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Influence of Nozzle Grid Precision in Abrasive Water Jet Numerical Simulation

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Abstract –The accuracy of grid was one of the sources of error between numerical computation and experimental values. The result of numerical computation was close to the experimental result as the grid number is controlled within a certain range. Four different accuracy grids were compared in this paper based on the grid quality inspection parameters. Low accuracy grid cannot assure calculation accuracy and high accuracy reduced speed of computer calculation and efficiency of solving problem. The relatively optimal accuracy was chose through comparison based on the grid quality inspection parameters. From the simulation result, differences were shown between high accuracy and low accuracy. The third grid that has small deviation was considered to be the best choice during simulation process.

Keywords –Abrasive water jet; nozzle; grid; simulation

1. Introduction

Abrasive water jet technology is a kind of non-conventional technology which had been widely used in many areas, such as mining, washing, cutting, drilling and so on.

For Abrasive water jet(AWJ) equipment that pressure being 30MPa and diameter of pipe being 10mm, Reynolds number of liquid-solid two phase flow is among 104-106, therefore, the flow of it belongs to turbulent flow. Because turbulent flow is instantaneous, optional and so on, so far the study of turbulent flow has been restricted in the level of certain hypothesis inference and empirical formula to calculation, which brings many difficulties to researching on abrasive water jet liquid-solid two-phase flow. The appearance of Numerical simulation method promotes hugely the study of turbulent flow.

The partial differential equations of turbulent flow is difficult to solve and is inconvenient to the study of fluid motion law, but the numerical simulation method, to a certain extent, solves this problem.

By discrete partial differential equations and selecting appropriate algorithm to calculate the numerical solution in the turbulent flow field, the motion law of fluid can be showed directly through the numerical way. This method in many fields has been verified by experiments and it is held that it is an important way to study turbulent flow [1-4].

2. Simulation process of AWJ

2.1. Establishing the physical and mathematical model

Calculation of non-compressible liquid-solid two-phase flow adopts the following basic hypothesis:

(1)Liquid phase is continuous medium, solid phase particles are used as pseudo-fluid and liquid-solid two phase has continuous velocity, pressure distribution and the transport of equivalence in space;

(2)The abrasive particles are rigid smooth balls which have the same diameter;

(3) liquid-solid two-phase temperature remained unchanged and there is no heat exchange with the outside world.

2.2. Model configuration

We simplify the structure of pipe and the nozzle and build a numerical simulation model of the nozzle and the jet flow field. Its profile is shown in Fig.1.

This figure shows process that the liquid-solid two-phase flows into the nozzle chamber, accelerates through cavity shrinkage segment and enter into the jet flow field from jet nozzle cavity in the form of AWJ.

The radius of nozzle entrance is 12mm.The radius of nozzle export is 3.4mm, The convergence angle of cone is 120 °, the length of cylinder is 10mm.The particle density of Liquid-solid two-phase flow is 0.18 and the particle size is 177μm, two-phase mix uniformly at the nozzle entrance. Entrance is speed entrance while exit is pressure outlet.

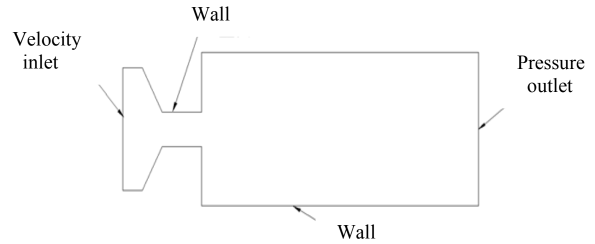


Fig 1. Nozzle configuration

2.3. Boundary conditions

The inlet velocity

$$u = 2m/s, \quad k = 0.1u^2,$$

$$\varepsilon = \frac{k^{3/2}}{0.05d}, \quad \left.\frac{\partial u}{\partial n}\right|_{out} = 0,$$

$$\left.\frac{\partial p}{\partial n}\right|_{out} = 0, \quad p_{out} = p_{ref} = 0,$$

$$\left.\frac{\partial k}{\partial n}\right|_{out} = 0, \quad \left.\frac{\partial \varepsilon}{\partial n}\right|_{out} = 0.$$

3. Plotting grid

Grid is generally divided into the structured grid and the unstructured grid. The Finite volume method (FVM) is that the computational region is divided into grids which do not overlap each other, and then determine the geometry location of the unknown physical quantity which should be computed in the grid. This grid whose nodes are arranged orderly is structured grid, character of which is that geometry arrangement is regular. Apparently, the unstructured grid is not regular and generation process is complex.

However, these kind of unstructured grids are popular extensively in recent years, and this attributes to the unstructured grid being strong in adaptability. So it shows great superiority for geometries with complex boundary calculation. The model of this paper adopts the unstructured grid, as shown in Fig.2.

