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Effect of filter layer thickness on the filtration characteristics of dual layer granular beds

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A R T I C L E I N F O

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A B S T R A C T

We herein report our investigation into the effect of the filter layer thickness on the filtration performance of dual layer granular bed filters using an experimental granular bed filter with an inner diameter of 100 mm and employing fly ash as the example dust. It was found that increasing the thickness of the upper filter layer from 180 to 280 mm reduced the average outlet dust concentration of the dual layer granular bed from 8.69 to 6.57 mg/m^3, in addition to prolonging the time between regeneration cycles from 43.3 to 56 min, and increasing the pressure drop across the bed from 1873 to 1978 Pa. Furthermore, increasing the thickness of the lower filter layer from 45 to 85 mm reduced the average outlet dust concentration of the dual layer granular bed from 8.69 to 3.94 mg/m^3 and extended the time between regeneration cycles from 43.3 to 59 min. However, this also resulted in an increased pressure drop across the filter from 1935 to 3077 Pa. These results indicated that an increase in the thickness of the upper filter layer reduced outlet dust concentrations and extended the regeneration cycles, without having a significant impact on the total pressure drop across the dual layer granular bed. Although an increase in the thickness of the lower filter layer significantly reduced outlet dust concentrations, the pressure drop across the dual layer granular bed filter was greatly increased in this case.

1. Introduction

Coal pyrolysis is a key intermediate process for thermochemical conversion procedures such as coal burning, gasification, and liquefaction, and it is also an important technique in the context of quality-based coal utilization [1]. In addition, the coal pyrolysis technique can be employed to obtain clean-burning gaseous fuels, high-value oil products, and high-quality solid fuels, thereby rendering it the primary technological pathway for the comprehensive utilization of coal [2]. However, a number of issues prevent the widespread adoption of coal pyrolysis techniques, including the large quantities of micron-grade dust particles generated along with the high temperature waste gases during coal pyrolysis [3], the carbon-forming tendencies of tar gases, and the lack of an effective solution for gas-solid separation. These issues subsequently lead to problems such as pipeline clogging, the production of tar with high dust contents, difficulties in subsequent coal gas applications, and severe wear in critical pieces of equipment [4,5]. However, as granular bed dust removers are characteristically tolerant of high temperatures, have a wide selection of filter media, and are relatively cheap [6,7], the development of a granular bed filter suitable for coal pyrolysis would represent a particularly significant achievement.

Granular beds are mainly divided into moving granular beds and stationary granular beds. Hsu et al. [8] used silica sand with particle size of 2–4 mm to study a granular bed filter. The granular bed model used a moving bed, and the inlet of the granular bed had a baffle arrangement. The influence of baffle angle and length on the filtration efficiency of the granular bed entrance was studied. The results showed that filtration efficiency of 98.55% could be achieved with baffle length of 170 mm and baffle angle of 50°, and the filtration efficiency of the granular bed filter could be improved by making the air distribution of the inlet uniform. Wenzel et al. [9] modified the model parameters of the moving granular bed filtration process and performed comparisons with the experimentally obtained pressure drop and filtration efficiency. El-Hedok et al. [10] studied the influence of the flow rate of filter particles on the filtration efficiency of a granular bed by using a moving bed with filter size of 1.6–3.2 mm. The results showed that the retention time of filter particles must reach the critical residence time for the filtration efficiency of the granular bed to exceed 99%. Chen et al. [11] examined the use of granular bed filters for filter power plant-generated fly ash with particle sizes ranging between 0.24 and 363.08 μm. For this purpose, they employed a moving bed granular filter measuring 1.07 m in length, 0.38 m in width, and 0.5 m in depth. The filter media of the granular bed consisted of sea sand with particle sizes ranging between 2 and 4 mm. Following filtration of the fly ash, it was found that the majority of dust particles >10 μm had been removed; however, the filtration efficiency of this granular

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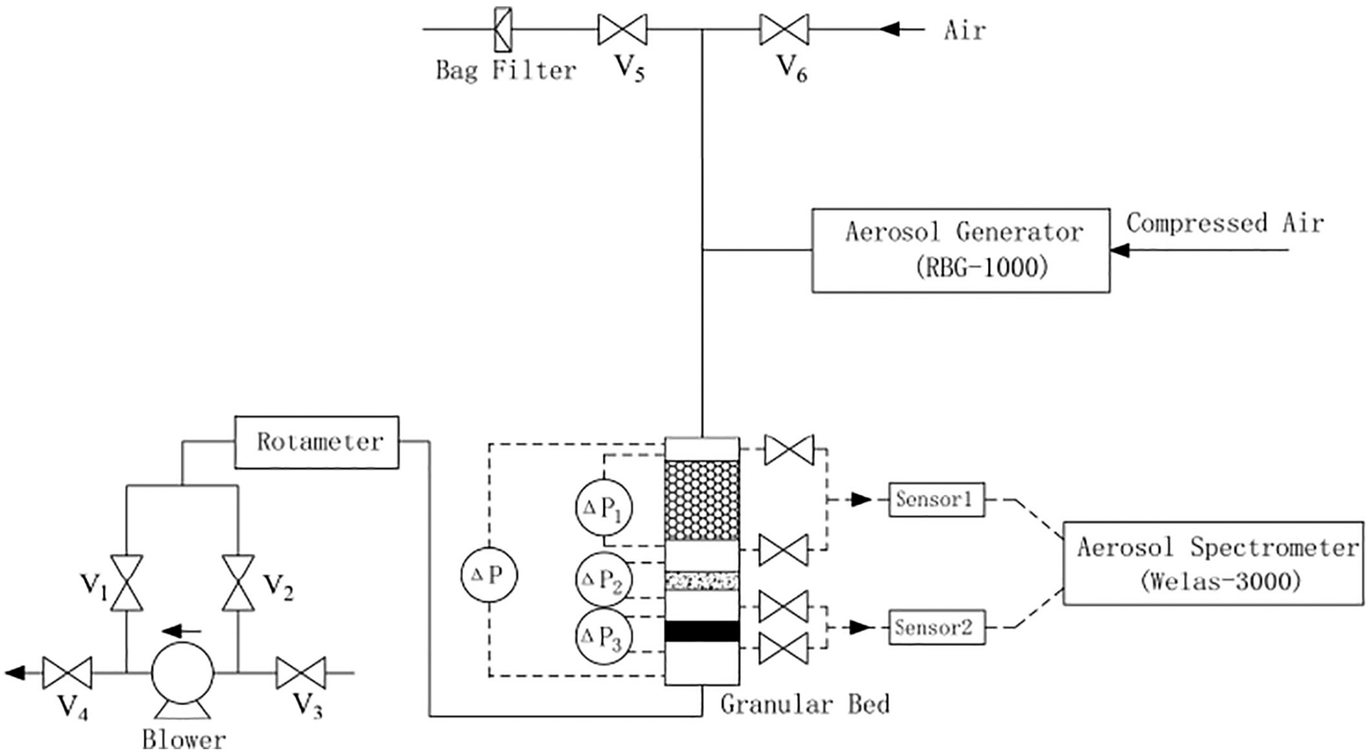

