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Numerical Study on the Spray Performance of the Nozzle Used for Sludge Drying

Yongkang HAO, Shubing TIAN, Baoling ZHANG, Fuyao WANG, Peikun LIU, Xiaoyu LI[1]
College of Mechanical & Electronic Engineering, Shandong University of Science and Technology, Qingdao 266590, China.

Abstract. Reducing the particle size of sludge is beneficial to improve the drying efficiency. In this paper, the spray method was introduced to the sludge drying process, and a new type of jet nozzle for sludge spray drying was designed. The effect of the structure parameters of the nozzle on the spray field at the nozzle outlet was discussed by numerical simulation. The crushing and drying effects of the sludge were improved by optimizing and improving the nozzle spray field. The results show that the pressure inside the nozzle and cylinder decreases with the increase of spray angle. The larger the spray angle, the smaller the maximum speed of air ejection from the nozzle and the wider the ejection width. The research results can provide theoretical support for the optimization design of the sludge spray drying process and have certain engineering significance and practical value.

Keywords: sludge drying, spray nozzle, numerical simulation

1. Introduction

With the rapid development of national economy and advance of the urbanization process, the output of waste such as sludge also grows at a staggering rate. At present, the sludge treatment in China is still in its infancy. As is known that sludge drying technology is an important and efficient sludge treatment method that not only reduces production but also provides conditions for harmless treatment [1-3]. However, there are many problems in sludge drying, such as high energy consumption, low efficiency, and high odor [4-5]. Current studies have shown that the size of sludge particles has a great influence on the drying rate during the drying process. Reducing the size of sludge particles can effectively improve the drying efficiency of sludge [6-8]. Spray drying technology, as a technical method for the drying disposal of materials dried after crushing and spraying, has great research and development potential in the drying disposal of sludge [9].

Recently, spray drying technology has been introduced into the field of sludge drying treatment. The sludge fluids were dispersed into small droplets by a jet nozzle, and dried into solid products. It shows high efficiency and facile operation [10]. Some research has shown that the spray process of the sludge was the continuous cutting and shearing of sludge fluids. With the increase of air velocity, the spray angle increases. It makes the filamentous decomposition of sludge more uniform, which means a better

[1] Corresponding Author: Xiaoyu LI, College of Mechanical & Electronic Engineering, Shandong University of Science and Technology, e-mail address: lixy2018@sdust.edu.cn

spray effect [11]. By comparing the spray characteristics of the single-phase nozzle, double-channel external mixing nozzle, and double-channel internal mixing nozzle, it is concluded that the double-channel external mixing nozzle is the most suitable for sludge spray [12].

The structure parameters of the jet nozzle have a great influence on its spray performance. In this work, the effect of structure parameters on the spray field on the nozzle outlet was discussed by numerical simulation, to guide the design of the jet nozzle.

2. Overview

The working principle of the jet nozzle is shown in Figure 1. The sludge was pumped into the middle pipe of the nozzle, and compressed air was ejected from the annular gap at high speed. When the two phases were contacted at the outlet of the nozzle, the sludge was torn apart into thin lines by the shearing force, which was caused by the large differences in speed between the two fluids. Then, the thin lines of the sludge were split continuously into droplets at the weak connection.

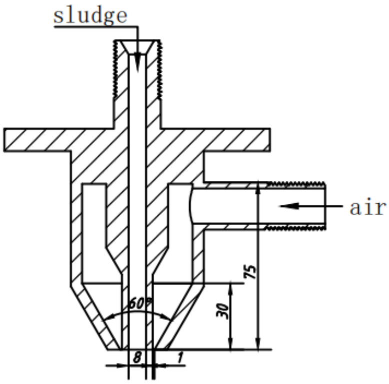


Figure 1. Working principle diagram of jet nozzle

3. Computational methods

3.1. Governing equations

The continuum equation is a concrete expression of the law of conservation of mass in fluid mechanics. It is based on the fluid continuum model. Continuity equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial}{\partial x_j}(\rho u_j)=S_m \tag{1}$$

Where, ρ is the fluid density and u_j is the component of the velocity in the j direction.

