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Numerical Study on Particle Suction Performance of Reverse Blowing Pickup Mouth

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Abstract. The particle suction performance of reverse blowing pickup mouth is studied by Computational Fluid Dynamics (CFD). The inhalation test of dust particle and large particle were studied by simulation, and a theoretical arithmetic design discipline was put forward. The result shows that theoretical arithmetic can be used as a preliminary selection guide. The front inlet means velocity increases with the increasing of the diameter-length aspect ratio (iDL). While the Outlet mean velocity and the pressure decrease with the increase of iDL. The front inlet mean velocity from 48.5m/s down to 40.2m/s when iDL is from 0.11 to 0.16. The shorter the residence time is, the large particle can be inhaled easier. The residence time is 1.83s, which is 0.29s shorter than 2.12s in the same position of the 160mm diameter when the brick is on the left side of the driving direction. While the residence time is 1.13s, which is 0.19s shorter than that of 1.32s in the same position of 160mm diameter when the brick is in front of the Outlet.

1. Introduction

Road sweeping by manpower is inefficient. Sweeper, a critical cleaning road sweeper product, is widely used to remove the dust accumulation [1]. Chen et al. [2] found that dust collection performance can be improved by adding wing plates. Tan et al. [3] designed the Y-type pickup mouth with the rear airflow, which made the swirl gas flow inside strong obviously. A large number of pickup mouth studies have been carried out in recent years at home and abroad [4-6]. A few studies focus on reverse blowing pickup mouth that is used in China. As a result, the calculation and analysis on particle suction performance of reverse blowing pickup mouth are performed based on the gas-solid coupled numerical method. The reverse blowing pickup mouth is modelled and simulated by using CFD technology. The simulation results were analysed and the optimum Outlet diameter was finally given, which provides theoretical support for the design.

2. Geometry and grid

2.1. Physical modelling and parameter selection

Schematic diagram of reverse blowing pickup mouth is showed in Figure 1. Particles are suctioned under the airflow sweeping at the Inlet. All the particles will enter the garbage collection through the Outlet.
So, the Outlet, as a core component of the reverse blowing pickup mouth, determines the effect of particle inhalation. And the constants used in this model are Length=1400mm, Width=480mm and Height=130mm.

![Figure 1. Schematic diagram of reverse blowing pickup mouth](image1)

2.2. Grid generation and independence
Then unstructured mesh methods are used to mesh the computational domain in the ICEM because of the complex construction. Boundary layer mesh needs encryption. The computational domain mesh is shown in Figure 2. The inlet velocity around the reverse blowing pickup mouth is hard to test. With expansion area around can avoid this problem. Different methods of mesh generation grids are tested to find the best methods and grid number. It is also for the sake of higher accuracy and efficiency of the calculation. Finally, 170 thousand grids are employed.

![Figure 2. Computational domain mesh model](image2)

2.3. Boundary conditions
The moving and static wall were applied to the pickup mouth shells. Pressure out and velocity inlet were applied to the Outlet and Inlet, respect. The turbulence effects were modelled by $k-\varepsilon$ model [7,8]. SIMPLE method, and second-order upwind interpolation scheme were chosen for pressure–velocity coupling during the calculation. Gas-solid coupled numerical method was adopted by DPM and the size distribution was also set as the Ref. [5].

3. Theoretical arithmetic
The rate of Outlet flow is fixed after stable operation of centrifugal blower. Symbol $S$, the Outlet circular area of the reverse blowing pickup mouth, defined as follows:
\[ S = \frac{Q}{3600V} \]  

(1)

Where \( Q \) is the rate of Outlet flow. \( V \) is the average velocity of the Outlet. In general, the velocity design of the Outlet is from 20 to 60 m/s, and the velocity of dust particles can be lower. While the velocity of large particle, such as stones, must meet the free suspension speed of large particles.

According to Zhou calculation [9], the free suspension velocity of spherical object can be known. The suspension velocities of spheres in different fluid regions are different. This area is the pressure differential resistance zone because of the inhalation of the large size particles. The Reynolds number is from 500 to \( 2 \times 10^5 \). The symbol \( V_0 \), the free suspension velocity of a spherical object, defined as follows:

\[ V_0 = 5.45 \sqrt{\frac{d_s(\rho_s - \rho)}{\rho}} \]  

(2)

Where \( V_0 \) is the free suspension velocity of sphere. \( d_s \) are the sphere geometry, such as it is diameter if the object is a sphere. \( \rho_s \) is the object density, and \( \rho \) is the airflow density.

The density of large particle is shown in Table 1. According to the industry standard of road sweeping vehicle, the equivalent diameter of particles absorbed by road sweeper should not be less than 30mm [10]. Therefore, the free suspension velocity of the sphere can be calculated based on the particle size and the density of various spheres by formula (2). The free suspension velocity of red brick is 36.17 m / s, the free suspension velocity of granite is 46.53 m / s, the free suspension velocity of glass is 42.63 m / s, the free suspension velocity of wood is 20 m/s.

| Category | Brick | Granite | Glass | Wood |
|----------|-------|---------|-------|------|
| Density(Kg/m³) | 1800 | 2978 | 2500 | 600 |  

The pressure difference of reverse blowing pickup mouth is constant because the negative pressure of Outlet is -2300Pa and the pressure value of expansion region is standard atmospheric pressure [11, 12]. The suction flow is direct proportion to the diameter of the Outlet according to formula (3), which means that the larger the diameter is, the more air flow intakes.

\[ Q = \mu A \left(\frac{2P}{\rho}\right) \]  

(3)

Where \( Q \) is the rate of Outlet flow. \( \mu \) is discharge coefficient and \( \mu \) is 0.6 in this paper. \( A \) is sectional area. \( P \) is differential pressure. \( \rho \) is the airflow density.

