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Study on Dust Particle Deposition Movement in Pipe of FF System

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Abstract

The Particle deposition position and subside curve equation was studied. Particle depositing Para-curve formula was generated through the dust particle dynamic analysis in the pipe. Settlement nephogram and the trajectory curve of dust particle were obtained by FLUENT numerical simulation. Depositing velocity of particle was simulated and the simulation results, the calculated results and the experimental result were compared and analyzed. The particle motion was reflected by coordinate equation and parabolic curves were drawn for the particle No.65 in the z direction. Various depositing velocities in horizontal rectangle pipe under different particle diameter and flow velocity circumstances were compared to summarize motion patterns.

Keywords*: Particle deposition, Dust particles, Tractive resistance, Numerical Simulation*

1. Introduction

Fabric filter, as a kind of highly efficient particulate collection device, owned the advantages of high collection efficiency, low dust emission concentration after once dust removal, not affected by the specific frictional resistance of dust, more flexible than other devices. It has a broad prospect for development today with increasing emphasis on environmental protection.

The concentration of the smoke, dust particle diameter size and other factors directly affect the life of the bag and pipe inner wall erosion. Practice showed that the dust which particle diameter more than 40μm took main responsibility for the bag's erosion [1-2] and this part of dust particles were removed off when the dust proportion of this part reached more than 5%. So the structure of pipe section was improved in the design of some pipe network in order to reduce dust proportion of large particles.

Therefore, study for the subsidence regularity of dust particles was of great significance.

Computational fluid dynamics (CFD) numerical method, which is becoming more and more popular with the development of modern computer technology, has important guiding significance for the study of the fluid flow [3], heat transfer, radiation and other issues.

Since the movement of the pipe inner dust particles are complex, their motion state cannot be exactly described by the way of numerical calculation and experience derived, but their movement trend curve and Sedimentation velocity rule could be found out by dynamics analysis. Meanwhile we can make use of the calculation method of numerical

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simulation for it not only intuitive and effective, but also prevent the calculation error analysis of the experiment [4].

2. Study of Particle Parabolic Equations

2.1 Equation of Discrete Solid Particles' Motion in Flow Field

The solid particles' motion in flow field was unsteady flow; solid particles were subjected to various forces in the process of movement [5], mainly including inertia force, gravity, Stokes viscous resistance and tractive resistance, added mass force, Basset force, *etc.* The Stokes viscous resistance, Basset force was related to the relative motion of the fluid and particle velocity, this leads to the flow field of dust movement presents a complex condition. In ventilation pipe, only consider the particle inertia force, gravity, and the tractive resistance ignored part of the secondary reaction, so discrete solid particles' motion for Eq.1.

$$\frac{du_F}{dt} = F_D(u - u_F) + \frac{g_x(\rho_F - \rho)}{\rho_F} + \frac{6F_x}{\rho_F \pi d_F^{\ 3}} \tag{1}$$

Where $F_D(u-u_F)$ is mass traction resistance per unit, u for the gas relative velocity, u_F for the particle velocity, μ for the fluid dynamic viscosity , ρ for the gas density , ρ_F for the particle density, d_F for the particle diameter , F_x for the weight of the inertial force in the x direction .

Tractive resistance was related to the velocity of the fluid and particles, when the fluid and particles at the same velocity, tractive resistance was neglected. When the dust particles and fluid into the pipe at the same rate, particles deposit was changed only when the dust particles' movement.

2.2 The Particle Motion Parabolic Equation

With only the effect of gravity considered in the vertical direction, the particle motion in a horizontal tube was regarded as a simple parabolic motion, and then the drag force effects on particle trajectory was to be considered. The drag force which could not be settled in Newton's law directly was a complex quantity. Suppose the drag force was a constant resistance in the horizontal direction [6]. Based on basic parabolic equation, for Eq.2

$$\begin{cases} x = v_0 t + 1/2\, at^2 \\ y = y_0 - 1/2\, gt^2 \end{cases} \tag{2}$$

The function relation between the acceleration and the velocity described as:

$$a = 2(\bar{v} - v_0)/t_0 \tag{3}$$

In the function t_0 was the time from motion beginning to the ending. Only gravity was considered in vertical direction, the t_0 was described as

$$t_0 = \sqrt{2y_0/g} \tag{4}$$

Get the function 3 and 4 into 2, and the coordinate function for Eq.5.

$$y = y_0 - 0.25y_0 \left(\left(-v_0 + \sqrt{v_0^{\ 2} + 4\frac{(\bar{v} - v_0)}{t_0} x} \right) \Big/ \left(\bar{v} - v_0 \right) \right)^2 \tag{5}$$

3. Numerical Simulation and Analysis of Particle Trajectory

3.1 Simulation Model and Boundary Condition

As the former analysis of the particle trajectory equation, only when the velocity difference was not 0, particles would deposit if the dust particles and fluid enter at the same speed. The dust entrance speed was the same as gas velocity in 90-degree elbow to guarantee different speed in outlet pipe. The elbow pipe structure was shown in Figure 1.with 4000mm pipe for entrance pipe and the 8000mm pipe for export.

