Internal Flow Field Uniformity Study of Dust Collector for A Street Vacuum Sweeper Based on CFD

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Abstract. Internal flow field of dust collector for a street vacuum is studied by Computational Fluid Dynamics (CFD). The causes of uneven distribution of flow field were diagnosed by simulation, and an improvement measure was put forward. The result shows that flow rate distribution of dust collector is uneven, the reason for which is the higher wind velocity at the Inlet. A baffle plate was added at the Inlet to improve the uniformity of internal flow field. The main technical parameters, maximum flow rate uneven amplitude and overall flow rate uneven amplitude, are decreased in this way. \( \Delta \tilde{k} \) is reduced from 0.3429 to 0.1308. While \( \Delta \tilde{\lambda} \) is reduced from 0.1012 to 0.0402.

1. Introduction

City sanitation attracts more attention for the past few years. Sweeper is typically practiced to remove the dust accumulation from road surface \[1\]. Li-Ming Lo found higher pleat ratios is effective for particle collection efficiency \[2\]. Some studies used fabric filter bags \[3\] and ceramic filters \[4\] to improve operating conditions of regenerable filtering systems, but fewer studies focus on sweeper dust collector \[5\]. The sweeper dust collector is modeled and simulated by using CFD technology. The simulation results were analyzed and discussed, and the distribution regularities of internal flow field were finally summarized, which provides theoretical support for the design and development for sweeper dust collector.

2. Numerical simulation

2.1. Model and grid generation

Fig1 shows the actual picture of dust collector, geometric model and mesh model. Dusty gas enters from Inlet (the purple in Fig 1 (b)). The cartridges, the green in Fig 1 (b), make dusty gas flow from outside to inside to collect the dust. The filtered air is finally discharged to atmosphere at the Outlet (the red in Fig 1 (b)). Cartridge model was established as cylinder because of complicated pleated structure \[5-6\]. The main size parameters are listed in Table1. Fig1(c) shows the mesh model.
Table 1. The main size parameters.

| Parameter           | Dimensions (mm)                                      |
|---------------------|------------------------------------------------------|
| Geometric Model     | 800×800×1500 (length×width×height)                  |
| Inlet               | 300×230 (length×width)                              |
| Outlet              | 600×250 (length×width)                              |
| Cartridge length    | 660                                                  |
| Cartridge diameter  | 325                                                  |

2.2. Boundary conditions
The flow field can be simplified as a single-phase flow because of particle low concentration [7-9]. SIMPLE method, and second-order upwind interpolation scheme were chosen for pressure–velocity coupling. Inlet surface was treated as the velocity inlet, and its velocity was set as 5.95 m/s based on the KASDA-KV621 hot-wire anemometer measured values. Outlet surface was treated as the pressure out, and its pressure was set as the atmosphere based on connecting to the atmosphere. Porous jump model was used to simulate porous medium of cartridge. The one-dimensional model provides the advantages of robustness and better convergence [10-11], and the static wall was applied to the rest of the dust collector shells. The main Face Permeability is $1.95 \times 10^{-9}$ m$^2$ and Medium Thickness is 1 mm.

3. Parameters of flow field distribution

3.1. Unevenness
Uniformity is evaluated with American RMS standard, and the formula can be expressed as follows:

$$\delta = \left( \frac{1}{n} \sum_{i=1}^{n} \left( \frac{v_i - v_p}{v_p} \right)^2 \right)^{1/2}$$  (1)

Where $v_i$ is the each point velocity, $v_p$ is the cross section average velocity, and $n$ is the amount of points. The uniformity of flow field is qualified when $\delta$ is not more than 0.25 [12].

3.2. Flow rate distribution coefficient
$K_i$ is flow rate distribution coefficient of each cartridge, and the formulas can be expressed as follows:

$$K_i = \frac{Q_i}{Q} \quad (i = 1, 2, 3, \ldots, n)$$  (2)

Where $Q_i$ is the flow rate through a single cartridge, $Q$ is the average flow rate.

3.3. Maximum and overall flow rate uneven amplitude
$\Delta k_i$ is the maximum flow rate uneven amplitude, and $\Delta k_{\bigcirc}$ is overall flow rate uneven amplitude. The formulas can be expressed as follows:
\[ \Delta k_i = k_{i_{\text{max}}} - k_{i_{\text{min}}} = Q^+ - Q^- \]  
\[ \Delta k_s = \frac{1}{N} \sum (|K_i - 1.0|) \]

Where \( k_{i_{\text{max}}} \) is the maximum flow rate distribution coefficient, \( k_{i_{\text{min}}} \) is the minimum flow rate distribution coefficient, \( Q^+ \) and \( Q^- \) are the maximum positive and negative deviation of flow rate distribution, respectively. \( N \) is the amount of cartridges. The smaller the \( \Delta k_i \) is, the better the uniformity of flow field is [7].

