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Removal of dust particles from fuel gas using a moving granular bed filter

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ABSTRACT

The goal of this study is to evaluate the performance of a moving granular bed filter designed to filter out dust particles. We investigate the flow patterns of the filter granules, and the filtration efficiency under different inlet dust concentrations, but with a fixed filtration superficial velocity and mass flow rate of filter granules. All filtration system experiments were performed at room temperature. A vertical shift of louvers on the inlet or outlet wall of the filter could be an appropriate solution to diminish the stagnant zones. The results of a study of the flow patterns and velocity fields of filter granules in a 2-D cross-flow moving granular bed system with vertically shifting louvers is presented. In addition, the results of cold tests show that using a higher dust concentration of 15,000 ppmw and a fixed-bed mode, the overall porosity of the filter granules decreased and the filter resistance and the filtration efficiency increased, with an increase in the amount of smaller-sized filter granules in a 3-D bed.

1. Introduction

Global energy structure transformation has been taking place in industries, especially in areas with limited conventional oil and gas resources. Due to lack of sufficient gas or oil reserves, coal is by far the world's most abundant and widely distributed of fossil fuel resources. Due to increasing concern about pollutant emissions from power plants in the context of global warming, technologies allowing for cleaner production of electricity from coal need to be developed. One such technology is that used in advanced coal-fired power generation plants. Among the advanced clean coal technologies for electric power generation, pressurized fluidized bed combustion (PFBC) and integrated gasification combined cycles (IGCC) are the dominant developing processes. However, it has been pointed out that commercialization of these technologies is critically hindered by problems with the dust removal system which must operate at high temperature and high pressure [1,2]. One of the most difficult tasks in hot gas cleaning, is the removal of particles from a complex mixture of combustion products using the flue gas as a downstream processing gas, as for a gas turbine.

In the IGCC and PFBC process, the syngas is cleaned after passing through a gas cooler, where the heat in the gas is converted into steam. The steam is then used to drive the steam turbine. Besides, IGCC and PFBC systems have driven the development of collection devices for gas cleaning at temperatures between 370–595 °C for IGCC and 760–870 °C for PFBC [1]. The reliability and efficiency of the dry hot syngas cleaning processes can be considered as the most important factor for the success of coal gasification based on lower emission power generation and fuel production technologies. Therefore, high-temperature dust particulate filtration has the potential to improve power plant efficiency. Conventional wet gas cleaning has been widely used in many industrial facilities for air pollution control technology, but is thermally inefficient and produces waste water sludge, in itself an environmental nuisance [3]. Cyclones, fabric filters, and electrostatic precipitators (ESP) are conventionally employed to control the emission of dust particulates in gas streams at temperatures between 150 °C and 300 °C [4–6]. Cyclone usually used in the filtration processing of first stage. Filtration efficiency of fabric filters is significantly greater than ESP and cyclones. Fabric filter with the limitation of maximum operating temperature is disadvantage. In addition, fabric bags tend to burn or melt readily at the temperature of 150 °C. The ESP has been widely used in the conventional coal-based power generation systems. The electrode development and operation problems in condition of high temperature of 300 °C

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is disadvantage of ESP. Consequently, the disadvantages of those systems were not increase power plant efficiency for IGCC and PFBC system.

The questions should be considered in the dust removal devices, especially for hot gas environment, include emission, reliability and cost. Ceramic candle and granular bed filters seem to be the most promising hot gas filtration technologies for removing solid contaminants. Rigid ceramic filters are a better solution for gas turbine applications. The ceramic candle filter is the most promising technology for hot gas filtration due to its ability to resist high temperature conditions (1000 °C) while preserving high filtration efficiency of 99%. However, in the ceramic candle filtering technology, successful long term operation with candles is still limited mainly by design and/or materials. There are certain fundamental limitations to improve due to the intrinsic material properties of the candle filters. The unreliability of the ceramic filter elements in demonstration trials and the high capital cost of these systems have hindered their application, restricting the uptake of gasification power plants in general [7–10]. Granular bed filters are another attractive option, and are frequently used to remove both particles and gaseous pollutants simultaneously [11–14]. They employ low-cost refractory granules as the filter media and can work under very high temperature of 850 °C. In addition, the reusability of filter granules in granular bed filters, constant pressure drop without periodic shut-down in the filter process, easy operation of filter system are advantages of granular bed filters. Of the available cleaning methods, moving granular bed filters are thought to be the most promising devices for hot gas cleaning. This system is keynote for the successful filtration of high temperature of 850 °C process streams [12]. Hence, it has the potential to improve power plant efficiency.

