The Numerical Simulation of Different Spacing Coordinate Double Cylindrical Vortex

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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, pressure loss and particles coagulation efficiency of different spacing L double vortex column was calculated in this paper, the results show that: The smaller of the spacing, the bigger of the turbulence and velocity effect between the two cylindrical; The value of pressure loss is biggest when L=0.4m, when the spacing L⩾0.4m, the bigger of L, the smaller of the pressure loss; The particles coagulation efficiency of all operating condition are very obvious, the proportion of particle size which＜8μm decreases obviously, while the particle size which＜2μm is the most obvious; The coagulation efficiency of condition D is the best one, while the condition A is the worst.

Keywords: PM2.5; coagulation device; LES; coagulation efficiency; numerical calculation

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) analysed 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 and the turbulence coagulation mechanism. Our company researched and developed a set of PM2.5 captured device which is called coagulation device in this paper, A full range of inertial particle turbulence coagulation kernel function is introduced in this paper, and coupled the double fluid model and PBM(the particle swarm balance model), different spacing coordinate double cylindrical vortex was calculated to provide theoretical reference for the optimization design of the coagulation device.

1 Geometrical model

The coagulation device is installed before the ESP, which makes small size particles condensed into large one to be removed in the ESP. The turbulence coagulation device makes different significantly speed between different size particles through specific scales of turbulence, and makes the particles local enrichment phenomenon, which enhances the chance of particles collision greatly, the cylindrical vortex is installed in the flow area of the coagulation device, which is one of the core components. The flow field and coagulation efficiency of different spacing double cylindrical vortex is simulated in this paper, the spacing size is: 2000mm×3000mm×5000mm, the diameter of vortex column is 220mm, the double vortex column is shown as pig 1, and the grid partition of it is shown as pig 2, which is the highest quality for the structural grid. The spacing L of double column is taken for: 300mm（A）、400mm（B）、500mm(C)、600mm(D)、700mm(E).

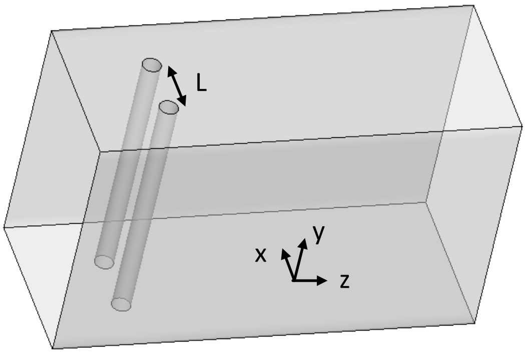

Fig 1 the structure diagram

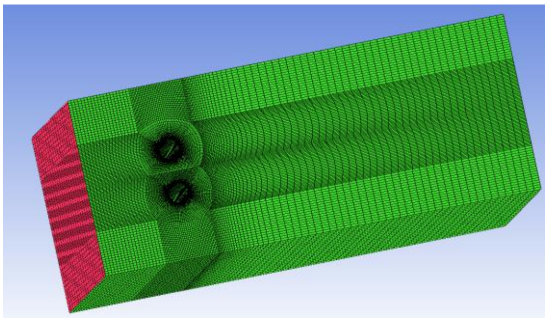

Fig 2 the grid diagram

2 Mathematical model

With the commercial CFD software, the movement of gas and particle phase was calculated by double fluid model, the standard *k-ε* model was selected, the coagulation efficiency of particles was calculated by PBM, the turbulence coagulation model is written into the CFD software through the user defined function(UDF), and the PBM was calculated by the software coupled with the double fluid model.

Based on the hypothesis of the particle spare and molecular chaos, the particle swarm balance model equation (PBM) is entered in the Eulerian coordinate with only considering the particle coalescence shown as formula 1.

$$\frac{\partial n(v,t)}{\partial t} = \frac{1}{2}\int_{v_{\min}}^{v} \beta(v-u,u,t)n(v-u,t)n(u,t)du \qquad (1)$$

$$- n(v,t)\int_{v_{\min}}^{v_{\max}} \beta(v,u,t)n(u,t)du$$

$\partial n(v, t)$ is the particle number concentration distribution of the volume *v* particle at *t* time; v_{min}, v_{max} is the minimum and maximum volume particle in the system; $\beta(u, u\text{-}v)$ is the turbulence coagulation efficiency between the volume *u* particle and volume *v-u* particle.

