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Analysis and Study on Performance of a New Integrated Dust Precipitator

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Abstract. The dust precipitator is integrated with cyclone and bag filter, With the aid of a mathematical model this paper proposed. the flow characteristics of dust-gas inside the new dust precipitator is studied. It is concluded that the new integrated dust precipitator combines the advantages of the cyclone and bag filter, avoids the violent fluctuation to bags when working, and raises the filtrating efficiency.

Introduction

The dust precipitator is used to separate and collect dust from dust-gas flow. It's the key equipment for a dust removal system. There are many types of precipitators used in industry. The cyclone, which is one of the most widely used equipment, has no moving parts inside [1]. But with the help of the dust-gas flow centrifugal force, only some bigger solid granules maybe separated from the dust-gas. Cyclone is often used as the first step equipment in the dust removal system. Bag filter separates the dust from the dust-gas by using organic fiber or inorganic fiber as filter bags. Bag filter is suitable as the second step equipment in the dust removal system, especially has comparative advantages for removing small solid particles. A new type of dust precipitator, integrating the two equipments, is put forward in this paper. The new dust precipitator not only simplifies the dust removal system, but also saves installed space, raises the filtrating efficiency.

1 The structure and working principle

The new dust precipitator consists of cyclone unit and filtrating bag unit. The structure sketch is shown in Figure 1. The cyclone unit includes dust-gas inlet, external cyclone shell, internal cyclone shell and ash outlet. The filtrating bag unit includes clean gas outlet, compressed gas tank, electromagnetic pulse valve, filter bag, bag framework, perforated plate, casing of filter and pulse control instrument. The two units are directly connected up and down with bolts in its entirety. Dust-gas goes through the dust gas inlet into the cyclone unit firstly. Inside the unit, some bigger solid granules are separated from the dust-gas. Then the gas enters to the filtrating bag unit, through the bags' filtrating effect, the residual solid granules are separated from the gas. After the two filtrating process, the much more clean gas vents to the gas outlet. And the ash discharges through the ash valve. Thus, one set of this new dust precipitator may achieve two steps of dust removal, and instead of two dust removal equipments such as one set of cyclone and one set of bag filter.

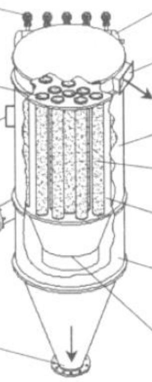

Figure1. The structure sketch about the new dust precipitator

2 The numerical simulation

2.1 The establishment of mathematical model

The dust gas inlet diameter of the new dust precipitator is d=0.14 m, the velocity is u=12 m/s. If the ambient temperature is 20 ℃ , the gas dynamic viscosity is μ_g=17.9×10-6 Pa·s, the density is ρ_g=1.205 kg/m^3. So, the Reynolds number of the flow field inside the new dust precipitator is

$$\mathrm{Re} = \rho_g ud / \mu_g = 1.205\times 12\times 0.14/(17.9\times 10^{-6}) = 113095 > 12000 \quad (1)$$

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According to the calculation result, the conclusion is known that the state of the flow field being located next to the gas flow inlet of the new dust precipitator is turbulent. As RSM model reflects the characteristic of the turbulence anisotropy, and has been widely used to simulate the gas-solid two-phase flow inside the conventional filters and achieved similar result compared with the actual state [2]. Furthermore, when the new dust precipitator works, three-dimensional strong rotary flow will comes into being inside it, and has the obvious characteristic of the turbulence anisotropy. So, if the whole flow can be regarded as unsteady compressible, the new dust precipitator may be simulated and calculated with RSM model according to the hydromechanics software Fluent [3]. The control equations are as follows.

