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Heterogeneous condensation coupled with partial gas circulation for fine particles abatement

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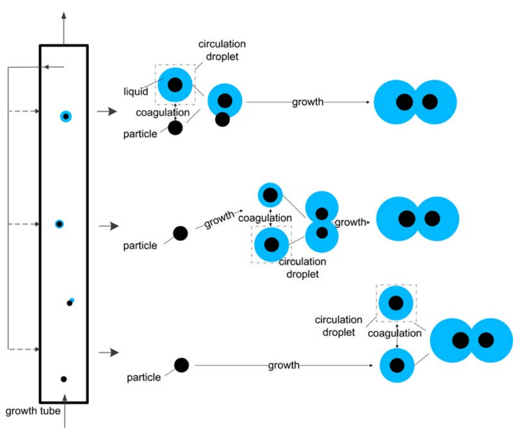
GRAPHICAL ABSTRACT



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ABSTRACT

The removal efficiency of $PM_{2.5}$ is very low in traditional dust removal devices, especially for the particles range from 0.1 to 1 μm, which can decreases to 25% and pretreatment must be conducted before fine particles enter into these devices. Vapor condensation on fine particles can improve the $PM_{2.5}$ removal efficiency of traditional devices. Therefore, a novel process was proposed for heterogeneous condensation on fine particles of water vapor with partial gas circulation in this paper. The essential supersaturation was established by adding hot water into cooled saturated gas, and the application of partial gas circulation technique in this process made the required supersaturation level decreasing. The fine particles were enlarged by the heterogeneous condensation and the collision-coalescence of droplet and particle in the partial gas circulation growth tube (PGCGT). The results indicated that the enlargement of fine particles in the PGCGT was more efficient than that in the conventional growth tube (CGT). The performance of fine particles enlargement by this process was influenced by many factors, such as circulation point at the growth tube, gas circulation proportion, supersaturation and initial particle concentration in the gas flow. Under the optimum conditions, the arithmetic mean diameter of the submicron particles could be enlarged to 6.156 μm. Moreover, the different growth pathways of particle enlargement in the PGCGT were elucidated.

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1. Introduction

Emissions of fine particles from coal combustion and vehicles have caused serious air pollution and health problems [1,2]. However, in contrast to the efficient separation of the particles from gases by conventional separators, like cyclones, venturi scrubbers, electrostatic precipitators, and filters, the efficient separation of fine particles is difficult and expensive [3,4], especially in the range from 0.1 to 1 μm, which is called Greenfield gap [5]. For particles ranging into this gap, the removal efficiency of traditional abatement systems based on diffusion, inertial impact, as well as sedimentation, decreases to approximately 25% [6]. The reason for this phenomenon is that the particles in this size range are too large for Brownian diffusion to be effective and too small for inertial impaction to be significant.

Obviously, the separation of fine particles from gases can be considerably simplified if the particles are enlarged to a size of some microns by a preconditioning technique. One example for this is heterogeneous condensation of water vapor on fine particles, which has been proved to be a promising pre-technique to enlarge fine particles [7–10]. Particles with a size down to a few nanometers can be enlarged with high growth rates to droplets with diameters of some microns [4] by heterogeneous condensation. In these processes, the essential supersaturation for heterogeneous condensation could be established by adding vapor in flue gas [10–12] or hot water into cooled flue gas [13] and then the fine particles would become larger droplet by vapor condensation on the particles surface spontaneously.

However, it was found that a considerable amount of particles could not be enlarged to above 1 μm under the lower supersaturated environment at higher particle concentration [14]. According to Kelvin equation [15], the critical supersaturation is in inverse proportion to particle size. So high supersaturation level is needed for more small particles to be activated (nucleated) and enlarged when this technique is used in a utility boiler due to the higher fine particle concentration in flue gas [6,16]. Certainly, the high supersaturation level means much more energy cost.

In fact, the Kelvin effect [17,18] also infers that the low supersaturation level can satisfy the small particle activation if the small particles have become larger before they go into the supersaturated environment. Based on this we have developed a novel condensation process with partial gas circulation, i.e. a partial gas is extracted from the exit of the growth tube and then is returned to the growth tube. In order to evaluate the performance of this new process, the particle enlargement by heterogeneous condensation in a partial gas circulation growth tube (PGCGT) of laboratory scale was investigated, and the influence of several parameters, such as circulation position at the growth tube, circulation proportion, supersaturation and initial particle concentration in the gas flow on the particle enlargement was considered.

