Two phase numerical simulation of continuous abrasive water jet system based on EDEM

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Abstract. To improve continuous supply ability of present pre mixed abrasive water jet (AWJ) system, a new type of continuous AWJ is proposed and its formation mechanism is revealed. Simulation of abrasive entrance and a mixing chamber, pipes, cutting nozzle flow field data using FLUENT software, with area ratio M change, the abrasive cutting nozzle end pressure and entrance into contradiction, the curve of intersection of M=5 is the key point of abrasive jet and material handling division. The solid-liquid coupling simulation method of abrasive particles and water was formed by using edem software.

1. Introduction
Abrasive water jet is a liquid-solid two-phase medium jet formed by mixing solid particles (corundum, quartz sand, ceramsite, etc.) with high-speed water flow or high-pressure water flow[1]. Because of its high efficiency, no thermal reaction zone, no chemical reaction and other advantages, it is widely used in oil, coal, machinery and other industries, such as oil well abrasive jet slotting technology[2], high-pressure abrasive jet anti outburst slotting technology[3], abrasive jet polishing technology[4]. According to the different mixing methods, the abrasive water jet can be divided into the mixture of mixed abrasive water jet and premixed abrasive water jet[5]. The mixing of the mixed abrasive water jet and the high-speed water flow is not enough, which greatly reduces the energy transfer efficiency of the abrasive water medium. In the same case, the cutting depth of the front mixed abrasive water jet is about twice that of the rear mixed abrasive water jet[6]. However, the continuous supply of abrasives is the key problem to restrict the large-scale application of premixed abrasive water jet. In this paper, a new type of continuous abrasive water jet system is designed, and its structure is simulated by fluent and edem.

2. The working principle and structure of AWJ
2.1. The system composition and working principle
The pre mixing abrasive water jet continuous feeding system is shown in figure 1. The system consists of a high pressure plunger pump, a jet pump, an abrasive feed bucket, a cutting nozzle and a plurality of high-pressure hose. As shown in figure 2, the jet pump is mainly composed of inlet section, abrasive inlet, jet pump nozzle, mixing cavity, throat, diffusion tube and so on, the structural parameters are shown in ‘Table 1’. The working principle of the system are as follows: high pressure piston pump high speed flow of water ejected from the nozzle jet pump, the mixing chamber pressure
decreased to form negative pressure, abrasive in the weight and pressure under the action of the abrasive hopper into the mixing chamber, and then with water and momentum exchange, flow through the throat, Stokes, the pressure gradient force under the action of force to accelerate, and then through the diffusion tube, high pressure hose, into the cutting nozzle, further accelerated in the cutting nozzle, finally from the cutting nozzle, forming a continuous abrasive water jet.

Figure 1. Continuous feeding system of premixed abrasive water jet.

- water tank; 2-motor; 3-high pressure plunger pump; 4-overflow valve; 5-front pressure gauge; 6-abrasive feeding hopper; 7-jet pump; 8-sand switch; 9-translation mechanism; 10-cutting nozzle end pressure gauge; 11-cutting nozzle; 12-sandstone specimen.

Figure 2. Structure diagram of jet pump.

1-jet pump nozzle; 2-suction chamber; 3-throat; 4-diffusion tube; 5-abrasive inlet.

Table 1. A slightly more complex table with a narrow caption

| Front nozzle diameter $d_1$ | Cutting nozzle diameter $d_3$ | Throat diameter $d_2$ | Throat length $L_k$ | Diffusion angle $\beta$ | Diffusion length $L_d$ | Distance between nozzle and throat $L_c$ |
|-----------------------------|-------------------------------|-----------------------|----------------------|------------------------|------------------------|----------------------------------------|
| $d_1$                        | $(1-3) \ d_1$                 | $1.85 \ d_1$          | $12.95 \ d_1$        | $13^\circ$             | $11d_1$                | $1.5 \ d_1$                            |

3. Optimization design of system parameters

3.1. Main factors affecting the performance of continuous feeding and jet

The main factors affecting the performance of the jet pump is a continuous feed mixing chamber negative pressure, the main factors affecting the performance of abrasive jet cutting nozzle. The mixing chamber negative pressure decided entrainment ability and concentration of abrasive abrasive, also under the condition of negative pressure increases, the entrainment of abrasive ability is strong, and abrasive concentration; cutting nozzle and abrasive water nozzle outlet pressure reflecting the cutting speed, which determines the performance of abrasive jet cutting. According to the principle of energy conservation, energy in the entrance of the jet pump, jet pump mixing chamber negative pressure and cutting nozzle outlet pressure relationship exists. Two the interaction with the cutting nozzle and the jet pump nozzle area ratio of $M= (d_3/ d_1)^2$ characterized, there is a optimal area ratio, while the jet pump mixing chamber have a greater negative pressure to ensure cutting nozzle outlet pressure is higher, to achieve continuous efficient abrasive water jet cutting.

In order to study the cutting nozzle and the jet pump nozzle area ratio of $M= (d_3/ d_1)^2$ effects on performance, this paper uses the numerical simulation method, the geometric dimensions of fixed jet
pump constant cutting nozzle diameter by changing different area ratio \(\left(\frac{d_3}{d_1}\right)^2\), and analyzes its influence on the performance of.

3.2. The solid model and calculation method

According to table 1 system structure size considering cutting nozzle diameter range from \(d_1=1.5\) mm, \(d_3=1.5\)–\(4.5\) mm, considering the bucket is connected with the entrance of abrasive abrasive, the diameter of 8 mm, axial distance 15 mm abrasive mouth throat, jet pump diffuser outlet to the cutting nozzle entrance distance of 200 mm, in order to solid modeling, including pipeline, entrance jet pump, a middle pipe, nozzle and cutting nozzle flow field, the establishment and division of flow model were carried out in the pretreatment module of GAMBIT in FLUENT. The system flow model used in this paper is shown in figure 3.