Continuity equation:

$$div\overline{V} = 0 \tag{2}$$

Momentum equation:

$$\frac{\partial \bar{u}}{\partial t} + \mathrm{div}(\overline{u}\overline{V}) = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial x} + v\mathrm{div}(\mathrm{grad}\bar{u}) - [\frac{\partial \overline{u'^2}}{\partial x} + \frac{\partial \overline{u'v'}}{\partial y} + \frac{\partial \overline{u'w'}}{\partial z}] \tag{3}$$

$$\frac{\partial \bar{v}}{\partial t} + \mathrm{div}(\overline{v}\overline{V}) = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial y} + v\mathrm{div}(\mathrm{grad}\bar{v}) - [\frac{\partial \overline{u'v'}}{\partial x} + \frac{\partial \overline{v'^2}}{\partial y} + \frac{\partial \overline{v'w'}}{\partial z}] \tag{4}$$

$$\frac{\partial \bar{w}}{\partial t} + \mathrm{div}(\overline{w}\overline{V}) = -\frac{1}{\rho}\frac{\partial \bar{p}}{\partial z} + v\mathrm{div}(\mathrm{grad}\bar{w}) - [\frac{\partial \overline{u'w'}}{\partial x} + \frac{\partial \overline{v'w'}}{\partial y} + \frac{\partial \overline{w'^2}}{\partial z}] \tag{5}$$

Where, $\overline{V}$ is the velocity vector, m/s; $\bar{u}$ $\bar{v}$, $\bar{w}$ are the subordinate and average velocity vectors in the direction of the x, y, z, m/s; u', v', w' are the pulse velocity in the direction of *x, y, z*, m/s.

The turbulent kinetic energy *k* equation and the dissipation rate ε equation are as follows:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}[(\mu + \frac{u_j}{\sigma_k})\frac{\partial k}{\partial x_j}] + \frac{1}{2}p_{ij} - \rho\varepsilon \tag{6}$$

$$\frac{\partial(\rho\varepsilon)}{\partial t} + \frac{\partial(\rho\varepsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}[(\mu + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial\varepsilon}{\partial x_j}] + \frac{1}{2}C_{1\varepsilon}p_{ij} - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} \tag{7}$$

Where, ρ is the fluid density, kg/m^3; k is the turbulent kinetic energy, m^2/s^2; μ is the dynamic viscosity, Pa·s; μ_t is the turbulent viscosity, μ_t=ρCuk^2/ε, Pa·s; p_{ij} is the shear stress production, 1; ε is the turbulent dissipation rate, m^2/s^3; C_u, $C_{1\varepsilon}$, $C_{2\varepsilon}$ are experience constants, C_u=0.09, $C_{1\varepsilon}$=1.44, $C_{2\varepsilon}$=1.92; σ_k, σ_ε are the turbulent Bronte numbers of turbulent kinetic energy *k* and turbulent dissipation rate ε, σ_k=0.82, σ_ε=1.3.

2.2 The filter's geometrical parameters

The dust-gas inlet is designed in the middle of the new dust precipitator. For the new dust precipitator, the total height is 2600mm, and the height of the clean gas chamber is 200mm. The diameter of the cylinder is 880mm, and its height is 1600mm. The height of the cone is 800mm, and its bottom diameter is 200mm. The diameter of the dust gas inlet is 140mm. The clean gas outlet is situated in the clean gas chamber, its width is 400mm, height is 160mm, nineteen filter bags are arranged along the radial direction, and the filter bag specification is Φ130 mm×1200 mm.

2.3 The boundary and initial conditions

For the new dust precipitator, the velocity is selected as the inlet boundary condition, and the free outflow is selected as the outlet boundary condition. It is utilized the bag's film property and chose the porous jump boundary condition to simulate the bag's filtrating [4]. The turbulent intensity is $I=0.16Re^{-1/8}$.

The input boundary condition values using for simulation and calculation about the model of the new dust precipitator are shown in Table 1.