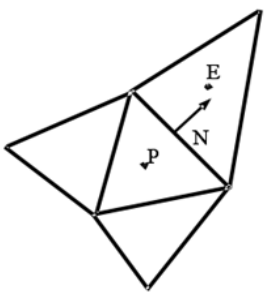
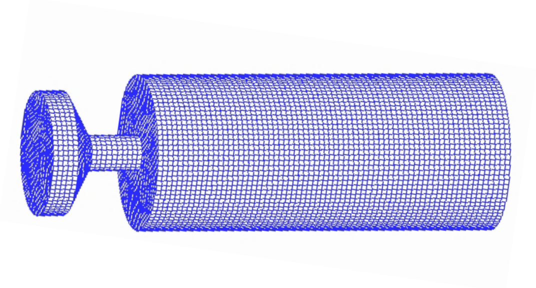


Fig 2. Two dimension unstructured grid

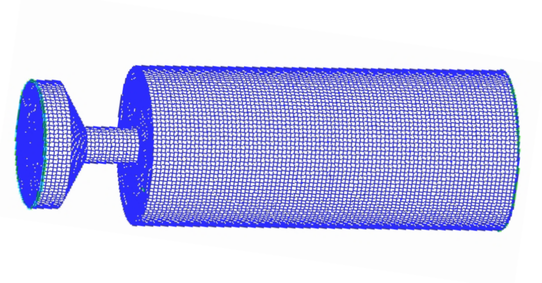
The accuracy of model affects heavily the process of numerical simulation. Low accuracy cannot assure calculation accuracy and its outcome has a great difference with the fact. High accuracy can affect the speed of computer and reduce efficiency of solving problem.

In order to assure the quality of grid generation, which would have a great impact on the result of calculation, we adopt A, B, C, D, 4 levels to generate grid and test it. The four different accuracy grids A, B, C, Dincrease gradually. The accuracy of grid A is the lowest and the unit of grid is big whose volume can reach 3.1mm3.Contrary, the accuracy of grid D is the highest and unit of grid is small whose volume is only 0.125mm3,while,for B and C the volume are 1.6mm^3 and 0.5mm^3 respectively.

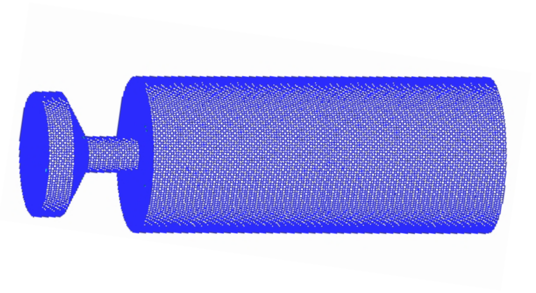
Finally we finish grid generation. The result is shown in Fig.3.



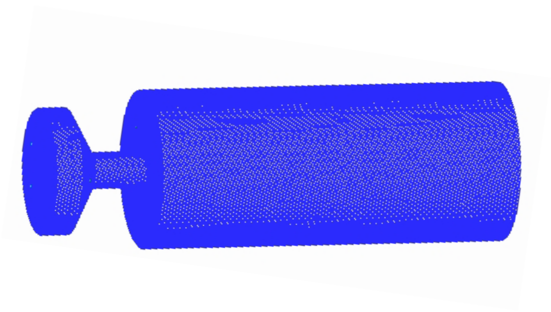
A



B



C

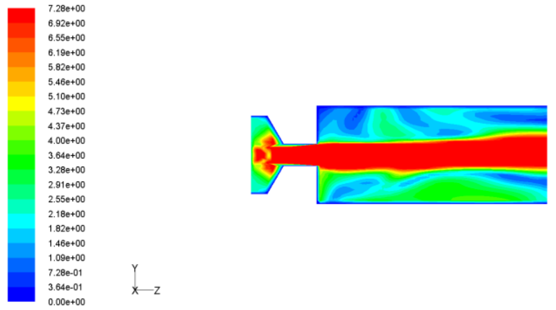


D

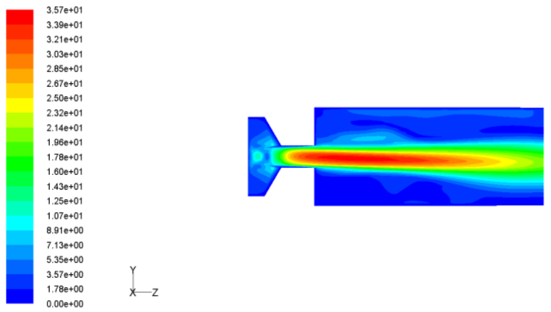
Fig 3. Comparison of different accuracy grid plotting

4. Simulation results comparison

As the meshes number of grid D are too many, which will decrease the computer running speed and calculation efficiency, so we use grid A, B and C for simulation.