The conservation-of-momentum equation is a vector equation. The net force of the fluid on the micro is equal to the rate of change of the momentum of the micro with time. Conservation-of-momentum equation:

$$\frac{\partial(\rho u_i)}{\partial t} + \frac{\partial}{\partial x_j}(\rho u_i u_j) = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}(\mu_t \frac{\partial u_i}{\partial x_j}) + (\rho - \rho_a) g_j \tag{2}$$

3.2. Computational geometry and grid

The structure parameters of the jet nozzle have a great influence on the performance of sludge spraying. To facilitate future selection and use, this paper uses the CFD model to simulate the spray process of droplets in the spray dryer using the airflow nozzle. The physical model of the spray dryer is a cylinder, and the nozzle is placed on the top of the cylinder. A cylinder with a diameter of about 700 mm and a eight of 1000 mm was set as the fluid domain of the nozzle outlets. The diameter of the nozzle sludge inlet is 8 mm, the annular gap is 1 mm, and the height of the air inlet is 30 mm. The nozzle model of 40°, 50°, 60°, 70°, and 80° is established by changing the nozzle angle, and the simulation analysis is carried out.

Considering that the process of sludge spraying into the cylinder through the nozzle is centrally symmetrical and has a strong symmetry, two-dimensional modeling is chosen. While keeping other variables consistent, the nozzle inlet angle is changed, and then the spray angle is changed. Since the lower cylinder is relatively simple and all modeling is the same, only the modeling of the 60° spray angle is shown in Figure 2.

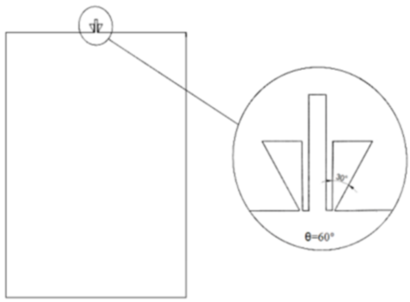


Figure 2. Geometric modeling diagram

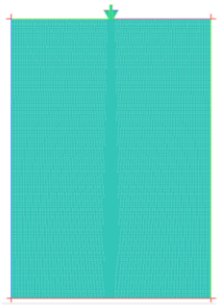


Figure 3. Global meshing of the fluid domain

The fluid domain of the nozzle and its outlet was meshed by ICEM CFD software. According to the geometry characteristics and internal flow field characteristics of the nozzle, tetrahedral mesh is selected for meshing. The maximum size of the mesh is set to 3 during the mesh partitioning process, and the nozzle section is encrypted. Due to the global meshing of the fluid domain is similar, only the 60° spray angle is shown in Figure 3.

The five different angle nozzles each have a grid number of around 90,000. Perform a grid quality check to ensure that there are no negative grids in all grids and that the grid quality is greater than 0.8.

3.3. Simulation model and boundary conditions

The turbulence model theory based on the Reynolds time-mean method is used to calculate the internal flow field of fluid machinery. The Fluent 18.0 software used in this paper uses the finite volume method, the jet nozzle and the inside of the cylinder belong to the turbulent flow field, and the grid is divided by a quadrilateral grid. On the premise of meeting the computational requirements, we choose the k-ε turbulence model with low cost, the QUICK scheme with discretization, and the SIMPLE algorithm with widely used pressure velocity coupling.

