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Dynamical Characteristics of Interaction between Water Droplet and Aerosol Particle in Dedusting Technology

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***Abstract*—**With the rapid development of national modern industry, people begin to pay attention to environmental pollution and harm caused by industrial dust. Based on above, a numerical study on the dedusting technology of industrial environment was conducted. The dynamic models of multicomponent particles collision and coagulation, breakage and deposition are developed, and the interaction of water droplet and aerosol particle in 2-Dimension flow field was researched by Eulerian-Lagrangian method and Multi-Monte Carlo method. The effects of the droplet scale, movement speed of droplet and the flow field structure on scavenging efficiency were analyzed. The results show that under the certain condition, 30μm of droplet has the best scavenging efficiency. At the initial speed 1m/s of droplets, droplets and aerosol particles have more time to interact, so it has a better scavenging efficiency for the particle.

***Keywords*—**Water droplet, aerosol particle, collision and coagulation, multi-Monte Carlo method.

I. INTRODUCTION

DUST can cause damages in various aspects. For example, explosive dust is harmful to safety production. Toxic or radioactive dust is harmful to human health, and huge dust emission will lead to massive air, soil and water pollution. Based on above discussion, the research of dust characteristics in production environment and dedusting technology has meaningful theoretical value and profound practical significance to protect human health and environment.

Dominant mechanisms for cleaning up solid particles are followed. Particles adhere to droplets, liquid membrane and bubbles after colliding and touching with them. Particles contact with liquid surface because of its diffusion effect. Particles agglutinate with humidifying gas. The coherency of particles is enhanced by the cooling and condensation of steam with particles as cores etc. Xu Licheng illustrates fine water mist dedusting mechanism with Cloud Physics Condensation Nucleation theory [1]. Zhang Xiaoyan designs dusty air flow clarification system based on the present dust-catching with water mist technology [2].

W. Balachandran et al. set up experiments to study the clearing effect of rotary atomizer formed electriferous droplets on superfine aerosol particles [3]. Tawatchi Charinpanitku et al. establish a deterministic model based on the Water droplets and dust particles momentum and mass conservation principles, for predicting the clearing effect of water mist on inert particles in open space [4]. Song-Miao Fan et al study the influence of droplet nucleation on the deposition and transportation of mineral dust aerosols [5].

Currently, there are few numerical study results for the dynamic properties and interaction mechanism of water droplets and aerosol particles during the dedusting process. Therefore, relevant researches should be conducted.

II. MODELS AND NUMERICAL STUDY METHOD

The characteristics of particles in complex environment are impacted both by aerodynamic and forces of flow field, as well as the interaction among particles. Thus, Two-phase Coupled Model is adopted.

A study on the diffusion and interaction process of water droplets and aerosol particles in two-dimensional space is conducted by establishing multicomponent particle dynamical model, utilizing the finite volume method and Multi-Monte Carlo method [6].

A. Governing Equation

Water Droplets Particle Population Balance Equation:

$$\begin{aligned}\frac{\partial n_d(V,t)}{\partial t} &= \{\frac{1}{2}\int_{V_{\min}}^{V} \beta_d(V-U,U,t)n_d(V-U,t)n_d(U,t)dU - \\ &\quad n_d(V,t)\int_{V_{\min}}^{V_{\max}} \beta_d(V,U,t)n_d(U,t)dU\}_{\text{coagulation}} \\ &\quad +\{\int_{V}^{V_{\max}} \gamma_d(U,V,t)b_d(U,t)S_d(U,t)n_d(U,t)dU - S_d(V,t)n_d(V,t)\}_{\text{breakage}} \\ &\quad -\{E_d(V,t)n_d(V,t)\}_{\text{deposition}}\end{aligned} \tag{1}$$