![Figure 3. Jet pump and nozzle model after three-dimensional flow field.](image)

In the solving process, the mixing chamber for annulus river basin, especially in the presence of a variety of three-dimensional direction of mixing chamber internal flow variable region, so the establishment of three-dimensional solid model and mesh, because of the complex internal structure, unstructured tetrahedral mesh selection, is divided into 456802 individual grid.

3.3. Analysis of fluent calculation results

In this paper, the model is simplified as a single numerical calculation, the reason is the negative pressure only needs to solve at the entrance and exit cutting speed and nozzle pressure, without using complicated Euler model, so using the standard k- turbulence model, the pressure and velocity coupling using SIMPLE algorithm, set the boundary condition: Front end and using imported abrasive pressure pressure entrance, 50MPa and 1 respectively. The standard atmospheric pressure, the outlet of the pressure outlet pressure of 1 atm, the wall surface treatment according to the no slip wall, the initialization for internal filled with water and set the incompressible water.

![Figure 4. Variation of negative pressure of abrasive inlet and static pressure of cutting nozzle with area ratio.](image)

When the cutting nozzle diameter (area ratio) gradually increases to a certain extent as the same with the pipe (i.e. assuming cutting nozzle diameter, infinite) inhaled abrasive ratio increased, the back-end energy loss and conversion leads to kinetic energy is greatly reduced, is not used for abrasive
jet cutting, only in material handling, so the continuous water jet system as far as possible selected according to figure 4 variation of the area ratio of less than 5 M for system design.

At 50MPa inlet pressure, at $M=2.77$, the static pressure cloud chart and velocity nephogram of the whole system and the velocity profile at the outside of nozzle exit are shown in figure 5-8.

![Figure 5. System static pressure nephogram](image)

![Figure 6. System velocity nephogram](image)

![Figure 7. Suction chamber static pressure nephogram](image)

![Figure 8. Suction chamber velocity nephogram](image)

From the figure 5-8 shows that this structure has the negative pressure in the suction chamber entrance and annulus, the speed is relatively small, in front of the nozzle to the throat between things turbulent the strongest region, the pressure and velocity change rapidly, after the flow field outside the nozzle can be seen, the speed is less than the speed of the nozzle, and the pipes at a fairly this, and the nozzle structure and energy loss.

The pressure changes along the central axis of the figure 9, in the initial stage of the entrance pressure changes a little, to the nozzle static into dynamic pressure, a sharp decline, negative pressure is generated in the mixing chamber and the maximum negative pressure at the entrance of the abrasive, the throat at the entrance to the throat back diffusion section dynamic pressure into static pressure increasing, finally to cut into the dynamic pressure at the nozzle and then, from the curve can be found, partial loss occurs in the jet pump, and the driving speed of zero abrasive need energy conversion, nearly $3/5$ of the cutting nozzle end pressure can reach the highest original (area ratio=1).

![Figure 9. The static pressure variation along the axis](image)
4. Two-phase flow coupling analysis of FLUENT-EDEM

The basic idea of CFD-DEM coupling method is: through the CFD technology to solve the flow field, use the DEM method to calculate the particle system motion force, two transmission quality, momentum and energy in a certain model, realize coupling.

4.1. Two-phase flow coupling analysis of FLUENT-EDEM

As shown in figure 10, the abrasive particles are set to ball type, and the radius of abrasive particles is 0.425mm according to the diameter of the system and the cutting nozzle.

![Particle model diagram](image)

Figure 10. Particle model diagram.

The particle poisson ratio is 0.3, the shear modulus is 2.3e7, the density is 2678kg/m³, and the particle material is recovered coefficient 0.1, coefficient of static friction 0.545, coefficient of rolling friction 0.01.

4.2. Simulation results

Select a single abrasive particle, such as the red abrasive in figure 11-12, and draw the speed Trace diagram of the motion in the whole system, as shown in figure 13-14. The abrasive enters the mixing chamber, moves irregularly in the mixing chamber, and the vacuum rolls are drawn into the throat, through the diffusion tube, and finally ejected in the cutting nozzle.

![Figure 11. The abrasive particle distribution (a)](image)

![Figure 12. The abrasive particle distribution (b)](image)
In figure 15, abrasive abrasive particles from the entrance into the mixing chamber, the irregular movement in the mixing chamber into the throat, the first large accelerated into the diffusion tube, with the flow deceleration in the tube, and finally through the nozzle cutting speed, abrasive particle speed of 129m/s (cutting flow center nozzle exit velocity 158mm/s) the abrasive acceleration efficiency reached 82%, much higher than the post mixed abrasive jet.

5. Conclusions
Simulation of abrasive entrance and a mixing chamber, pipes, cutting nozzle flow field data using FLUENT software, with area ratio M change, the abrasive cutting nozzle end pressure and entrance into contradiction, the curve of intersection of M=5 is the key point of abrasive jet and material handling division.

The results show that the abrasive abrasive particles from the entrance into the mixing chamber, the irregular movement in the mixing chamber after entering the throat first big acceleration into the diffusion tube, with the flow deceleration deceleration in the tube, and finally through the nozzle cutting speed, cutting the nozzle abrasive particle speed of 129m/s (cutting flow center nozzle exit velocity 158m/s) abrasive acceleration efficiency reached 82%, much higher than the post mixed abrasive jet.

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