Brown et al. [15] found that a moving granular bed filter can operate with a high collection efficiency, typically exceeding 99%, and low pressure drop without the need for periodic regeneration through the use of a continuous flow of a fresh granular filter medium in the filter. Fine particles are mainly filtered through the formation of a dust cake on the surface of the granular layer. In moving bed filters, granules are constantly moving and thus a dust cake cannot be formed, accounting for the resulting low filtration efficiency of the fine particles [16]. Wu et al. [3] studied the flow characteristics of solid particles in a two-dimensional moving bed. They found that the mass velocity of the solid particles and the placement of baffles in stagnant zones have no effect on the flow pattern but that the sharpness, size, and angle of repose of the particles affect the flow pattern greatly. Smid et al. [17] made a complete review of the patent literature about moving bed filters and the necessary equipment in different countries around the world. In 2007, Bai et al. [18] investigated the performance of a circulating cross-flow moving bed granular filter with conical louvre plates in terms of the filtration efficiency and pressure drop achieved by varying the mass flow rate and the size of the filter media as well as the dust/collector particle types. They also reported that the filtration efficiency of dust was related to the effects of the solid mass flow rate, the collector particle size, and the separator type. El-Hedok et al. [19] evaluated the effect of the granular flow rate on the performance of a counter-current moving bed granular filter designed for hot gas filtration of fine char particles produced during fast pyrolysis of the biomass. They concluded that when increasing the granular flow rate or decreasing the residence time of the granular filter media, the hold-up of char in the filter could be reduced. Igci et al. [20] developed filtered two-fluid model equations to calculate the aerosol removal in the filter system. They presented a methodology where computational results obtained through highly resolved simulations of a given microscopic two-fluid model are filtered to deduce closures for the corresponding filtered two-fluid model equations. Hsiau et al. [21] developed a method in which a louver was inserted into the bed of a moving granular bed filter to guide the gas flow pattern to increase the path length in the filter and the particle filtration efficiency. Hsiau et al. [22] used Johanson's [23,24] "theoretical design", with information about PE beads, to construct the geometry of louvered sections with saddle-roof inserts. The flow of PE-granules became close to a mass-flow type, with satisfactory improvement in diminishing stagnant zones compared with the louvered section without corrective flow elements. Later they also took into account the flow properties of the silica sand in their construction of the moving bed and used silica sand as filter granules. The results were also very promising.

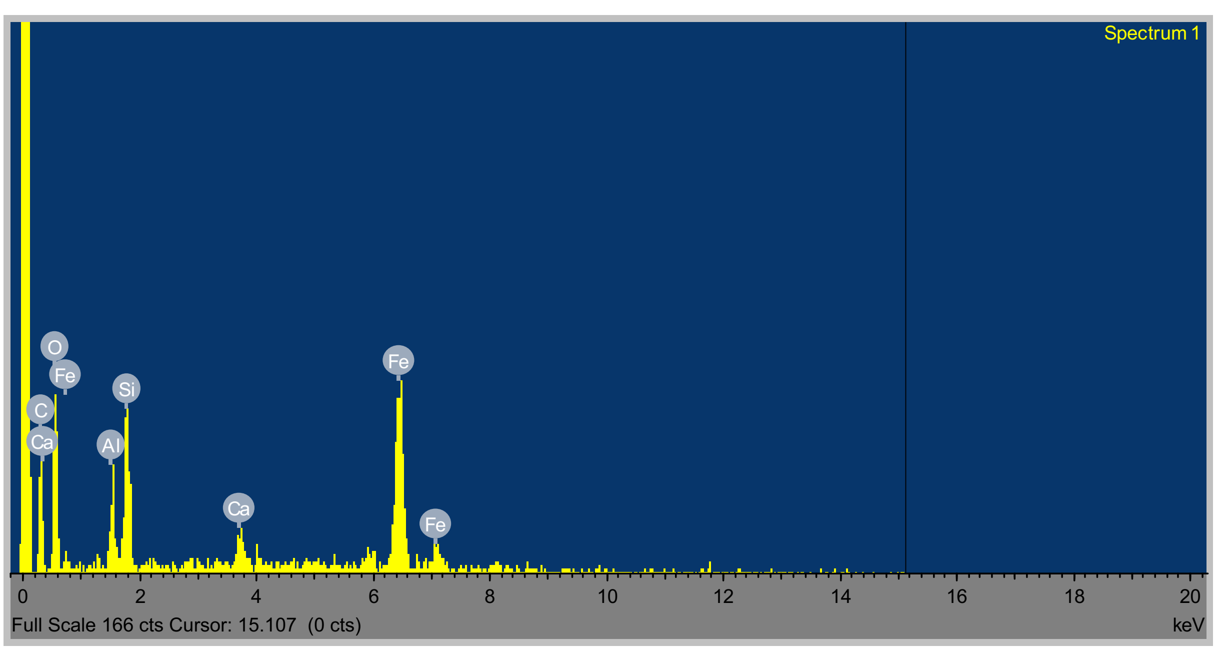

Fig. 1. Chemical components of dust particulates.