Table 1. The input boundary conditions

The input boundary conditions	The value of boundary conditions
The inlet diameter[m]	0.14
The inlet velocity[m/s]	12
The turbulence intensity[%]	4
The surface permeability[m^2]	1×10^5
The thickness of perforated plate[mm]	3
The pressure step coefficient[m^{-1}]	0

2.4 The simulation results and analysis

2.4.1 The simulation results

The velocity vector and pressure of the new dust precipitator taking from simulation are as shown in Figure 2 and Figure 3.

From Figure 2 and Figure 3 , when dust-gas goes into the cyclone unit at the velocity of 12 m/s, a strong swirl appears in its cone, and the more distance away from the cone centre, the more high velocity and pressure. On the circumference near the inlet the velocity and pressure reach to the maximum, but near the center part fall significantly.

By means of the strong swirl effect, coarse particles and high density particles from the dust-gas directly drop to the cone's bottom, which reduces the impact on the bags. Thus, the bag life is extended and the injection cleaning frequency may be reduced so as to saving energy. At the

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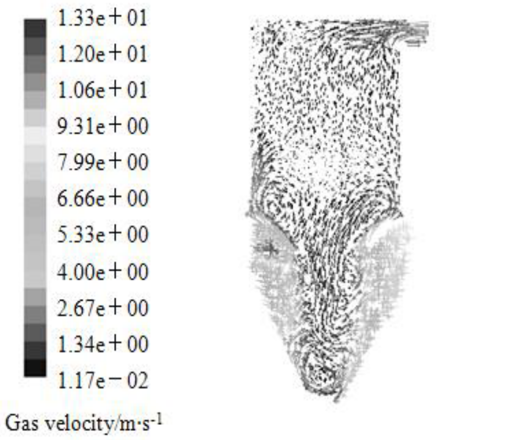
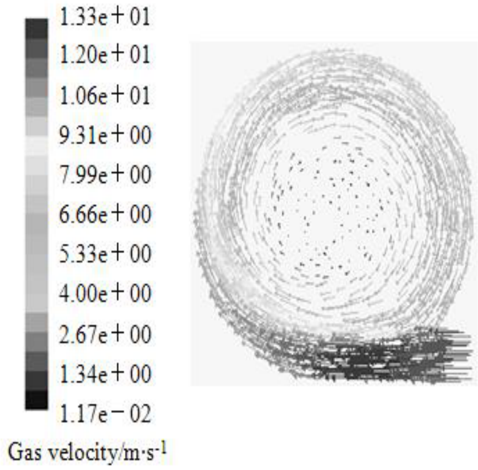
same time, the most critical, it significantly raises the dust removal efficiency.

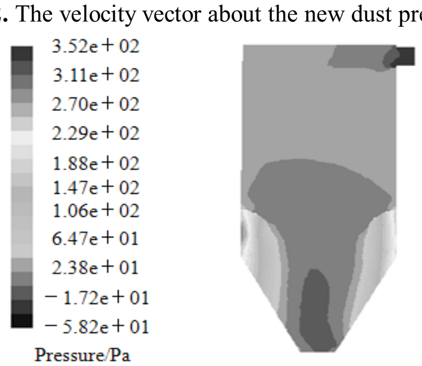


(a) The velocity vector of vertical section

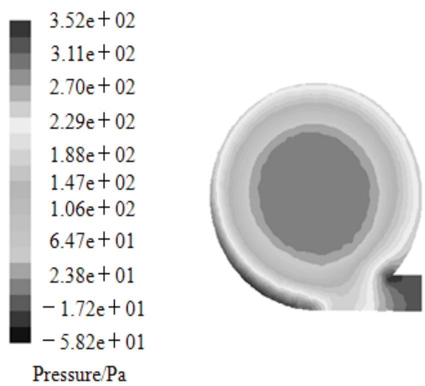


(b) The velocity vector of cross section near inlet

Figure 2. The velocity vector about the new dust precipitator



(a) The pressure cloud of the vertical section



(b) The pressure cloud of the cross section near inlet

Figure 3. The pressure cloud about the new dust precipitator

2.4.2 The internal gas distribution of the filter

The layout of the filtering bags in the new dust precipitator is shown in Figure 4. The gassy mass flow rate through each filter bag is shown in Table 2.