4. Modeling verification and analysis

4.1. Numerical modeling verification

Fig 2 shows cartridge number and location of the monitoring points (Row 1 & 3). Cross section \( Z=400 \) and \( Z=600 \) mm were selected. Numerical and experimental results, velocities of 16 monitoring points on Row 1 and Row 3, were compared.

Fig 3 shows the comparison between numerical and experimental values. 4 points are selected because sensors’ position effect the flow field. And maximum relative error of the comparison is 12.8%. The result shows that the simulation precision is high and reliable. The reasons which cause experiment errors are as follows: (1) Porous jump model was used; therefore the flow was treated as isotropic [11]. (2) The sensors position have effects on the internal flow field.

Figures and graphs are not included in thenatural text representation.
4.2. Analysis of the velocity field
As is shown in Fig 4 (a) (b) (c), the “climbing” phenomenon appears because airflow rises along the side walls gradually. This can be explained by the fact that the resistance is smaller between the cartridges and the side walls, and dusty air flows along the direction of smaller resistance. The velocities of filtered air reduce significantly because of the existence of cartridges.

4.3. Analysis of parameters of flow field distribution
According to the equation (1), the unevenness of cross section Z=200, Z=400, and Z=600mm can be obtained. The unevenness of Z-axis Section is shown in Table 2.

| Unevenness Z-axis Section (mm) | Z=200 | Z=400 | Z=600 |
|--------------------------------|-------|-------|-------|
| δ                             | 0.59  | 0.65  | 0.76  |

The distribution of internal flow field is uneven because of δ > 0.25. The reasons for this phenomenon may lie in the fact that the big change of section area when dusty air enters from the Inlet, and dynamic - static pressure converts drastically, which leads to the disorder of local airflow. In order to improve the uniformity of the internal flow field, and service life of the cartridge; therefore the orifice or baffle plate should be added at the Inlet to achieve dynamic - static pressure conversion.

Flow distribution coefficient is shown in Table 3. Flow rate through cartridge 1 and cartridge 2 is larger, while flow rate through cartridge 3 and cartridge 4 is smaller. According to the formulas (3), (4) and (5), the maximum flow uneven amplitude Δk_i is 0.3429, and overall flow uneven amplitude Δk = 0.1012. Neither Q^+ =17.45% nor Q^- =16.84% is in the error range of -15% to 15%. The results show that uniformity of flow field is poor and flow distribution is uneven.

| Flow distribution coefficient of the original model | Cartridge number |
|---------------------------------------------------|------------------|
| iK_i                                              | 1.0278 1.1745 0.9660 0.8316 |

4.4. An improvement measure
Considering interference between the sweeper and the dust collector, the structure of the dust collector should not be changed drastically. In order to reduce the velocities of Inlet, a baffle plate is employed at the Inlet. The final program is determined after several repeated simulations and optimizations. Actual picture of the improvement measure is shown in Fig 5 (a), and Fig 5 (b) shows the partial enlargement of baffle plate.
Flow distribution coefficient of the improved model is shown in Table 4. The maximum flow rate uneven amplitude is 0.1308, and overall flow rate uneven amplitude is 0.0402. Both $Q^+ = 6.63\%$ and $Q^- = -6.45\%$ are in the error range of -15\% to 15\%. The results show that flow rate distribution is even. The intensity of jet flow becomes weaken because of the existence of the baffle plate, the distribution of internal flow field is even, and the erosion of cartridges is prevented.

**Table 4. Flow distribution coefficient of the improvement model.**

| Cartridge number | 1    | 2    | 3    | 4    |
|------------------|------|------|------|------|
| $K_i$            | 0.9841 | 1.0663 | 0.9355 | 1.0141 |

5. Conclusion

(1) The maximum flow rate uneven amplitude $\Delta k_i$ is 0.3429, and overall flow rate uneven amplitude is $\Delta k_z = 0.1012$. Neither $Q^+ = 17.45\%$ nor $Q^- = -16.84\%$ is in the error range of -15\% to 15\%. So the uniformity of flow field is poor and flow rate distribution is uneven.

(2) The main technical parameters are $\Delta k_i = 0.1308$, $\Delta k_z = 0.0402$, $Q^+ = 6.63\%$, and $Q^- = -6.45\%$ after adding a baffle plate at the Inlet. The improvement measure makes the flow filed more uniform without changing the structure drastically, which is economical and practical.
6. Acknowledgments

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7. References

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