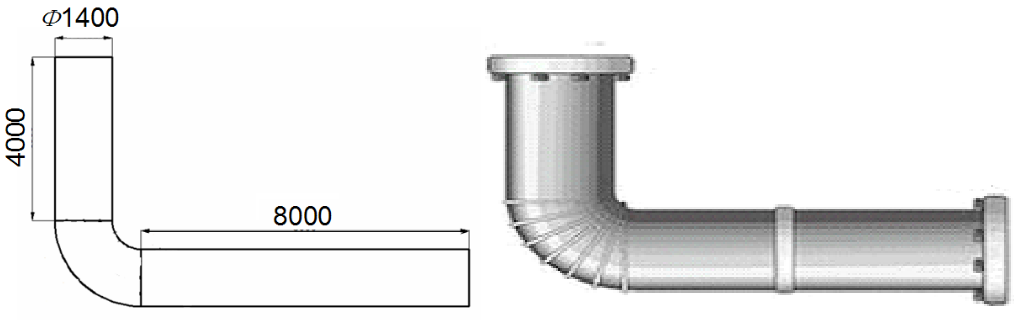

Figure 1. 90-Degree Elbow Pipe Structure

The gas fluid was considered as the continuous phase, and the particle phase with relative motion and unique orbit was the discrete phase. The FLUENT boundary conditions were set as shown in Table.1.

Table 1. 90-Degree Boundary Condition Setting

Inlet mode	Velocity inlet	Turbulence intensity	Pressure outlet	Turbulence model	Particle diameter	DPM setting	Density
Velocity-pressure	18.76m/s	2.59%	-2264.5Pa	Standard k-ε model	0.1mm	reflect	2000kg/m^3

3.2 Simulation Results and Analysis

The contour was shown in Figure 2.

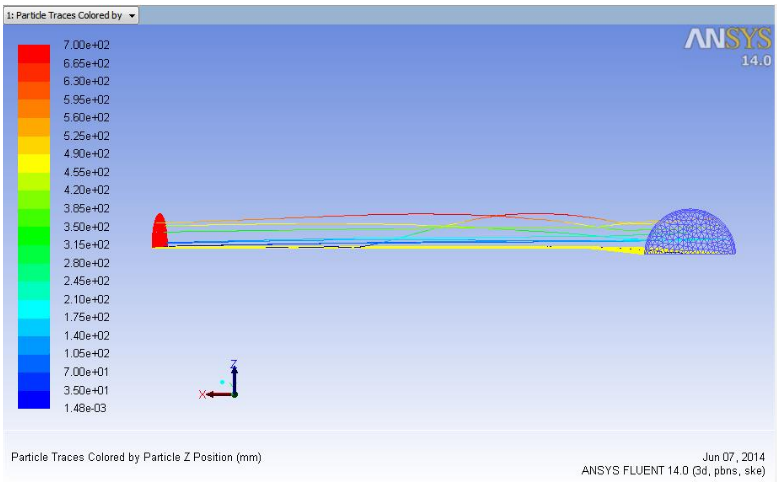

Figure 2. Particle Trajectory Contour

Particle horizontal positions were almost parallel to the symmetry plane in the entrance pipe, while in the elbow export pipe, particles appear depositing trend or even settle down to be subsidence. As too many particles with the same motion trend, one of them was selected as observed subject. The No.65 particle was selected, and X axis was the distance along the pipeline, Y axis was particle position coordinate along the diameter direction. The trajectory curve was shown in Figure.3.The particle motion coordinates with the fluid before the elbow. The effect of gravity could be ignored when pipeline distance less than 4 meters, meanwhile particle motion was horizontal, the motion equation for Eq.6.

$$x < 4,\quad y = 0.535 \tag{6}$$

$x \geq 4$, After dust particle passes through the elbow, the effects of drag force expressed more obviously. The inertial range was calculated, $s = 7.3m$.