The inertial particle turbulence coagulation efficiency model was deduced by L.I. Zaichik(2006)[8] in isotropic turbulence, which is suitable for the whole range of inertial particle(from zero inertia to large inertia particles), and the efficiency of coagulation function was considered, which is the coagulation efficiency increasing effect of turbulence and coagulation.

The coagulation nucleus is generated by half area of the impact range surface, $\langle|\omega_r|\rangle$ is the mean particle size related velocity, and Γ is the radial distribution function, which is shown as formula 2.

$$\beta = 2\pi d^2 \langle|\omega_r(d)|\rangle \Gamma(d) \qquad (2)$$

The formula was amended again by L.I. Zaichik later, which was suitable for any density particles condensation, as shown in the literature[9]. In this paper, the turbulence coagulation model is written into the CFD software with the UDF, and the PBM equation is calculated by the partition algorithm, then the coagulation efficiency is calculated.

3 Boundary conditions

The entry condition is velocity-inlet, which is 12m/s, the air viscosity is $14.8\times10^{-6}m^2/s$, the air density is $1.1691kg/m^3$, the particle density is $2100kg/m^3$, the particle volume fraction is

7.02×10^{-6}; The export conditions is pressure-outlet; The rest boundary conditions of surface are wall; The size distribution of initial particle is 0.45μm *to* 12.5μm which was measured by Andersen, see table 1.

Table 1 the volume fraction of different particles

	D_i（m）	f_i
Bin-0	1.2472366e-05	0.50124
Bin-1	7.7596774e-06	0.19804
Bin-2	4.8276799e-06	0.10513
Bin-3	3.003539e-06	0.08313
Bin-4	1.8686505e-06	0.02445
Bin-5	1.1625801e-06	0.02445
Bin-6	7.2329872e-07	0.03667
Bin-7	4.4999999e-07	0.02689

4 Result and analysis

4.1 Velocity distribution

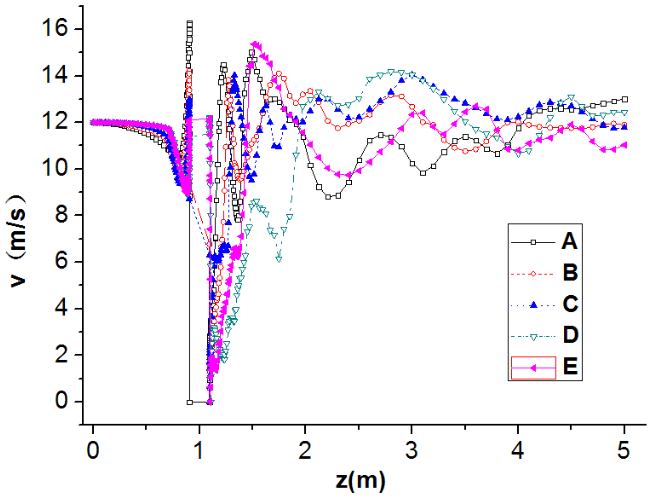

Fig 3 The velocity curve along the z axis with different L

The cylindrical center line was taken along the z axis, and the velocity curve of the line was shown as Fig 3. The cylindrical position is near z=1m, and the velocity of all condition fluctuated significantly, the fluctuation is most obvious behind the cylindrical from z=1m to z=1.5m, which gentled gradually along the z axis because of the speed dissipated, and the speed vortex is so weak after z=3m.