A



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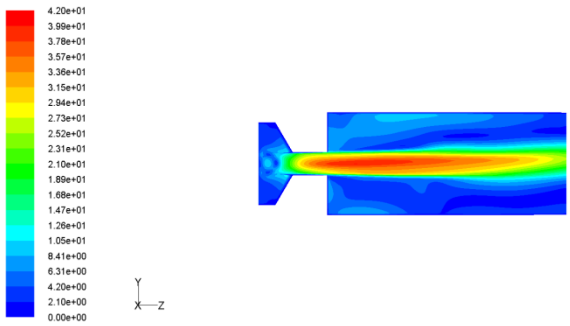
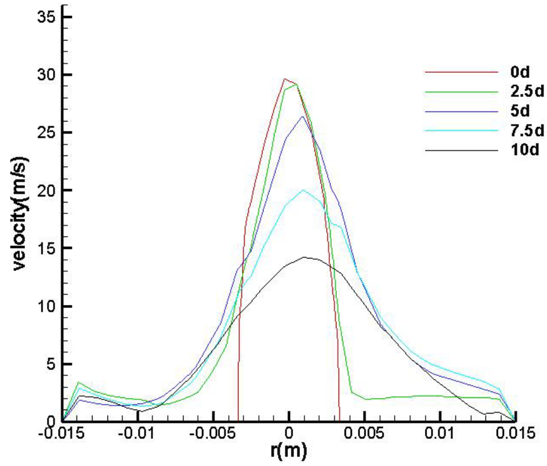
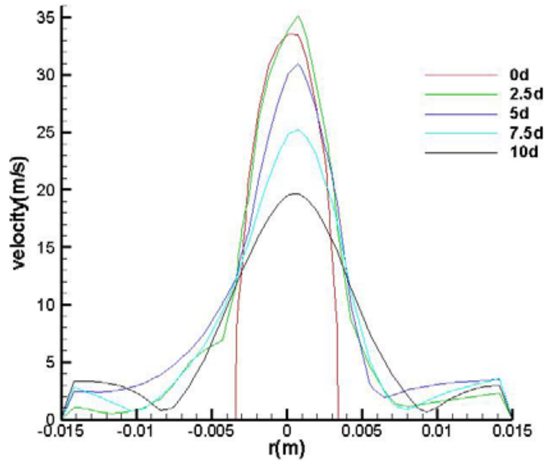


C

Fig.4 Comparison of velocity distribution of different precision grid



A



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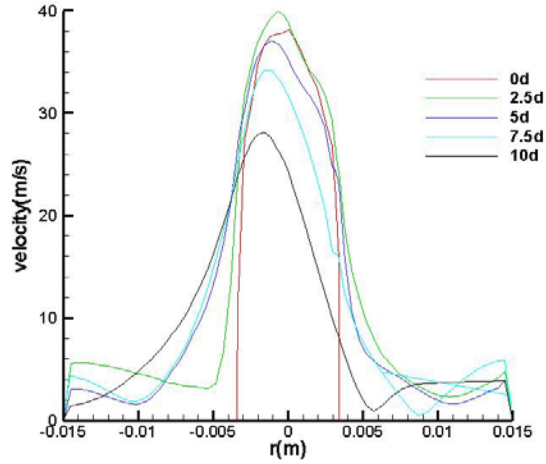

C

Fig 5. Radial velocity comparison in different precision grid

5. Discussion

As we can see from figure Fig.4, the velocity magnitude in the area of grid A are evidently higher than that of B and C, especially in the convergent section of the nozzle and jet flow area. The velocity distribution in grid B is close to that in grid C， in which the jet flow is stable. The velocity magnitude in grid C is slightly higher than B.

Fig.5 shows radial velocity comparison of numerical simulation results of different precision grid A, B and C.

We choose five cross-sections 0d, 2.5D, 5D, 7.5d, 10d in the nozzle outlet region to compare the velocity magnitude, where d represents nozzle diameter. The speed change trends are consistent to that in Fig.3.In the radial direction, with the increase of jet spray distance the velocity magnitude decreases. The curve in the abscissa direction widened gradually, the distribution region of the jet flow in the radial direction are expanded.
Comparing data in Fig.3 and Fig.4 with experimental data, calculation results of the grid A have great difference with experiment data. And the results of grid C are relative close to experimental data. Grid C is more accurate to be used in numerical simulation.

6. Conclusion

In this paper, the quality of grid was considered to have great influence on simulation results. The accuracy of grid was one of the sources of error between numerical computation and experimental values. The result of numerical computation was close to the experimental result as the grid number is controlled within a certain range. Based on the grid quality inspection parameters, this paper compared four different accuracy grids. The analysis of findings led to the following conclusions.

(1)The grid quality has great influence on calculation accuracy of model and the calculation time. Low accuracy caused big error and high accuracy led to large amounts of data for computer calculation and reduces efficiency.

(2)The grid A made grid quality bad, simulation accuracy low and simulation result inaccurate.

(3) The grid D will lower the numerical calculation speed.

(4)The numerical value of grid B and C are close, and they can basically meet the demand of grid quality. The value of grid C with high performance doesn’t have much impact on calculation speed.

(5)Comparison of four accuracy grid velocity along axis and radial direction led to the conclusion that the velocity magnitude in the area of grid A are evidently higher than that of B and C, The velocity magnitude in grid C is slightly higher than B. In the 0d, 2.5d, 5d, 7.5d, 10d cross-sections, the velocity magnitude decreases along the axis direction, the distribution region of the jet flow in the radial direction are widened gradually.

(6)According to the comparison between numerical simulation results and experimental data, the calculated results of grid A are quite different with experimental data. The simulation results of grid C and are close to experimental data, which are appropriate for numerical simulation.

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