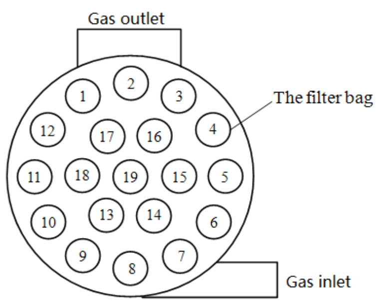


Figure 4. The layout of the filter bags

Table 2. The gassy mass flow rate through each filter bag

Serial number	Gassy mass flow rate
1	0.143549350
2	0.178450410
3	0.142806680
4	0.090841241
5	0.065733500
6	0.048651427
7	0.038259007
8	0.031632427
9	0.030742709
10	0.046368368
11	0.073229834
12	0.097862132
13	0.043250829
14	0.043056201
15	0.060569424
16	0.088580698
17	0.091376156
18	0.063441195

19	0.060418278

By analyzing the corresponding data from Figure 4 and Table 2, it is known that the bags near the gas outlet of the filter number 1, 2 and 3 passed through the maximum amount of gas, the bags away from the gas outlet number 7, 8, 9 passed through the minimum amount of gas. This is because, when the dust-gas goes into the inlet of the new dust precipitator, it would rotate downward along the surface of the cyclone unit to finish the first step dust removal. Then, the dust-gas rotates upward along the axis into the bag filter unit. Due to the gas moving toward the gas outlet, making the flow rate for each bag fluctuating but small. Of course, by optimizing the layout of filter bags and fitting a guide plate, the gas distribution will be more uniform. So, the structure of the new dust precipitator can avoid the defect of large flow rate at the gas inlet zone for the traditional bag filter, and it cannot make the bags have violent fluctuation.

2.4.3 The analysis of residuals and mass flow rate

Through optimizing the grid, improving the set of various parameters, choosing rational initialization parameters, and controlling relaxation factor, convergence of iteration may be ensured and improved. When calculation reaches convergence, whether or not the balance about the inlet or outlet gas mass flow rate of the model is reached should be checked, and whether or not the calculations achieves convergence should be judged according to the balance of the residual history and gas mass flow rate. Through multiple iterations, the final result is near the residual preset 1×10^{-3}, the iterating is convergence.

Through Fluent calculating, it is known that, for the new dust precipitator, its inlet gas mass flow rate is 1.4401137 kg/s, outlet gas mass flow rate is 1.440114 kg/s, and the difference value is 3.0×10^{-7} kg/s. The non-balance ratio is $3.0\times10^{-7}/1.440114=2.08\times10^{-7}<0.01\%$.

This calculation verifies that gas mass flow rate goes through inlet or outlet of the filter model having come to balance and the result being accurate.

3 Conclusion

The new type of new dust precipitator combines the advantages of cyclone and bag filter, integrates the two step traditional dust removal equipments to one . Its structure is simple and compact, and the dust removal efficiency is rising.

when the dust-gas goes through the inlet into the cyclone unit of the new dust precipitator, the outside vortex takes away the particles from the wall to the bottom and removes them by ash valve. The inside vortex takes the small particles (not separated) to the filtrating bag unit. The remanent small particles are obstructed by the bags and clean gas goes through the bags to atmosphere. In the filtrating bag unit the gas velocity is significantly smaller, and the pressure is much lower. At the same time, the low dust concentration of the inside vortex may decrease the dust jet times, thus not only extends the using life of bags, but also saves energy.

The layout of each filter bag affects the amount of its processing mass flow. The numerical simulation and optimization of bag's arrangement may achieve the uniform of gas flow, and provide theoretical evidence to research and design this type of dust precipitator.

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