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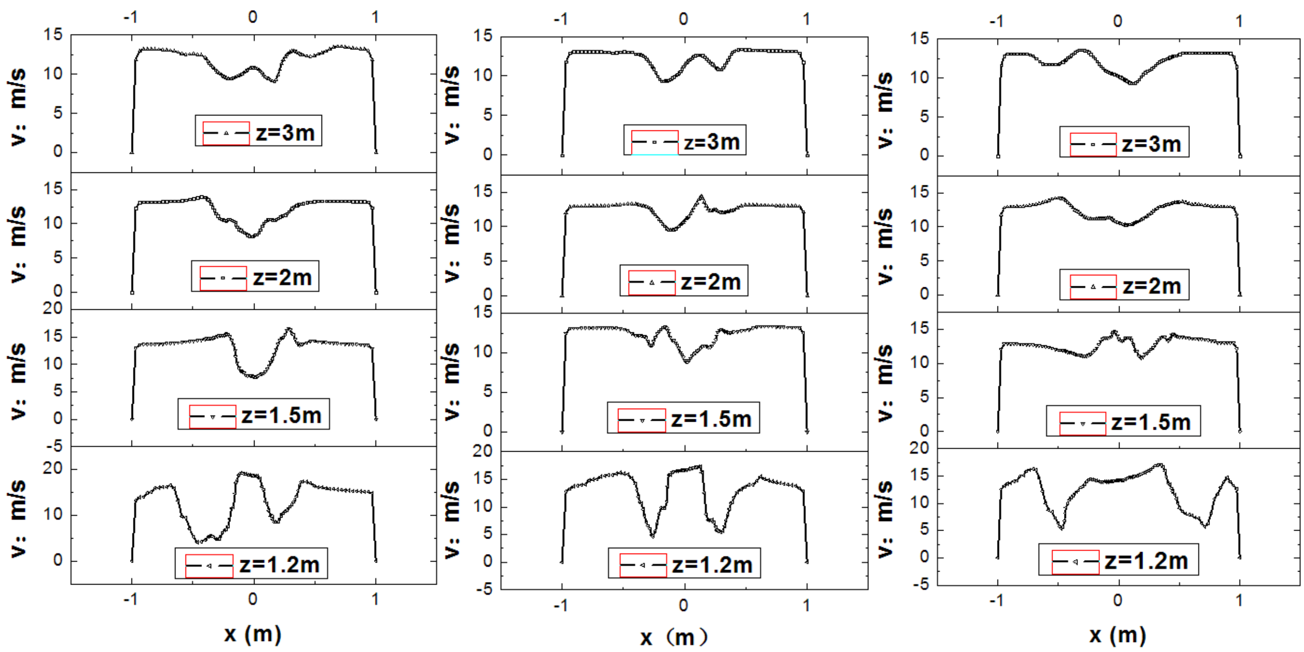
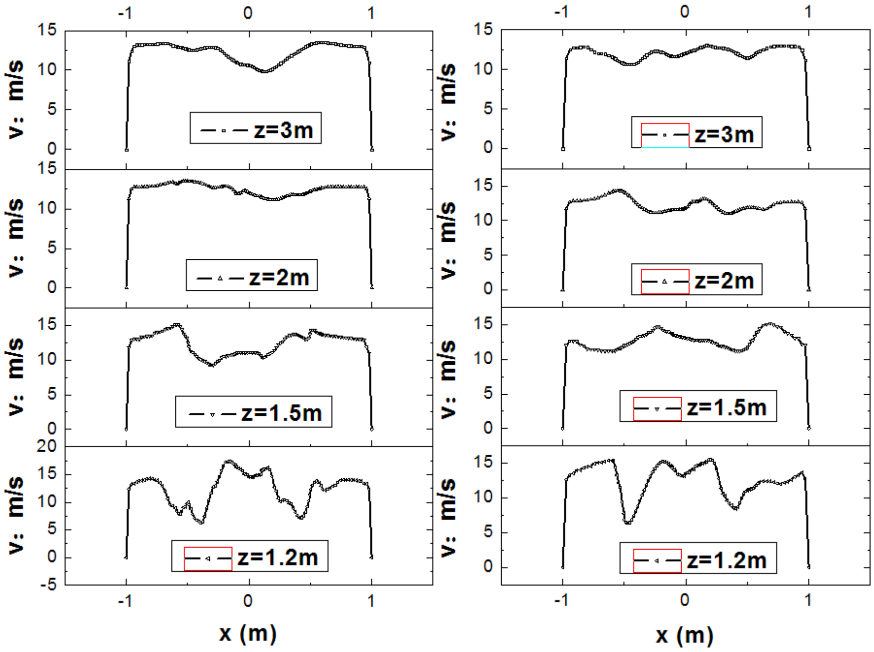