4. Influence of dust removal performance

4.1. Diameter-length aspect ratio

Front inlet mean velocity, Outlet mean velocity and pressure were selected to evaluate the effects [12]. The effects of diameter-length aspect ratio on simulation results is shown in Figure 3. The front inlet means velocity increases with the increasing of the Outlet diameter. While the Outlet mean velocity and the pressure decrease with the increase of iDL. The front inlet mean velocity from 48.5m/s down to 40.2m/s when iDL is from 0.11 to 0.16. The reason for the above phenomenon lies in the fact that the
inlet area increases with the increase of the diameter, and the power of the dust suction increases, which results in the increase of the mean velocity of front inlet due to the constant pressure at the Outlet. However, the increasing flow rate of the Outlet is smaller than that of the cross-section area, so the mean velocity decreases. The increase of the diameter reduces the distance between the Outlet and the front baffle, and it also make the loss along the side descend. The inlet is affected by the Outlet pressure obviously and approaches the pressure of exit gradually, so the mean pressure is reduced.

4.2. Dust particle

The dust size distribution mentioned in Ref. [5] was employed. Velocity and trajectory at different Outlet diameter are shown in Figure 4. It can be seen from the diagram that the particles are blown to the suction end and inhaled under the negative pressure of the Outlet. The particles velocity in 160mm diameter is lower than with 200mm diameter. Therefore, the omission of particulate matter in the right front is serious. It was found that the particle velocity around the Outlet was higher, which indicated that the particles were obviously affected by negative pressure under the action of the larger diameter. The Outlet has higher dust suction power and makes the particles have higher kinetic energy, which is easy to be inhaled into the reverse blowing pickup mouth.

Figure 3. Effects of diameter-length aspect ratio on simulation results

Figure 4. Velocity and trajectory at different Outlet diameter

(a)Particle velocity, D=160mm             (b)Particle velocity , D=200mm
4.3. Larger particle

The equivalent diameter of the object must be not less than 30mm according to the industry standard QC / T 51-2006 [8]. Bricks and tiles are common large particles on the road. Therefore, the brick with 30mm diameter and 1800 kg / m$^3$ density were used to verify the gas-solid coupling calculation. The suction of the weakest and strongest position was chosen in order to calculate the residence time in the reverse blowing pickup mouth, respectively. The residence time and trajectory at different positions are shown in Figure 4.

![Figure 4](image)

(a) Leftmost direction
(b) In front of the Outlet

**Figure 4.** D=160mm, ds=30mm. Residence time and trajectory at different positions

It can be found that the brick with 30mm diameter can be transported smoothly to the dust removal through the Outlet from the Figure 5. Leftmost position of the driving direction is the weakest place compared to the whole pickup mouth. It took 2.12s for the brick to be sucked in from here (Figure 5. (a)). It also can be seen from the trajectory that the brick that inhaled from the left side impacts on the right wall. The following property of large particle is not as good as small particles with the wind because of the inertia of large particles. The brick is easy to be inhaled into the Outlet and its residence time is 1.32 s because the position is in front of the Outlet (Figure 5. (b)).

![Figure 5](image)

(a) Leftmost direction
(b) In front of the Outlet

**Figure 5.** D=160mm, ds=30mm. Residence time and trajectory at different positions

The Outlet with 200mm diameter takes less time than the 160mm diameter by comparison with Figure 5 and 6. The trajectory of the Outlet with 200mm diameter is simpler and shorter than the smaller diameter when the brick is on the left side of the driving direction. This is because the increase of the diameter shortens the distance from the wall around, and the suction pressure is constant, that is to say, the suction power of the suction nozzle is increased, so the brick with 30mm diameter is more easily inhaled. When the brick is on the left side of the driving direction, its residence time is 1.83 s, which is

![Figure 6](image)

(a) Leftmost direction
(b) In front of the Outlet

**Figure 6.** D=200mm, ds=30mm. Time and trajectory at different positions
0.29 s shorter than 2.12 s in the same position of the 160mm diameter. When the brick is in front of the Outlet, the residence time is 1.13 s, which is 0.19 s shorter than that of 1.32 s in the same position of 160mm diameter. The shortening of the residence time had a good advantage for the inhalation of large particle. It is evident that particle suction performance must be combined with dust leakage, large particle inhalation smoothly and product material cost. An optimal commercial product should take various elements into the comprehensive consideration, so the Outlet diameter is 180mm, which is suggested.

5. Conclusion
The present contribution investigates the influence of Outlet diameter and particles inhalation in reverse blowing pickup mouth, aiming at providing design discipline. A three-dimensional device is computed, which enables the large particles can be inhaled smoothly and product material cost can be saved. Theoretical arithmetic can be used as a preliminary selection guide. The particles velocity in 160mm diameter is lower than with 200mm diameter, and the omission of particulate matter in the right front is serious. The shorter the residence time is, the large particle can be inhaled easier. The front inlet mean velocity from 48.5m/s down to 40.2m/s when $\text{Re}_{DL}$ is from 0.11 to 0.16. The Outlet with 180mm diameter is suggested combing with the model in this paper.

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