces (fluid drag, gravity, impact force and so on) suffered by particles, which helped to update the information such as position, velocity of particle. Finally, particles' properties were added to the CFD calculation in the form of a momentum sink, thus impacting upon the flow field. Figure 3 illustrates the modeling approach.

- **Empirical approach** - Conveying conditions of ore particles in the hole bottom should be simulated by some experimental means. The flow field was tested in the laboratory to obtain the necessary data. Most of all, the transportation mode with the most extensiveness and far distance could be chosen. Comparison of the simulation results with experimental results, enabled updating of the established system model through the final results

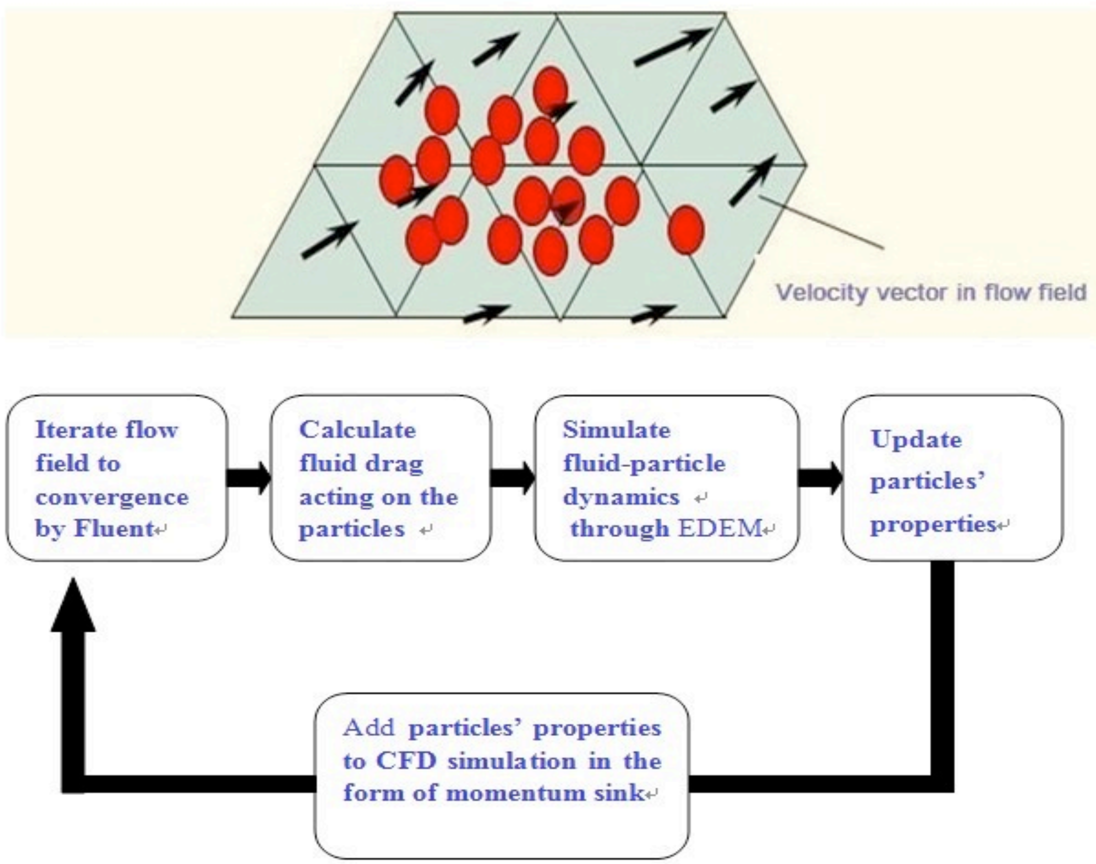
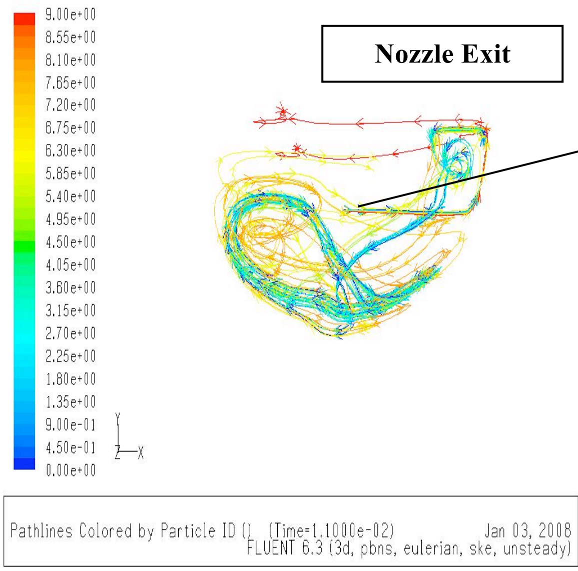


Fig.3 Fluent—EDEM coupling simulation process

4. Test results

The flow field in the hole bottom of the borehole mining system was a spiral line that was made of sinks and vortices, and the direction of slurry flow was clockwise (in the Northern Hemisphere). Once established, the form of flow field was unchanging, but there were some differences in the aspects of degree of completeness, symmetry, and curvature.