A B C



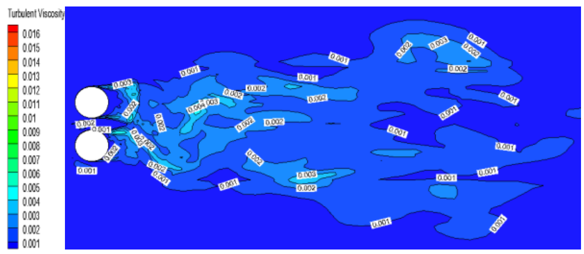
D E

Fig 4 The velocity curve of each section with different L

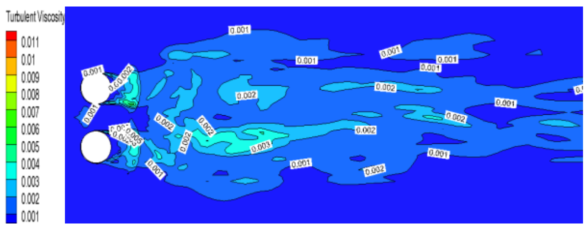
The velocity curve along the x axis was taken for: z=1.2m, z=1.5m, z=2m, z=3m, as shown in Fig 4. The velocity distribution curve of all different spacing double cylindrical vortex is double "V", the smaller of the spacing, the more deep of the "V" bottom, this is because the smaller of the spacing, the bigger of the turbulence effect between the two cylindrical, and the velocity curve of condition A, which is z=1.5m, is close to the single "V" produced by the single cylinder vortex; the velocity dissipated gradually along with z axis, and the speed vortex is so weak at z=3m, which show that the turbulence source should be set before it to make the turbulence continuous

4.2 Turbulence intensity distribution

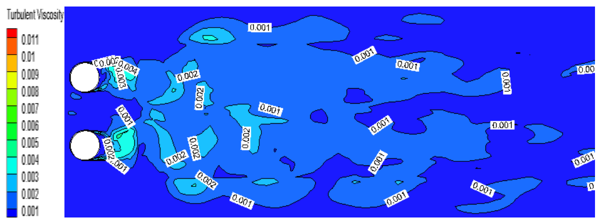
The turbulence intensity distribution of double cylinder with different L is shown as Fig 5, the vortex distribution of all condition is very good, and the turbulence intensity value at the cylindrical rear is the largest, which dissipated gradually along the z axis, The mutual interference of vortex produced by double cylindrical existed at the cylindrical rear, and the smaller of the spacing, the more intense of the interference effect, the turbulence vortex interference effect of condition E is very small, while the condition A has been closed to a single cylindrical disturbing flow condition; The vortex distribution area of condition D is the biggest, while the value is the minimum, the turbulence intensity of condition A is the maximum.



