EXPERIMENTAL STUDY OF AEROSOL DISTRIBUTION AND CONCENTRATION VARIATION THROUGH CURVED DUCTS

by

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Short paper
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This paper presents an experimental investigation of an aerosol problem by adopting two methods. One approach utilizes scanning electron microscope to study the realistic aerosol deposition status in a typical duct bend. Through scanning electron microscope images and on-site observation, the aerosols tend to deposit and accumulate more on the outer bend wall and bend outlet wall. The other approach is to design systematic experiments to measure aerosol concentration variation and distribution through 90-degree curved ducts. This experimental method is simple for realistic applications. Measured results show that the average particle volume concentration diverges greatly after flowing through the bend. The loading ability decreases significantly for larger particles at bend outlet under higher Dean number.

Key words: *scanning electron microscope, concentration change, deposition, bends*

Introduction

The environments we are living are filled with suspended aerosol particles [1]. Previous studies of aerosol flow in the bends focus mainly on averaged deposition, penetration and deposition velocity, by both experimental methods [2] and numerical modeling [3, 4]. However, they were primarily conducted in the whole enclosed environment, and the concentration distribution of the duct (especially the bend) as air passage deserves more attention and investigation. The interaction between concentration distribution and particle deposition in bends is rarely discovered.

Field study

Samples of galvanized steel duct were collected from the ventilation duct system of The Hong Kong Polytechnic University. The particles on two surfaces of different dirty levels were imaged by Scanning Electron Microscopy (SEM, JEOL Model JSM-6490).

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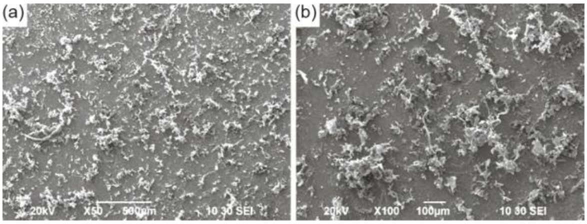

Figure 1. SEM images of particles deposited in real ventilation ducts; (a) ×50 times, (b) ×100 times

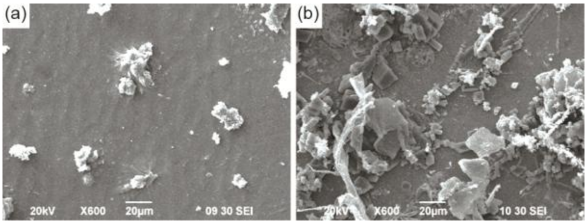

Figure 2. SEM images of particles deposited in real ventilation ducts; (a) ×600 times on clean area, (b) ×600 times on relatively dirty area

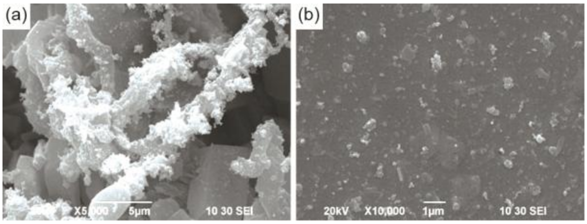

Figure 3. SEM images of particles deposited in real ventilation ducts; (a) ×5000 times on dirty area, (b) ×10000 times on relatively clean area

Results of SEM images for deposited aerosol

Figures 1-3 demonstrate the conducted SEM images of practical particles on galvanized ventilation ducts. The duct surfaces are enlarged for 50-10,000 times, which corresponds to the measure scale of 500-1 μm. It can be observed that the duct is full of deposited particles which accumulate mainly on outer bend wall. This dirty status is probably attributed to the fact that ventilation ducts, especially non-industrial ducts, are seldom cleaned. Since there is a large amount of different function rooms connected with ventilation ducts, in realistic practice, it is hard to take the cleaning process into operation. Without cleaning, these dirty particles may contain a variety of components, including solid particles and bioaerosol. In addition, the shapes of the deposited aerosol particles are noticed to vary in a wide band (*e. g.* semi-spherical, crystal, and fibrous).