2. Experiment section

2.1. Experimental facility

The experimental facility is shown in Fig. 1. It includes aerosol generation part and the particles growth part. The aerosol generation part consists of an aerosol generator (Model SAG-410, Germany) and an air compressor that supplies pure air as carrier gas. The particles growth part consists of a growth tube, a cooling unit and a hot water thermostat. The growth tube was made of glass with an internal diameter of 1.5 cm and a length of 40 cm, a same one as reported by Tammaro's work [19] and our previous work [14], which is called conventional growth tube (CGT). In order to extract partial gas circulation in the growth tube, a probe tube is set at the outlet of the growth tube, which inserts into the growth tube and is coaxial with the growth tube. Three circulation gas inlets were set up along the growth tube wall to understand the effect of the circulation position: top, middle and bottom of the growth tube.

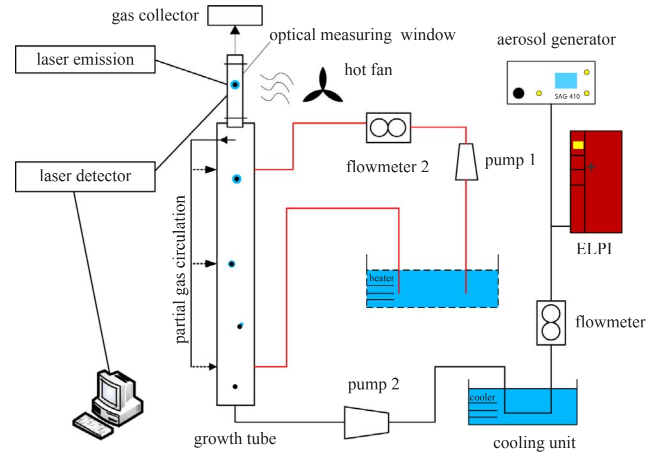

Fig. 1. Experimental apparatus.

In the growth tube, the supersaturation environment was constructed by adding hot water. The hot water inlet to the growth tube was designed as tangential to assure a perfect adhesion of water with the tube walls. In the experiment, the liquid temperature was kept at the desired value, T_h, by means of a thermostatic bath. The cooling unit cooled the aerosol gas into dew point, and then the cooled and saturated gas was sent into the growth tube where it mixed with the water vapor coming from the evaporation of the hot water supplied by the thermostatic bath, generating supersaturation environment, for the mass diffusivity is bigger than the heat diffusivity of water vapor. So the supersaturations could be controlled by adjusting the hot water temperature.

2.2. Measurement technique

The measurement part consists of a laser droplet measuring instrument (Model OMEC-DP-02, China), an optical measurement window and a hot wind fan. The laser instrument allows the measurement of PSD (particle size distribution) in the range between 0.05 μm and 1500 μm. The optical measurement window, which was made of optical glass, is closed to the outlet of growth tube to avoid the evaporation of droplets containing particles. The hot wind fan provides a hot airflow around the optical window to avoid droplet evaporating and condensing on the window. Additionally, an electrical low pressure impactor (ELPI, Dekati, Finland) was used for particle concentration measurement.

3. Results and discussion

3.1. Blank test

In our experiments, the aerosol was generated by employing fine particles of SiO_2. This is because the particle enlargement highly depends on the particle composition and SiO_2 is one of the major components in the coal-fired fine particles [20]. Particles in the growth tube will be lost in the growth tube by inertia effect, gravity sedimentation and Brown motion etc. In order to avoid these effects on measurement of PSD of the enlarged particles, the blank test was taken with the water temperature consistent with the gas temperature, which assure that the environment in the growth tube remain saturation. The blank test PSD at the outlet of the growth tube is shown in Fig. 2. It can be observed from Fig. 2 that most of the particles are concentrated in the submicron range, the peak of particles distribution is in about 0.06 μm and 98.1% particles are less than 1 μm. The arithmetic mean diameter of the initial fine particles is 0.130 μm.