Aerosol Particles Particle Population Balance Equation:

$$\begin{aligned}\frac{\partial n_p(V,t)}{\partial t} &= \{\frac{1}{2}\int_{V_{\min}}^{V} \beta_p(V-U,U,t)n_p(V-U,t)n_p(U,t)dU - \\ &\quad n_p(V,t)\int_{V_{\min}}^{V_{\max}} \beta_p(V,U,t)n_p(U,t)dU\}_{\text{coagulation}} \\ &\quad +\{\int_{V}^{V_{\max}} \gamma_p(U,V,t)b_p(U,t)S_p(U,t)n_p(U,t)dU - S_p(V,t)n_p(V,t)\}_{\text{breakage}} \\ &\quad -\{E_p(V,t)n_p(V,t)\}_{\text{deposition}}\end{aligned} \tag{2}$$

where, $n_d(V,t)$, $n_p(V,t)$ represent the volume distribution

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function of water droplets and aerosol particles ($m^{-3}m^{-3}$) per unit volume respectively; $n_d(V,t)dV$, $n_p(V,t)dV$ represent the number concentration of water droplets and aerosol particles at time of t, with length scale in V~V+dV per unit volume respectively.

B. Particle Collision and Coagulation Models

In water mist system, collision and coagulation [7] happen not only between water droplets and aerosol particles, but also between themselves which has made the discrete system especially complex. The water droplets and aerosol particles collision and coagulation nuclear [8], [9] adopted in this paper is:

$$\beta = \mathrm{K}(d_p, D_d)\mathrm{E}(d_p, D_d) \tag{3}$$

where $K(d_p, D_d)$ is collision nuclear, representing the collision probability of aerosol particles (d_p) and water droplets (D_d) caused by the cross of their geometric orbits. The expression is:

$$K(d_p, D_d) = \frac{\pi D_d \left| U(D_d) \quad U(d_p) \right|}{4} \tag{4}$$

where, $U(D_d)$ and $U(d_p)$ represent the speed of water droplets (D_d) and aerosol particles(d_p)respectively.

$E(d_p, D_d)$ is the collision efficiency which is the result by effects of turbulent diffusion, Brownian diffusion, thermophoresis, and electrostatic adsorption. Moreover, various kinds of external factors, such as aerosol particle scale spectrum, water droplet scale spectrum, physicochemical characteristics of aerosol particles and water droplets will also affect the clearance effect of aerosol particles. Based on Navier-Stokes equation, semi-empirical expression of collision efficiency by Slinn [10] is as followed:

$$\mathrm{E}(d_p, D_d) = \{\frac{4}{\mathrm{Re} \bullet Sc}[1 + 0.4\mathrm{Re}^{\frac{1}{2}} Sc^{\frac{1}{3}} + 0.16\mathrm{Re}^{\frac{1}{2}} Sc^{\frac{1}{2}}]\}$$

$$+ \{4\frac{d_p}{D_d}[\frac{\mu_a}{\mu_w} + (1 + 2\mathrm{Re}^{\frac{1}{2}})\frac{d_p}{D_d}]\} + \{(\frac{\rho_w}{\rho_p})^{\frac{1}{2}}[\frac{St - S^*}{St - S^* + \frac{2}{3}}]^{\frac{3}{2}}\} \tag{5}$$

where, Re is Reynolds based on the radius of water droplets, $Re = D_d U_d \rho_a / (2\mu_a)$. ρ_a is air density. Sc is the Schmidt number of aerosol particles, $Sc = \mu_a / (\rho_a D_{diff})$. D_{diff} is the diffusion coefficient of aerosol particles, $D_{diff} = k_b T C_c / (3\pi\mu_a d_p)$. T is the absolute temperature(K) of environment. St is the Stokes of aerosol particles, $St = 2\tau_p U_d C_c / D_d$; T=296.15K, ρ_a =1.193kg/m^3. S^* is a dimensionless parameter, $S^* = [1.2 + (1/12)\ln(1+\mathrm{Re})]/[1 + \ln(1+\mathrm{Re})]$ μ_a =1.83245×10^{-5}kg/(m·s), μ_w =9.591×10^{-4}kg/(m·s).

III. STUDY RESULTS AND ANALYSIS

The two-dimensional computational domain is 30m (length) ×10m (width). The initial speed of airflow is 2m/s. The size distribution of water droplets and aerosol particles all adopt exponential distribution function. At the initial stage, the water mist is presented as water curtain. The aerosol particles distributed in the computation domain evenly, as in Figs. 1 and 2.