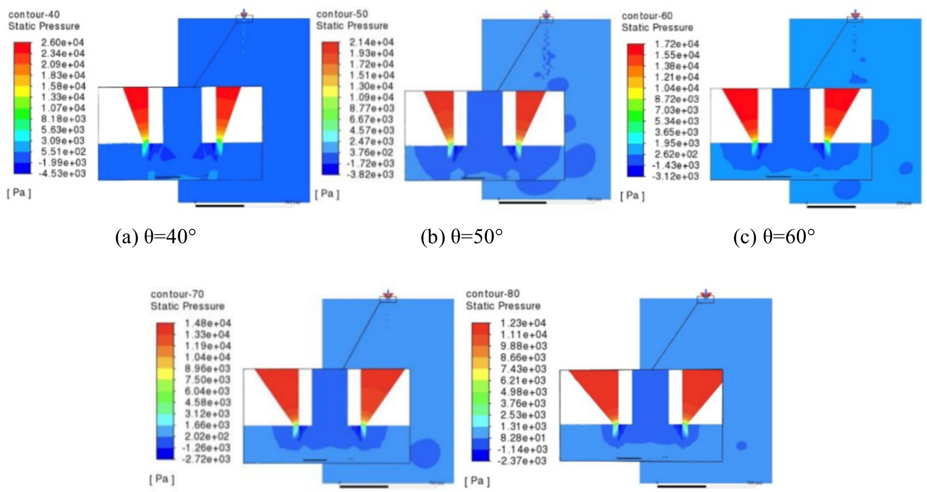
The inlet condition is set to velocity-inlet, and the Velocity direction is set perpendicular to the boundary. The volume flow rate of the compressed air was set as 50 m^3/h. The inlet velocity of the nozzle varies with different spray angles. It can be calculated that the inlet velocity of the nozzle with the spray angles of 40°, 50°, 60°, 70° and 80° is 14.32 m/s, 10.19 m/s, 7.47 m/s, 5.58 m/s and 4.21 m/s, respectively.The inlet pressure and turbulence intensity are set to 8 MPa and 5%, respectively. Considering that an excessive angle may cause the nozzle to spray to the edge of the cylinder, the edge and bottom of the cylinder are set as pressure-outlet. Outlet pressure was set as 0 (atmospheric pressure). Wall conditions use standard wall functions without wall slippage. The fluid in this paper is set to air.

4. Numerical simulation results and analysis

4.1. Selection of characteristic sections

In this paper, two characteristic surfaces are selected for nozzles with different spray angles. Among them, the first characteristic section is the connection between the nozzle outlet and the cylinder(y=-50 mm). The second characteristic section is the lower end of the cylinder 100 mm from the connection between the nozzle and the cylinder(y=-150 mm). The pressure and velocity of the nozzle outlet at different spray angles are analyzed, and the results are as follows:

4.2. Pressure Distribution



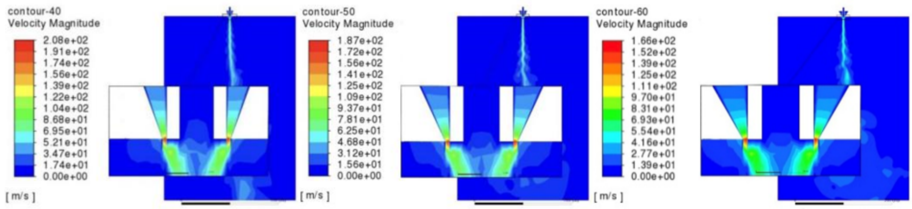
(a) θ=40° (b) θ=50° (c) θ=60°

(d) θ=70° (e) θ=80°

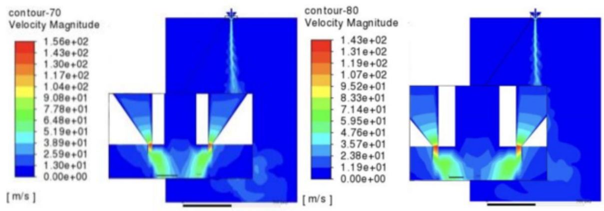
Figure 4. Pressure distributions of the global fluid domain with different nozzles

As shown in Figure 4, although the spray angles are different, the pressure distribution is symmetrical, and the pressure inside the cylinder gradually decreases with the increase of the spray angle. This is because the pressure energy of high-speed air is continuously converted into kinetic energy to maintain the motion state during the movement. It can be calculated that the maximum internal pressure of the nozzle with the spray angles of 40°, 50°, 60°, 70°, and 80° is 26000 Pa, 21400 Pa, 17200 Pa, 14800 Pa, and 12300 Pa, respectively. Although the intake volume is maintained, the inlet speed of the nozzle is different at different angles, which leads to differences in the nozzle pressure.

