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Cascade filtration properties of a dual-layer granular bed filter

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ABSTRACT

Dual-layer granular beds consist of a lower layer of fine granules and an upper layer of coarse granules. In order to study the individual functions of the two granular layers with respect to filtration, a small granular bed filtering device (inner diameter of 100 mm) was employed. The two granular layers were separated using a wire mesh such that the upper layer was laid over the wire mesh. A welas® 3000 aerosol spectrometer was used to determine the dust concentrations and size distributions of the inlets and outlets of the upper and lower layers. According to the results, the upper layer was able to remove 96.08–98.78% of the dust. Moreover, owing to the features of the upper bed, including the coarse nature of its granules, its large voidage, and its deep-bed filtration ability, the pressure drop through the granular layer increased slowly with the amount of dust deposited. The lower layer, which had fine granules, was able to effectively remove the fine particulates that passed through the upper layer, reducing the dust concentration at the outlet to 3–7.5 mg/m^3. The experimental results confirmed that the dual-layer granular bed filter exhibits unique synergistic properties, namely, a low pressure drop because of the upper layer and a high filtration efficiency because of the lower layer.

1. Introduction

In the realm of energy technologies, hot gas cleanup is considered a key component in advanced energy systems such as the integrated gasification combined cycle (IGCC), coal gasification-based polygeneration, and polygeneration based on coal pyrolysis. The dust in the involved gases has a significant impact on the operational systems used in the gas industry, resulting in 1) equipment wear and tear; 2) pipeline and equipment clogging due to dust deposition; 3) deterioration in the quality of the target products (oil and gas) owing to dust contamination; and 4) challenges in meeting the emission allowances related to environmental regulations. Therefore, the development of hot gas cleanup techniques is of great interest to researchers both domestically and internationally [1,2,3].

Because the media in granular bed filters are inexpensive and stable in high-temperature environments [4], granular bed filters are attractive in the hot gas cleanup domain. The filtration efficiency and bed pressure drop are two important indicators for assessing the performance of granular bed filters, and extensive studies have been carried out previously by researchers on these parameters [5,6,7]. These studies have demonstrated that the filtration efficiency increases with a decrease in the granule size. However, along with the increase in dust deposition, the bed pressure drop also increases rapidly. Thus, it is very difficult to achieve both high filtration efficiency and low bed pressure drop simultaneously. This posed a major challenge and had limited the use of granular bed filters. To solve this issue, a novel granular bed filter called the dual-layer granular bed filter was invented [8].

The dual-layer granular bed consists of a lower layer of fine granules and an upper layer of coarse granules, which is laid on top of the lower layer. The media in the upper layer are low-density coarse granules while those of the lower layer are high-density fine granules. During filtration, the dirty gas containing dust enters from the top. First, it flows through the upper layer, where most of the dust is trapped; this process is known as “crude filtration.” Then, the gas passes through the lower layer, where the rest of the fine particulates are trapped; this is known as “fine filtration.” The complete process is known as “cascade filtration” and has the advantages of a high dust loading capacity because of the use of coarse granules as well as a high fine particulate filtration efficiency owing to the use of the fine granules. During regeneration, clean gas enters from the bottom and passes vertically upward through the lower and upper layers. Both layers are fluidized simultaneously, and the dust previously captured in the granules is blown away. After the regeneration process, the two layers are stratified naturally and never mix. Thereby, the granular bed is regenerated. The filters used in industrial applications used consist of multiple parallelly arranged dual-layer granular beds. While one dual-layer granular bed is being regenerated, the other dual-layer granular beds participate in filtration. The dual-layer granular beds are regenerated in turns, so that the filter can purify gas continuously.

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Dual-layer granular bed filters have been used successfully for flue gas purification in several aluminum melting furnaces; the flue gas processing capacity of these filters can be as high as 120,000 m^3/h for flue gas temperatures of 50–450 °C, with the filtration pressure drop being less than 1600 Pa and the emitted dust concentration after filtration being lower than 10 mg/N m^3 [9].

Dual-layer granular beds have a distinctive feature in that they exhibit a low pressure drop as well as a high filtration efficiency [10]; however, the individual properties and functions of the two layers have not been studied quantitatively. Hence, in this study, the roles of the upper and lower layers in the filtration process were investigated quantitatively.

2. Material and methods

2.1. Experimental apparatus

The experimental apparatus used is shown in Fig. 1. It is composed of a ventilation system, a dust-generating system, the granular bed, and a measurement system.

2.1.1. Ventilation system

This system is a cold test model wherein air is pumped in from the atmosphere. During filtration, valves V_2, V_4, and V_6 are switched on while the other valves are shut off. Driven by blower, the gas containing dust passes through the granular bed from the top to the bottom; the granular bed pressure is negative. During regeneration, valves V_1, V_3, and V_5 are switched on while the other valves kept closed. Under the blowing pressure of a blower, air passes through the granular bed from the bottom to the top; this causes the granular bed pressure to become positive.