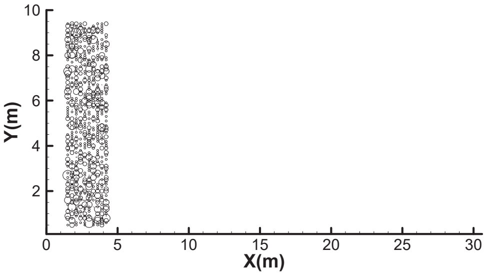

Fig. 1 The initial distribution of water droplets

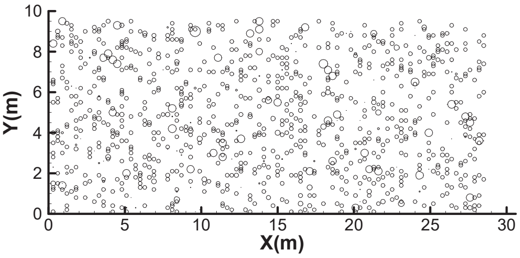

Fig. 2 The initial distribution of aerosol particles

The movement speed of water droplets in discrete system is 0-3m/s. The average size of suspending aerosol particles is 1μm. When water droplets diffuse to the right boundary of the flow field, the computation cycle stops (one-time period).

A. The Influence of The Aerosol Particle Average Size

The interaction process of water mist droplets with 30μm average size and aerosol particles with 1μm average size is analyzed.

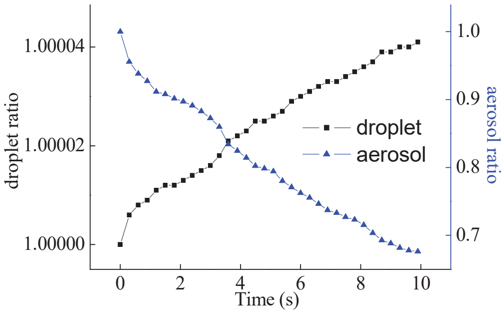

Fig. 3 The mass change of droplets and particles

During diffusion and interaction of particles (9.9s), the mass concentration of droplets rise about 0.0041%. And the mass concentration of aerosol particles is decreased to 67.63% of the original.

The distribution diagrams of particle number concentration for 30μm droplets and 1μm aerosol particles are shown in Figs. 4 and 5. Combining with computed results of the mass concentration shows that the droplets spread gradually out as time development. The aerosol particle number is significantly decreased in the water mist droplet area.

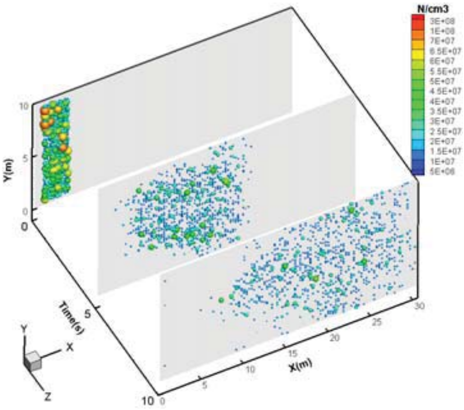

Fig. 4 The number concentration distribution of the droplets

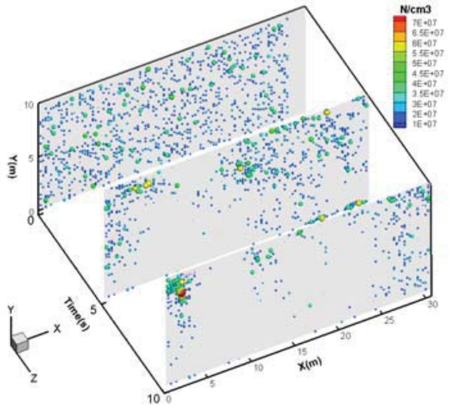

Fig. 5 The number concentration distribution of the particles

Table I shows the mass change influenced by different droplets scales. It is showed when the scale of the water mist droplets is increased from 10μm to 30μm, the mass concentrations of aerosol particles are changed significantly. As the scale of the droplets rising from 40μm to 50μm, the mass concentration of the aerosol particles is changed slightly. So it can be concluded that dynamic mechanism played a dominant role in the water mist dust. Namely through inertia collision between the droplets and particles, interception and coagulation, diffusion, aerosol particles can be cleaned by droplets. Furthermore, the droplets deposition effect also need to be considered in the process of diffusion, so the scale of the droplets is medium for the best effect.