4.3. Velocity Distribution



(a) θ=40° (b) θ=50° (c) θ=60°



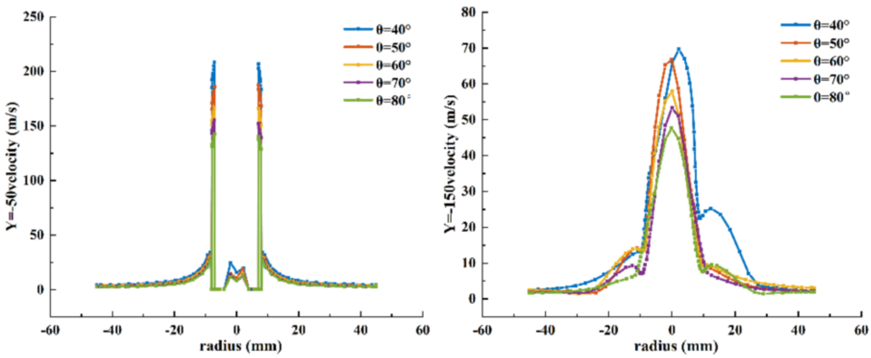
(d) θ=70° (e) θ=80°

Figure 5. Velocity distributions of the global fluid domain with different nozzles

As shown in Figure 5, the distribution of spray velocity is symmetrical like that of pressure distribution. From the nozzle inlet to the nozzle outlet, the speed gradually increases, and then gradually decreases in the cylinder. Inside the cylinder, it is seen that the nozzle emits two velocity streams, which meet at the center. After the nozzle ejects high-speed air, it convects with the cylinder air, so the kinetic energy of high-speed gas is converted into friction to do work. The farther the distance, the more kinetic energy dissipated, and finally completely mixed with the gas in the cylinder. It can be calculated that the maximum speed of air ejecting with the spray angles of 40°, 50°, 60°, 70°, and 80° is 280 m/s, 187 m/s, 166 m/s, 156 m/s, and 143 m/s, respectively. The two streams converge together, and with the increase in spray angle, the width of the nozzle will be larger.

4.4. Velocity distribution on the characteristic surface

Figure 6 shows the velocity distribution of different spray angles on the characteristic surface. With the increase of spray angle, the nozzle exit velocity gradually decreases, which is consistent with our speculation. This is due to maintaining a certain amount of imported air volume, but the different spray angle leads to different setting of the inlet speed, so the smaller the spray angle, the maximum inlet speed, and the maximum speed of air sprayed from the nozzle.



(a) y=-50 mm (b) y=-150 mm

Figure 6. Velocity distribution curve at different sections

5. Conclusions

In this study, the effect of the spray angle of the jet nozzle on the spray field was carried out by numerical simulation. The following conclusions were drawn:

(1) The pressure and flow velocity distribution of the nozzle is symmetrical. From the nozzle inlet to the nozzle outlet, the pressure and speed gradually increase. From the nozzle outlet to the cylinder body, the pressure and speed gradually decrease.

(2) With the increase of spray angle, the internal pressure of the nozzle outlet cylinder decreases gradually, the maximum speed of jet air is smaller and the spray width is wider.

(3) When the spray angle of the jet nozzle is 60°, the pressure stratification is clear, the airflow intersection is intact, and the spray distance meets the requirements. After experimental verification, the jet nozzle with a spray angle of 60° has the best spray effect on the sludge.

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