The depositing time and average velocity of inertial range were described as follows:

$$t_0 = \sqrt{2y_0/g} = 0.33s \qquad \bar{v} = s/t_0 = 22.12m/s \tag{7}$$

Get the two into formula 5, and the relative function between Y and X for Eq.8.

$$y = 0.535 - 0.011847 \times (\sqrt{351.94 + 40.73x} - 18.76)^2,\ x > 4m \tag{8}$$

The drag force was one of the most important factors leading to complex particle motions.

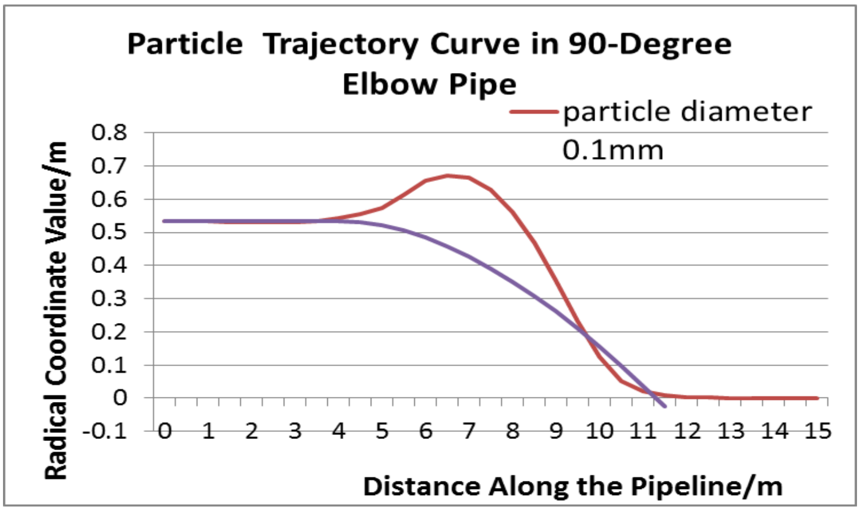

Figure 3. The Trajectory and Parabolic Curves of Particle No.65

4. Analysis of Dust Particle Movement

4.1 Particle Motion Analysis

Dust particle's speed was affected by particle diameter and the wind speed. For the horizontal tube, particle diameter and the dust particle's sedimentation velocity were in accordance with V curve. That means, with the increase of particle diameter, turbulent diffusion and inertial force were the leading effects, so the dust particle's sedimentation velocity would increase. If the dust particle whose diameter was smaller than one micrometer is in the majority, the near wall was most affected by Brown diffusion, so with the increase of particle diameter, the dust particle's sedimentation velocity would decrease. The dust particle from 0.1 micrometer to 1 micrometer would appear the lowest speed [7-8]. So the dust particle from 0.3 micrometer to 0.4 micrometer was most difficult to collect in the filtration technology. Brown motion and turbulent diffusion effect were at their lowest point at the same time. There was the tendency of deposition in the horizontal tube. But once increase the wind speed of the horizontal tube; these dust particles were brought out by the wind before deposited. In order to prove the effect on the dust particle movement brought by particle diameter and the wind speed. The same rectangular pipe was used in the Mark R. Sippola [9-10] particle sedimentation experiment, by means of numerical simulation, research different sedimentation velocity of dust particle with different diameter in different wind speeds of the tube.

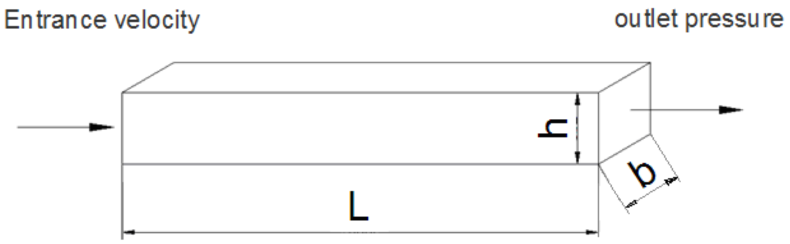

Figure 4.Tthe Size of the Model

4.2 Simulation Research

Matlab numerical model [11] supplied a good fitting effect in solving particle depositing velocity in horizontal pipeline [12]. Comparing the simulation results of depositing velocity with results of calculation model and experimental, these were displayed in Table 2.