B. *The Influence of the Initial Velocity of Droplets*

The velocity of droplets is reduced to 1m/s. The peak number of the droplets is 3.0×10^8 per cubic centimeter, and the peak number of the particles is about 4.0×10^8 per cubic centimeter.

TABLE I
COMPARISON OF MASS CONCENTRATION FOR DIFFERENT SCALES DROPLETS

Parameter	Time	The increase of droplets	The decrease of aerosols
10μm	11.7s	0.0005%	95.62%
20μm	10.8s	0.0026%	79.52
30μm	9.9s	0.0041%	67.63%
40μm	9.3s	0.0044%	64.43%
50μm	9.0s	0.0047%	62.98%

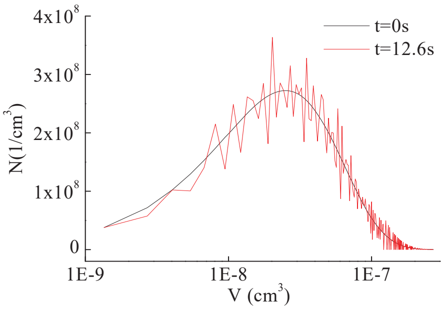

Fig. 6 The distribution of droplets

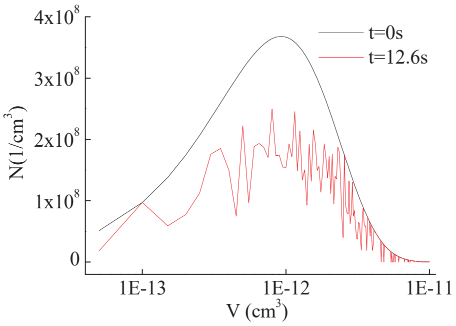

Fig. 7 The distribution of aerosols

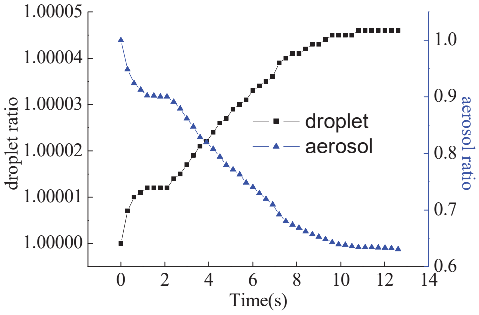

Fig. 8 The mass change of droplets

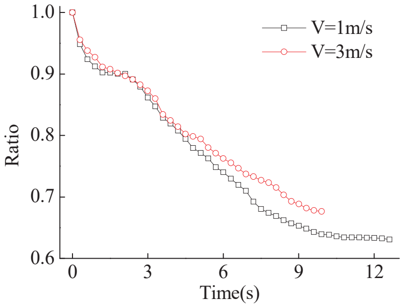

Fig. 9 The mass change of aerosols

The mass concentration of droplets is increased about 0.0046% at time 12.6s, and the mass concentration of particles is decreased to 63.06% of the original. The mass change of particles for droplets different velocities is shown in Fig. 9. It shows that the interaction between the droplets and particles can last longer, and it is more likely to collide for droplets 1m/s, which can clean the particles more effectively.

IV. CONCLUSIONS

The dynamic models of multi-component particles collision and coagulation, breakage and deposition are developed, and the finite volume method and Multi-Monte Carlo Method are utilized. The results show:

The droplet scale has influenced on scavenging efficiency. With the droplet scale from 10μm rising to 30μm, the quality of aerosol particles is reduced to 67.63% of initial quality, which changes obviously. With the droplet scale rising to 40μm, 50μm, variation of aerosol particles quality is less. Moreover, dynamic mechanism is dominant in the scavenged processing for aerosol particles. Water droplets remove particles through the ways of inertial impaction, intercept, condensation and diffusion.

Movement speed of droplet has influenced on scavenging efficiency. With the speed 1m/s of droplets, droplets and aerosol particles have more time to interact, so it has a better scavenging efficiency for the particle. At 12.6s，the mass concentration of aerosol particles is reduced to 63.06% of the original. Therefore, during the period of time, smaller droplet velocity helps to remove more aerosol particles.

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