2.1.2. Dust-generating system

The dust-generating system consisted of an air compressor and a dust aerosol generator (RBG-1000, Palas Gmbn, Germany). The air flow generation rate of the Palas aerosol generator used was 0.6 m^3/h. The dust aerosol generator scatters dust using high-pressure air and a rotating brush. It adds dust to the air flow of the granular bed's air intake pipe in a steady, continuous, and measured manner. The dust used in this study was power plant fly ash ground by a mill. The dust particulate size was measured using a laser diffraction particulate size analyzer (Mastersizer 2000); the size distribution is shown in Fig. 2. The sizes of the dust particulates were 0.19–45.71 μm, while the volume median diameter of the particulates was 7.2 μm and the geometric standard deviation was 2.45. The density of the dust particulates was 2.437 g/cm^3, with the porosity being 67.2%. The refractive index was 1.533 and the adsorption coefficient was 0.1 [11]. The main chemical components of the dust particulates were SiO_2, Al_2O_3, CaO, and Fe_2O_3.

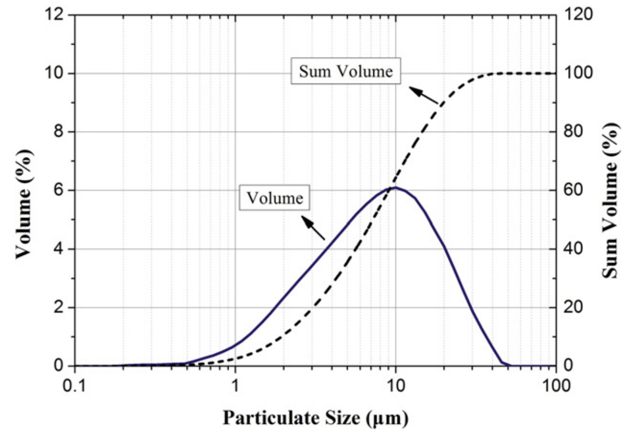

Fig. 2. Size distribution of the ash particulates.

2.1.3. Granular bed

The granular bed body was made up of an acrylic tube with an inner diameter of 100 mm. As shown in Fig. 3(a), the granular bed was composed of three granular layers: a flow-evening layer, a lower layer, and an upper layer.

The flow-evening layer was laid over a mesh and served to distribute the air flow more uniformly during the regeneration process and improve the fluidization of the filter media. The lower layer was laid over the flow-evening layer, while the upper layer was laid above the lower layer, forming a structure consisting of three granular layers. There are three rules for determining the granule sizes of the upper and lower layers. Firstly, in order to increase the dust-loading capacity, the granule size of the upper layer should be as large as possible, while in order to improve the filtration efficiency of the lower layer, its granule size should be as small as possible. Secondly, the granular density of the upper layer should be lower than the density of the granules of the fluidized bed formed by the lower layer. Thirdly, the velocity of the fluidizing gas in the two layers should be similar, so that a similar degree of fluidization can be achieved in the two layers concurrently. Based on the results of calculations and a large number of tests, expanded perlite (granular size of 1.0–2.0 mm and a bulk density of 70 kg/m^3) was used as the media for the upper layer. Its chemical composition was as follows: SiO_2 of 69–72%, Al_2O_3 of 12–18%, K_2O of 3–4.5%, Na_2O of 3–4.5%,

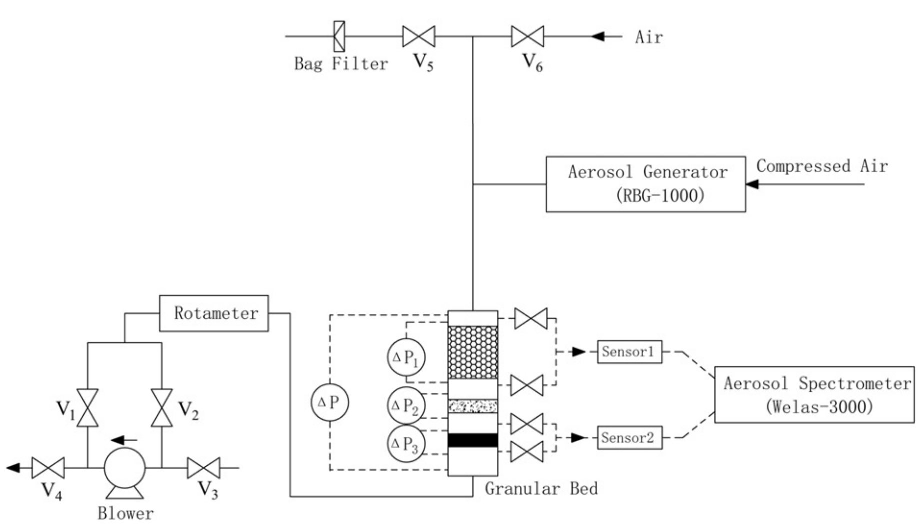

Fig. 1. Schematic of the filter test facility. V_1–V_6 denote valves.