Figure 1 illustrates large visible deposited aerosol aggregates which could be seen by naked human eyes. These aggregates are around 100 μm, and those larger than 500 μm are seldom observed. In fig. 2(b), many crystalloids could be found from about 1 to 20 μm. These crystalloid particles may be caused by common installation, decorating or maintaining works in the served rooms. In contrast, the left sample duct in fig. 2(a) [2] contains much less large particles than the right one. Figure 3 shows relatively small particles with considerable fine particles and nanoparticles on the surfaces of the two samples. Large particles may be formed from these fine or nanoparticles [5]. In short, particle pollutions in the ventilation system are observed to be comprised of a wide size range from several nanometers to hundreds of microns with a tremendous quantity. Therefore, the Arizona standard test particles, which possess high similarity with the realistic particles, are selected in the following experimental measurements.

Systematic experimental methods

After the field study, particle flow through bends was measured by an improved systematic measurement setup as shown in fig. 4. Detail description can be found in the previous study [6].

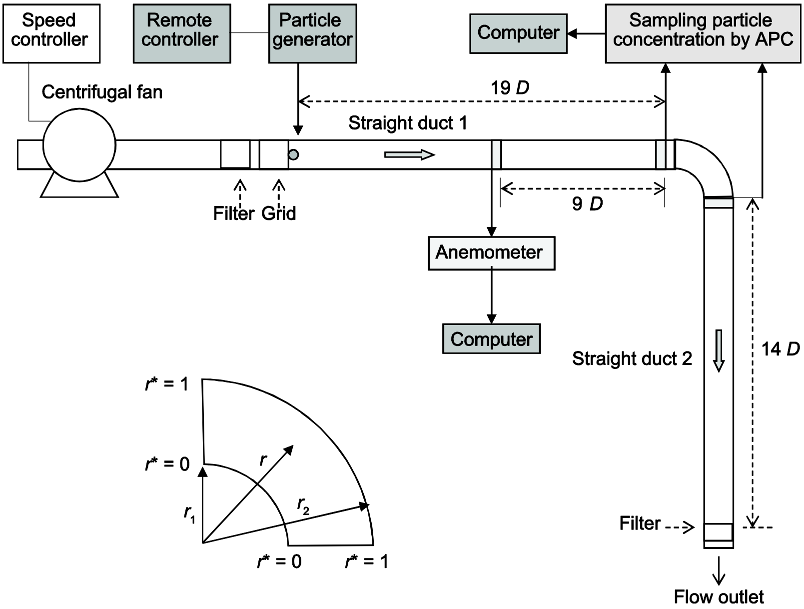

Figure 4. Schematic diagram of the measurement set-up (not to scale)

Experimental results and discussion

Particle concentration ratio is introduced as a new angle of experimental view in this part to illustrate the concentration and deposition change at the inlet and outlet of 90° bends along with De = 9700 and 19300. Since the penetration through a 90-degree bend of particles with diameter d_{pn} = 1 μm is almost 100% compared to those of other larger particles according to previous research [2], the concentration of particles with diameter d_{pn} = 1 μm is selected to be the base denominator for the concentration comparison. Ratio of average volume concentration, R_{CV}, is defined as $R_{CV} = C_v/C_{v1}$, where C_v is the average volume concentration of particle diameters d_{pn} = 1-25 μm, and C_{v1} stands for that concentration of d_{pn} = 1 μm. Figure 5(a) shows the volume concentration ratio at bend inlet and outlet under two Dean numbers. The test particles contained larger particles of d_{pn} = 5-25 μm in terms of volume percentage. To better describe the particle response to turbulent airflow, the Stokes number is defined as St = $\tau_p u_a/(D_h/2)$, where u_a is the air velocity, τ_p is the particle relaxation time, and D_h is the hydraulic diameter of the duct. From St = 0.011 to 0.55, the volume concentration decreased with the increase of particle diameter or Stokes number. Between bend inlet and outlet, the decrease could also be observed, especially for particles of larger Stokes number. This behavior can be attributed to the reason that particle inertia and centrifugal forces dominate the deposition in bends. Particles of larger Stokes number, therefore, deposited higher than smaller ones as demonstrated in the deposition quantifications in figs. 5-7 of previous experimental results [6] and in fig. 6 of previous simulation data [3]. In addition, the averaged volume concentrations under three Stokes number were found to be relatively more uniformly distributed for higher Dean number, because airflow with high velocity can load heavier particles more easily. However, after flowing through the bend, concentrations become less flat. The capability of high velocity loading can be more clearly illustrated in fig. 5(b) which presents the concentration ratio between two Dean numbers at the bend inlet and outlet.