Fig. 1. Schematic representation of the experimental apparatus employed herein.

bed filter for fine dust was less than ideal. To address this issue, Rodon et al. [12] developed a granular bed filter using sand with particle sizes of 0.3–0.42 mm, and examined the filtration of fly ash at a filtration velocity of 0.111 m/s. In this experiment, the granular bed achieved filtration efficiencies of 99.99%, and the high filtration efficiency of the granular bed was found to be due to the formation of dust cakes on the surface of the filter media. However, these dust cakes also significantly increased the pressure drop across the filter bed. In addition, Wu et al. [13] employed three different types of filter media (i.e., 0.3–0.42 mm silicon carbide, 0.3–0.42 mm grit, and 0.15–0.42 mm copper particles) to study how the deposition of dust in the filter layer affected its filtration efficiency towards sub-micron grade particles in addition to its pressure drop. It was found that dust deposition led to gradual increases in the filtration efficiency for sub-micron grade particles. However, after the quantity of deposited dust reached an optimal level, any further increases in dust deposition led to decreases in the filtration efficiency. Furthermore, excessive quantities of dust led to enhanced pressure drops, which in turn led to perforations in the dust layers.

In view of the low filtration efficiencies and low pressure drops of coarse-particle granular layers, and the high filtration efficiencies, high pressure drops, and short regeneration cycles of fine-particle granular layers, Yang [14,15] developed a novel graded filtering technique using a dual layer granular bed that promised to combine the strengths of these filter layers while eliminating their weaknesses. This dual layer granular bed consists of lower and upper filter layers, where the upper filter layer contains low-density, coarse particles, and the lower filter layer contains highly dense, fine particles. During filtration, the dust-containing airflow enters from the top of the filter, and passes through the upper filter layer where the majority of dust is captured; this is known as “coarse filtering”. The fine particles that penetrate the upper filter layer are then captured by the lower filter layer, thus completing the “fine filtering” process. The combination of these layers therefore provides a cascaded filter.

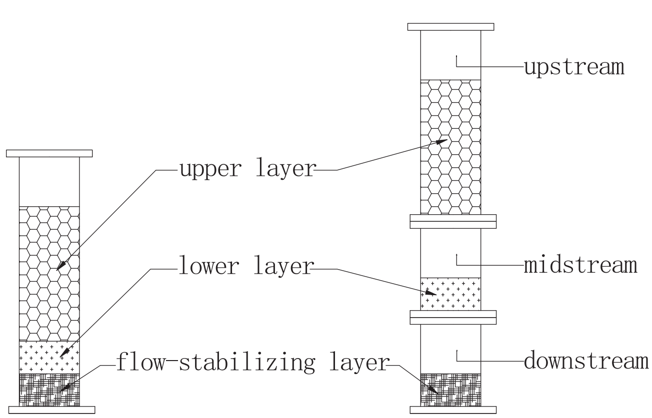

Fig. 2. Schematic representation of the dual layer granular bed filter employed herein.

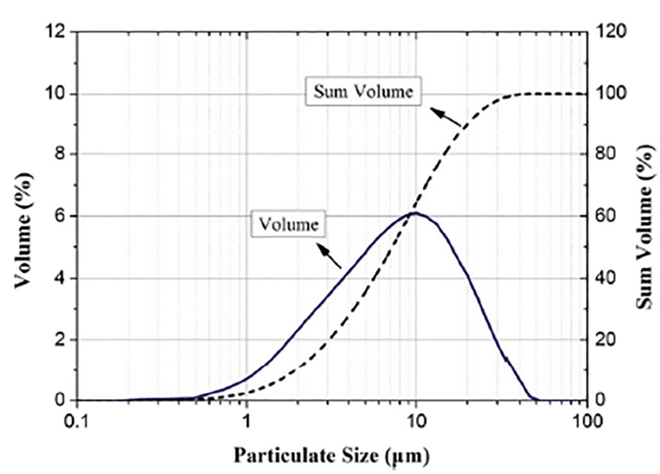

Fig. 3. Particle size distribution of the fly ash dust employed herein.