Table 2. Comparing the Simulation Results with Calculation Model and Experimental

N0.	Velocity u (m/s)	Particle Diameter /μm	Simulation result (m/s)	Matlab model calculation			Sippola experimental result (m/s)
				Dimensionless depositing velocity V_f^+	Friction velocity U(m/s)	Calculation result (m/s)	
1		1	0.00169	4.25E-04		5.10E-05	1.40E-03
2		3	0.001311	2.51E-03		3.01E-04	5.00E-03
3		5	0.000554	8.40E-03	0.12	1.01E-03	1.40E-02
4	2.2	9	0.002106	1.95E-02		2.34E-03	2.40E-02
5		16	0.010616	6.50E-02		7.80E-03	7.80E-02
6		40	0.075927	—	—	—	—
7		1	1.27E-04	1.90E-04		5.32E-05	8.10E-04
8		3	0.0005033	1.40E-03		3.92E-04	4.70E-03
9		5	0.0012568	6.10E-03	0.28	1.71E-03	2.90E-02
10	5.3	9	0.0038942	1.30E-02		3.64E-03	2.80E-02
11		16	0.0121068	4.80E-02		1.34E-02	1.50E-01
12		40	0.075711	—	—	—	—
13		1	0.000216	1.30E-04		5.85E-05	6.50E-04
14		3	0.000593	1.00E-03		4.50E-04	4.80E-03
15		5	0.001348	8.70E-03	0.45	3.92E-03	2.80E-02
16	9.0	9	0.003987	2.10E-02		9.45E-03	2.20E-02
17		16	0.012237	6.60E-02		2.97E-02	8.60E-02
18		40	0.075927	—	—	—	—

Transform the results to line chart. As is shown follow:

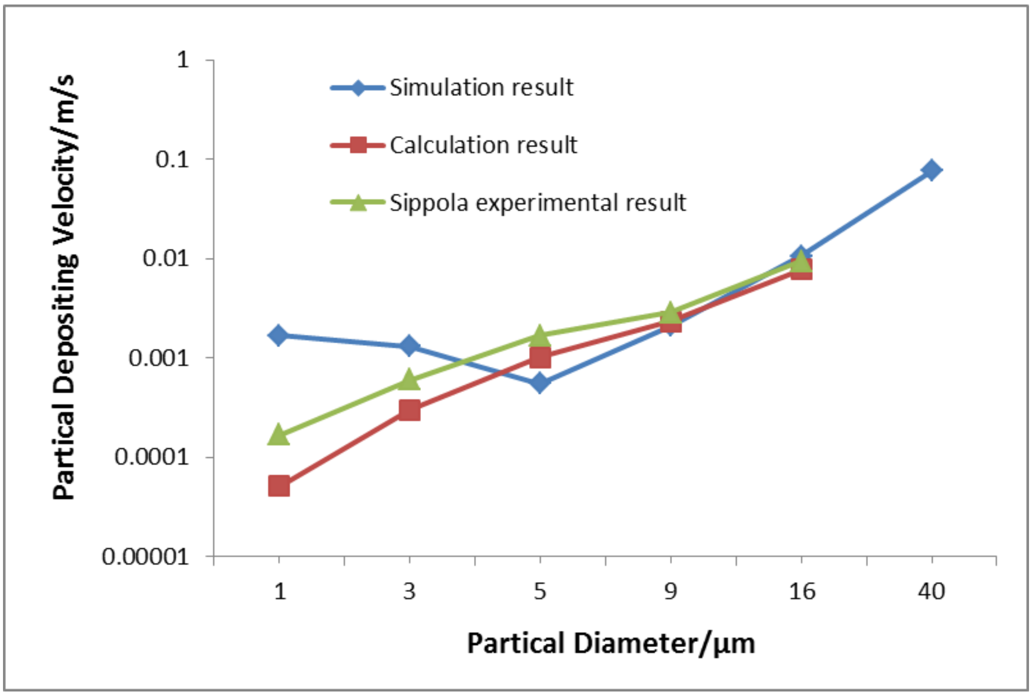

Figure 5. Particle Deposition in Horizontal Rectangle Pipe U=2.2m/S U*=0.12m/S

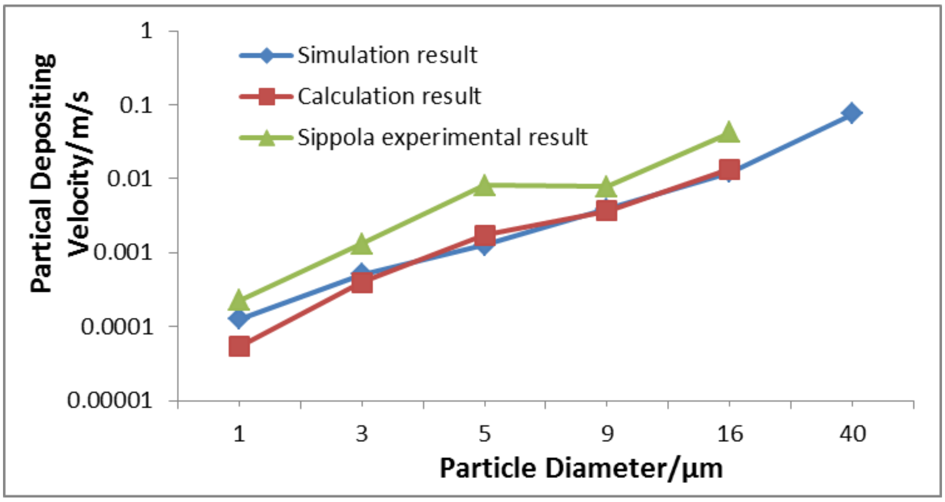

Figure 6. Particle Deposition in Horizontal Rectangle Pipe u=5.3m/s u*=0.28m/s

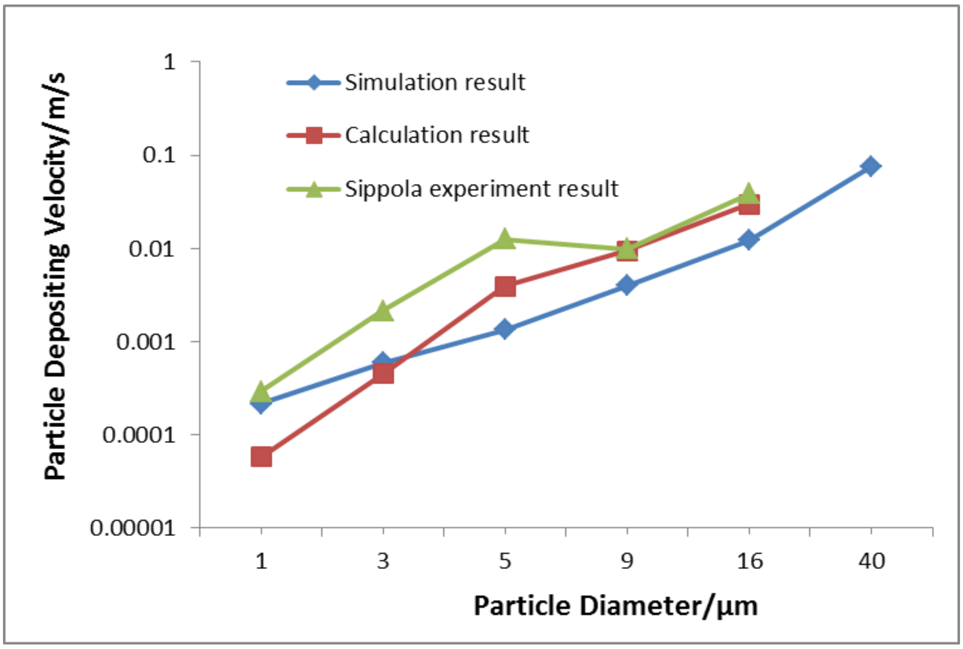

Figure 7. Particle Deposition in Horizontal Rectangle Pipe u=9.0m/s u*=0.45m/s

In the same movement speed, with its diameter increase, its sedimentation velocity increase. But the tendency of dust particle's deposition gradually decreases when the diameter of dust particle increases. The diameter of dust particle was limited in dust palletizing system, turbulent diffusion and inertial force also limited effects on dust particle.

Comparing dust particles in same diameter and different movement speeds, their sedimentation velocities were different. Generally speaking, dust particle's movement speed was greater, their sedimentation velocity is greater. When the speed increases to a certain degree, sedimentation velocity was mainly affected by the influence of particle size.

For dust particles whose diameter was larger than 40 micrometers, the flow velocity in the tube little impact on their sedimentation velocities. So improving dust particle's sedimentation velocity by increasing flow velocity in the tube was not recommended. These dust particles were removed at first by physical methods before they enter the dust-removal system, such as gravity and cyclone dust collector.

5. Conclusion

1. Traction resistance is an important factor causing the particle's complex motion; mathematical formulas under certain conditions were worked out.

2. Considering only the effect of gravity, to solve the parabolic equation of the dust particles that moving in the horizontal tube, the function relationship between the movement Y and X of the dust particles were found out.

3. Dust particles in same diameter and different movement speeds, their sedimentation velocities were different. If dust particle's movement speed was greater, their sedimentation velocity was greater. When the speed increases to a certain degree, sedimentation velocity was mainly affected by the influence of particle size.

4. For dust particles these diameter is larger than 40 micrometers, the flow velocity in the tube has little impact on their sedimentation velocities. So improving dust particle's sedimentation velocity by increasing flow velocity in the tube is not recommended. Suggest using physical methods remove them at first.

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