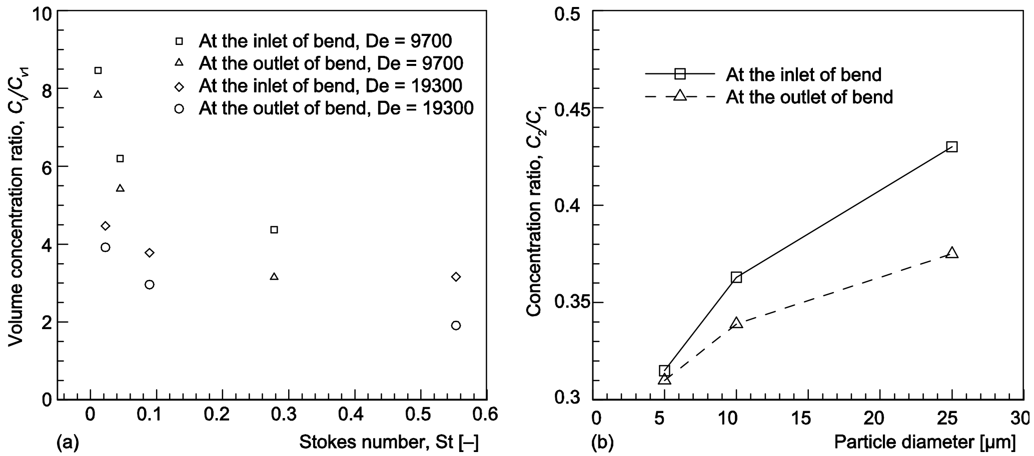

Figure 5. Averaged volume concentration ratio; (a) under different St number, (b) between two Dean numbers for different particle diameters

The symbol C_2 and C_1 are the concentration for particles of d_{pn} = 5-25 μm under De = 19300 and 9700, respectively. This figure also demonstrates a fast decrease of the particle loading for high Dean number through the bend, especially for larger particles. This phenomenon is caused by the inertial impaction between large particle and bend wall during deposition and rebounding process [7]. Although the rebounding energies of particles increase with the increases of air Dean number, the approaching particle number to bend walls increases in a more tremendous degree. Particle deposition with larger diameter or Stokes number is thus enhanced, and concentration decreased severely under De = 19300.

Conclusions

This paper investigates particle deposition in 90° bends of rectangular cross sections by two experimental methods. Through these approaches, particle deposition and concentration distribution have been measured and analyzed. In short, the experimental results are concluded as:

- Through SEM images, the deposited particles in realistic ducts were observed to range from several nanometers to hundreds of micrometer with varied shapes. They accumulate mainly on outer bend wall.
- Particle average volume concentration decreases with the increase of particle diameter or Stokes number, and it diverges more after flowing through the bend. For higher Dean number, a fast decrease of the particle loading ability can be found after the bend, especially for larger particles.
- When particles flowing through duct bends, the particle inertia, the centrifugal force and particle-wall impaction become the important factors of control mechanism for particle deposition and concentration.

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