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Particle grouping and agglomeration assisted by damper oscillation systems

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ABSTRACT

In this study, a novel system is proposed with the aim to promote particle agglomerations, and to assist the downstream process with better particle removal efficiency. In the batch process, the polluted air enclosed in a chamber is used to simulate the indoor stagnant air. It is found that the addition of a damper could speed up the reduction of particle number and the faster damper could lead to a greater reduction. The concentration of particle number in a chamber could be notably reduced by up to 73% after half an hour using two dampers with a cycle time of 0.5 s. It is found that the flow oscillations induced by the damper movement can facilitate particle collisions, and agglomerations, which also increase the particle deposition rate. On the other hand, a continuous flow is applied to simulate a reference process where particle laden air is continuously entering the chamber for downstream treatment. The use of a damper with a cycle time of 1 s has increased the particle removal efficiency of the downstream filters from 36% to 48%. By comparing the particle size distribution, the addition of dampers has been demonstrated to promote a shift towards larger particle sizes. Therefore, the results clearly demonstrate the efficacy of revolving dampers for reducing particle number, increasing filtration efficiency and reducing the risk associated with air pollution.

1. Introduction

Emissions from industries, manufacturing activities, and burning of fossil fuels have caused numerous issues to mankind and environment [1]. Particulate matters (PMs) are one of the most severe pollution sources which have grabbed notable attention due to their close association with many diseases [2–5]. The fine particles can penetrate deeply into human lungs, causing detrimental effects to human beings such as lung cancers and severe cardiopulmonary diseases [6,7]. Moreover, the increasing level of fine PMs in atmosphere is directly related to the deterioration in atmospheric visibility and agriculture growth, which could further impact on the society and economy negatively [3,8–10].

Many techniques have been developed up to date for the removal of these harmful particles [11–15]. Cyclones separators, scrubbers, bag houses, and electrostatic precipitators are some commonly used methods in industries, but these mature technologies also result in challenges such as safety hazards, high energy consumption and generation of secondary wastes [16–18]. On the other hand, various filters have been developed for indoor air cleaning. However, they have their own advantages and limitations. For example, most of fabric-made filter cartridges need to be replaced when particles clog in between the fibers, causing a large pressure drop and becoming a potential home for bacteria growth. Hollow fiber membranes are a new type of filters which is designated for the removal of ultrafine particles, yet this comes along with a higher pressure drop up to 2000 Pa [19,20]. Polypropylene (PP) non-woven filters belong to another type with a low pressure drop, but their removal performance of smaller particles needs to be improved [21].

Due to the difficulties in the removal of smaller particles, there have been growing interests recently in developing pretreatment methods to ease the challenges for the downstream treatment processes [22–25]. For example, acoustic agglomeration is one well-known technology which could help group and agglomerate smaller particles into bigger ones. The acoustic waves cause particles of different sizes to be entrained at different rates, thus create relative motions between particles for subsequent collisions and agglomerations [26–32]. The agglomeration of smaller particles results in the formation of larger particles and lead to a faster decrease in the total particle numbers. However, the energy and the associated noise have prevented such technology from being adopted in real applications.

In this study, we introduce a novel system with dampers which can be operated in a batch mode or a continuous mode to promote particle agglomeration and effectively reduce the particle number concentration in ambient air. A damper is a part which can be easily fitted into a duct or other flow systems and allows us to regulate the air flow simply by

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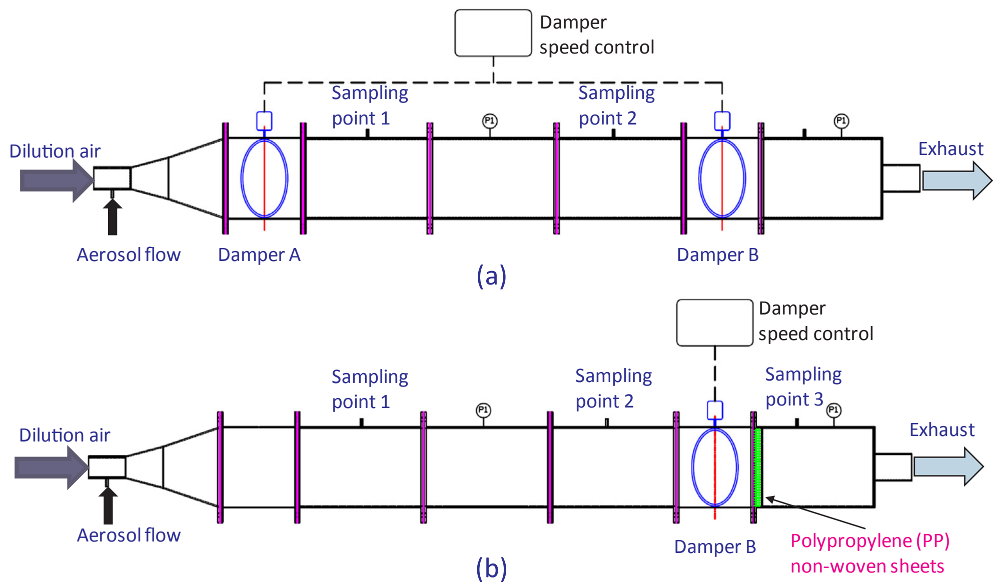