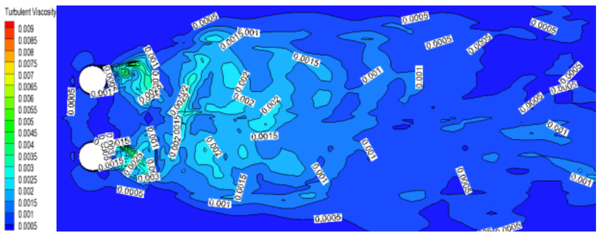
A



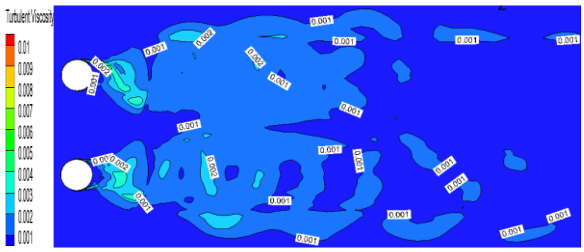
B



C



D



E

Fig 5 The turbulence intensity distribution with different L

4.3 Pressure loss

The pressure loss is an important performance parameter of the coagulation device, and the pressure loss curve with different spacing L of double cylinder is shown as Fig 6. The pressure loss of all condition is obvious, and the value of pressure loss is biggest when L=0.4m, and when the spacing L ⩾0.4m, the bigger of L, the smaller of the pressure loss value.

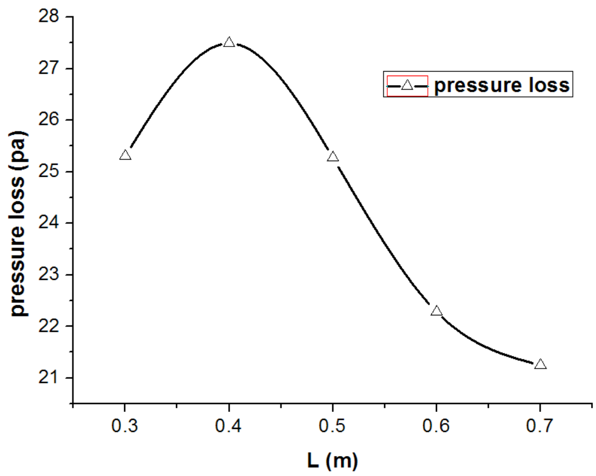


Fig 6 The pressure loss curve of different L

4.4 Coagulation efficiency

The turbulence coagulation model was written into the CFD software with the UDF, and the PBM equation was calculated by partition algorithm, the result are shown as fig 7, the abscissa is the particle diameter size, the ordinate is the particle diameter distribution function of the volume fraction, defined as:

$$d_{fi}/d_{\log(Dp)} = \left|\frac{f_i}{\log(Dp)}\right| \qquad (3)$$

D_P is the particle aerodynamic diameter, f_i is the volume fraction of particle i.

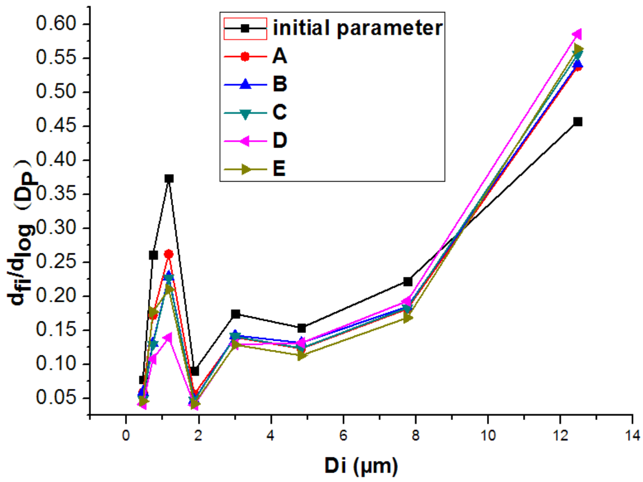


Fig 7 The coagulation efficiency of different L

The initial particle diameter distribution was measured by Andersen which shows bimodal distribution, there is a peak at 0.6μm, and the cure shows drab rising trend at 2.5～10μm; The particles coagulation efficiency of all operating condition are very obvious, the proportion of particle size which ＜8μm decreases obviously, while the particle size which ＜2μm is the most obvious; The coagulation efficiency of condition D is the best one, and the condition A is the worst.

5 Conclusions

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 double fluid model, the turbulence coagulation model was written into the software with the UDF, the PBM equation was calculated by partition algorithm, the velocity distribution, turbulence intensity, pressure loss and particles coagulation efficiency of different spacing L double vortex column was calculated, which provided reference for the design of the coagulation device.

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