The numerical simulation of flow field characteristics for single vortex column in different shapes

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Abstract. The coagulation technology of turbulence can improve the PM2.5 removal efficiency of ESP effectively, which is a hot technology researched by the scholars and manufacture. The turbulence produced by vortex column is the main power supply in the turbulence coagulation device, the velocity distribution, turbulence intensity, turbulence viscosity and pressure loss of single vortex column in different shapes and sizes were calculated in this paper. The turbulence produced by angle-steel had a better velocity and character than cylindrical vortex, and if the size of angle-steel and cylindrical vortex was bigger, the turbulence effect of the flow field would become better, but the pressure loss of different shapes would increase. We need to ensure the turbulence effect as well as minimize unnecessary pressure loss in practical applications.

1. Introduction
The PM2.5 capture efficiency of traditional ESP is low, the pretreatment section added before the ESP to make the PM2.5 bigger and bigger by physical or chemical role and removed easily in the ESP, this is one of the hot direction of dust removal technology[1-4]. Saffman and Turner have researched the particles turbulence coagulation as early as in half a century ago[5]. Feldman(1999) analyzed the ultrafine particles coagulation in the laminar flow condensation, and has done a lot of experiments in the power plant, which shows that the particle size increased and the coagulated obviously[6]. Xu ShiSen(1999) pointed that the coagulation of small size particles in the turbulence fluctuation is very significant[7]. But there was less report on the optimization design of turbulence coagulation device. A numerical method was introduced in this paper, and the flow field characters of single vortex in different shapes were calculated by using of LES and k-ε model separately, designing to provide a theoretical reference for the optimization design of the coagulation device.

2. Geometrical model
The coagulation device, which makes small size particles condensed into large one to be removed inside ESP, is installed before the ESP. The turbulence coagulation device makes different significantly speed between different size particles through specific scales of turbulence, and results the particles local enrichment phenomenon that enhances the chance of particles collision greatly. The cylindrical vortex installed in the flow area is one core components of the coagulation device.

The turbulence produced by vortex column in different shapes is simulated in this paper, and the spacing size is: 1000mm×1000mm×10000mm, shown as Fig 1. The working condition is as: Dia.220mm cylinder (A), Dia.180mm cylinder (B), Side length 155mm angle-steel(C), Side length
125mm angle-steel (D). The grid partition of it is shown as Fig 2, both of which are structural grid with highest quality, and the grid quality report is shown as Fig 3.

3. Mathematical model
There are main methods of turbulent numerical simulation such as: direct numerical simulation (DNS), Reynolds-averaged (RANS) and large eddy simulation (LES). LES is a turbulent numerical calculation method between RANS and DNS. In this paper, we made the numerical calculation of vortex column flow field in turbulence area based on the commercial CFD software, simulated the flow field instantaneous value using of LES model, simulated the flow field time-averaged value using of k-ε model.

4. Boundary condition
The inlet condition is velocity-inlet, which is 12m/s, the air viscosity is 14.8×10^-6 m²/s, the air density is 1.1691kg/m³; The outlet condition is: OUTFLOW; The rest boundary conditions of surface are wall; Time step is 0.001s; Pressure - velocity coupling method uses the SIMPLE algorithm, and the pressure - continuity equation difference method uses the PRESTO method.

5. Result and analysis
A Velocity distribution
The velocity curve along the z axis was taken for: x=3.15m, x=3.3m, x=4m, x=6m, as shown in Fig 4. The velocity distribution curves of all vortex columns in different shape and size are “V”, while the vortex resulted by angle-steel is deeper than that caused by cylinder, and become significantly as time goes on, reaching the peach at x=6m; For the same shaped vortex column, the bigger the characteristic scale is, the deeper the “V” will be, especially in the short range after vortex column. The comparative result of vortex velocity is: B < A < D < C.

B Turbulence parameter

Fig 5 is the turbulence intensity time-averaged value curve of each section, and Fig 6 is the turbulence viscosity cloud chart of different shaped vortex columns. The figures show that, there are good vortex distribution in each condition, the turbulence intensity and turbulence viscosity near the behind of the column is the largest, so as to the amplitude of variation, which dissipated gradually along the x axis direction; the turbulence of angle is better than the cylinder, the magnitude and variation are greater than cylindrical turbulence, which is more and more obvious during the future development. Turbulence comparison results: B < A < D < C.
Fig 5 The turbulence intensity time-averaged value curve of each section (k-ε)

(a) x=3.15m  
(b) x=3.3m  
(c) x=4m  
(d) x=6m

Fig 6 Turbulence viscosity cloud chart of different shaped vortex columns (LES)

A Dia.220mm cylinder  
B Dia.180mm cylinder  
C Side length 155mm angle-steel  
D Side length125mm angle-steel

C Mean parameter

Fig 7~9 is the velocity, turbulence intensity, total pressure curve of the center section y=0.5m, the turbulence disturbed flow of angle is better than cylindrical which can be seen in figure 7 and 8, while
the total pressure loss of angle is significantly greater than the cylindrical which can be seen in figure 9. The turbulence effect should be good enough on the premise of reducing the total pressure loss as far as possible, which should be considered in the practical engineering application.

Fig 7 The velocity curve of center section    Fig 8 The turbulence intensity curve of center section

Fig 9 The total pressure curve of center section

6. Conclusion
The performance of coagulation device has a direct influence of the ESP PM2.5 removal efficiency, the vortex column is one of the important component of the coagulation device, the turbulence produced by vortex column is the main power supply in the device. This paper makes use of the commercial CFD software, adopts the LES and k-ε model, the velocity distribution, turbulence intensity, turbulence viscosity, pressure loss of different vortex column was calculated, which provided reference for the design of the coagulation device

Acknowledgements
The National High Technology Research and Development of China (863 Program) (2013AA065002)

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