Fig. 1. Schematic diagrams of agglomeration chambers, (a) for a batch process and (b) for a continuous flow process with downstream filters.

their opening and closing motions. Our main objectives in this work are to investigate (1) the effect of the initial particle concentration on particle number reduction rate; (2) the efficacy of dampers and the optimal cycle time of dampers to assist particle number reduction; (3) the changes of airflow pattern incurred by the damper movement; and (4) the effect of dampers on particle size distribution and particle filtration performance of downstream filters.

2. Experimental

2.1. Aerosol generation

A sodium chloride solution was used to generate aerosol particles with the help of a TSI atomizer (Model 3076) according to the procedures reported in the literature [21]. A stream of clean and dry compressed air at 207,000 Pa (30 Psi) flowed into the atomizer at a flow rate of 2 L/min. The generated aerosols went through a diffusion dryer to remove excess water droplets. A neutralizer is activated so that the particles are in electrostatic neutral state. Subsequently, the aerosol flow is mixed with another stream of clean, dry dilution air into an agglomeration chamber, as illustrated in Fig. 1. Fig. 2 shows the particle size distribution of the mixed air after diluting a stream of 2 L/min aerosol flow with a dilution air of 48 L/min. The shape is similar to the ambient air that has a particle number concentration of 105,400 #/cm3 and a mean size of 48.7 nm.

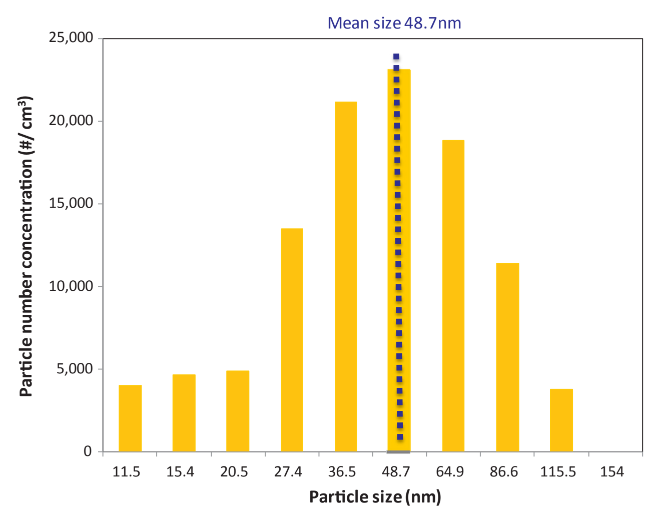

Fig. 2. Typical particle size distribution after dilution (an aerosol flow of 2 L/min dilutes with a dilution flow of 48 L/min). The total particle number concentration was 105,400 #/cm^{3}with a mean size of 48.7 nm.

2.2. Particle agglomeration chamber with dampers

Fig. 3(a) shows the actual particle agglomeration chamber with two built-in dampers A and B. The chamber is made of stainless steel with an inner diameter of 212 mm and a length of 1500 mm. The two dampers are at their open position by default as shown in Fig. 3(b). The damper speeds are separately controlled by a control panel with a programmable logic controller (PLC) (Fig. 3(c)). Once being set, the dampers starts moving periodically and keeps repeating the close-open motion until stopped by the control panel. The faster the damper rotational speed, the shorter the damper cycle time.

2.3. Particle number evolution under a batch process

Before investigating the effects of dampers on particle grouping, we studied how the initial particle concentration would affect the evolution of particle number inside the chamber under a batch process. As shown in Fig. 1(a), an aerosol flow of 2 L/min was mixed with a precalculated amount of dilution air according to the desired dilution ratio at the chamber inlet and then sent into the chamber body. The dilution ratio was defined as the total mixed airflow dividing by the aerosol flow. Both dampers were kept at open positions until particle concentrations at sampling points 1 and 2 were stabilized and remained consistent for consecutive 5 min. Thereafter, the air flows were stopped and the outlet of the chamber was sealed. The particle number concentrations at points 1 and 2 inside the chamber were recorded using a water-condensational particle counter (WCPC 3782, TSI) for 30 min under various dilution ratios, while the particle size distribution was also determined by the same device which measured the particle size from 11.5 nm to 365.2 nm. A cleaned make-up air flow was sent into the chamber during the measurements to ensure isokinetic sampling.

To study the effects of damper cycle time on the reduction of particle number, the dilution ratio was kept at 25 (i.e., the total mixed airflow = 25 times of the aerosol flow). After particle concentrations at sampling points 1 and 2 were stabilized, the air flows were stopped and the outlet of the chamber was sealed. The cycle times of dampers A and