4.2 Under the assumption of flow in the hole bottom and velocity at entrance of the slurry achieving the required values, the whole bottom could be affected by fluid movement. However, there was a sphere of influence (called the effective suction field) leading ore particles to converge around the entrance, whose features were large negative values, high velocity, high pressure, and large velocity gradient. The strength of the effective suction field depended on the velocity



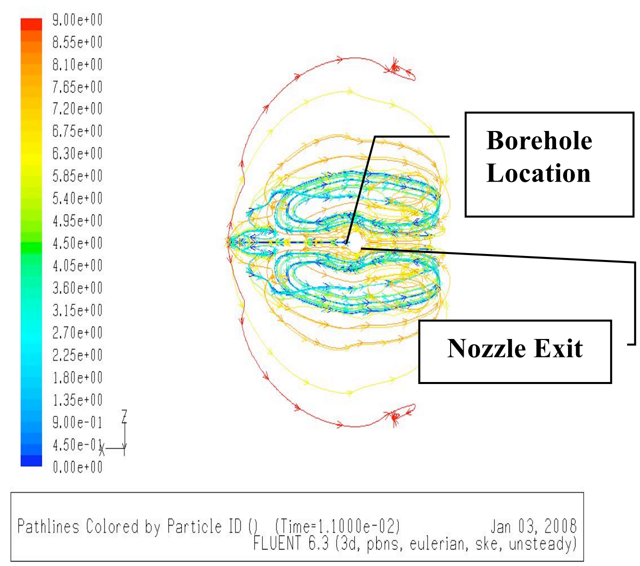


Figure 4: Elevation drawing of flow field in the hole bottom

Figure 5: Plan view of flow field in the hole bottom

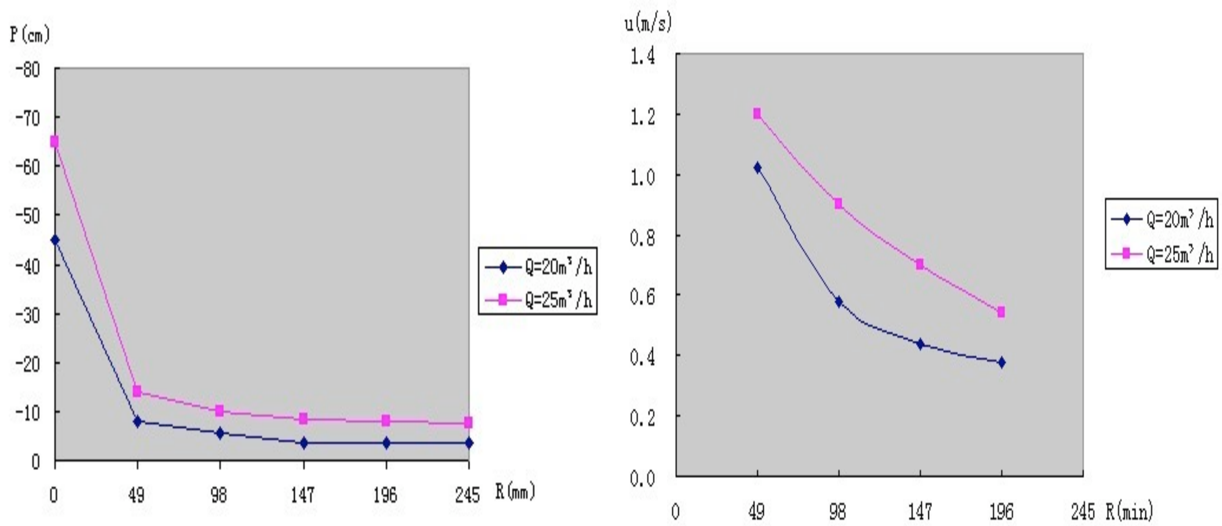


Fig.6 P-R, u-R curve under different pump volume at entrance and diameter (actual flow).

5. Conclusion

(1) Results in this paper can provide reliable design basis reasonably and sufficiently for designing other equipment for borehole mining, which is of great economic significance.

(2) Research on the interaction between high pressure jetting flow and the system carrying particles contributes to a rich multiphase flow theory.

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